METAL CONCENTRATIONS OF SENTINEL LYCOSID SPIDERS INHABITING REMEDIATED AREAS

by

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DEDICATION

I dedicate this paper to my family, who have encouraged and motivated me to always chase my goals and dreams.

My wife has shown me unwavering support, love, patience, and motivation throughout the sleepless nights, long days, weekends, and stressful times during the entire program.

My mother, with support, love, and patience, has served as a role model, guiding me to never stop learning and educating myself and to always work on self-improvement throughout my life, as she has done.

Their support has been invaluable in helping me persevere through this program.

Lastly, I would like to dedicate this to my newborn daughter, showing her that when she gets older and has a dream or goal, with hard work, dedication, and passion, no dream or goal is unachievable.

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GLOSSARY or NOMENCLATURE

Abbreviation	Full Terminology
EPA	Environmental Protection Agency
NPL	National Priorities List
BPSOU	Butte Priority Soil Operable Unit
MBMG	Montana Bureau of Mines and Geology

ABSTRACT

Mining in Butte, Montana, has a history spanning more than 140 years, beginning in the 1880s and continuing to the present. Consequently, the Butte area became covered in mine waste containing high levels of various metals. For nearly 100 years, mining in Butte was conducted irresponsibly and without regulation; the area was ultimately designated a Superfund site in 1984, one of the largest Superfund complexes spanning 140 km (approximately 140 miles) in length. Since then, measures have been taken to secure the mine waste in place and prevent it from interacting with the environment. However, questions remain about the efficacy of these measures. Therefore, to determine whether the waste left in place is not interacting with the environment, I used a sentinel animal taxon, wolf spiders (Family Lycosidae), to evaluate the possible accumulation of these metals in the area. Using pit traps, I caught 51 spiders at three sites throughout Butte and a control site in the Grass Range, Montana. The lycosid spiders caught at these sites were weighed, acid-digested, and run through an inductively coupled plasma mass spectrometer (ICP-MS). This analysis revealed the identity and concentrations of the metal isotopes accumulated in the spiders. The metal content of the spiders was analyzed per site and collectively across all sites. The metals identified with the highest concentrations and abundance across all locations are Mn at 3.1, Cu at 3.17%, Zn at 19.12%, Fe at 27.27%, and Al at 46.10%. This metal content was then compared to the spiders' weight to see if there was a relationship. My results show that the larger the spider, the more metal that was bioaccumulated, and the sites with the waste left in place had higher levels of metals in the spiders. These results demonstrate that wolf spiders may be an effective and reliable sentinel species for the Butte area, indicating potential negative environmental effects and remediation effectiveness.

INTRODUCTION

Mining extracts essential metals and minerals are vital to everything we own and use daily. Consequently, mining and its materials significantly contribute to our economy and society. While mining is necessary, it can have adverse environmental effects, particularly if it is not conducted ethically. These negative impacts have been observed worldwide, including land degradation, air and water pollution (surface and ground), and loss of plant and animal species (Jhariya et al., 2016).

Background

Hard rock mining has occurred in Butte, Montana, since the 1860s. More than 500 underground mining companies mined the area's rich ore body. The ore body present in the area is known as the boulder batholith, a sulfide ore body. These 500 companies would develop vertical shafts into the ground, reaching depths of 1.6 km (5,300 ft), and excavate connecting horizontal tunnels underneath Butte that spanned more than 16,000 km (10,000 miles). The mining was done to access the precious metals in the batholith (Gammons et al. 2006).

During the mining process, four forms of waste are created. The first is waste rock, which is produced during the extraction of ore from the earth. This is the material surrounding the ore that does not have enough metal to move on to the following process. The next type of waste is tailings, the materials left over after the metals have been extracted from the ore. The final process, smelting, purifies the metals, and the impurities come out as waste, known as slag and smelter smoke (Lottermoser 2007). The waste generated by mining creates highly acidic conditions and introduces elevated metal concentrations into the environment. For decades, the

mine waste produced was uncontained and disposed of in environmentally unacceptable ways (Gammons et al. 2006).

In 1983, the Upper Clark Fork River Basin, which is about 225 km (140 miles), was listed under the U.S. Environmental Protection Agency (EPA) National Priorities List (NPL) as a superfund site. The site resulted from more than 100 years of hard rock mining damage. The area was separated into three sites: the Milltown Sediment/Clark Fork River, the Anaconda Smelter, and the Silver Bow Creek/Butte Area site (Figure 1). Two types of clean-up procedures were used within these sites: restoration and remediation. Restoration is to repair a damaged area to what it was like before the damage and restore ecosystem functions. Remediation or waste left in place practice, cleans or secures a damaged area to protect human health and the environment (Alexander, 2006).

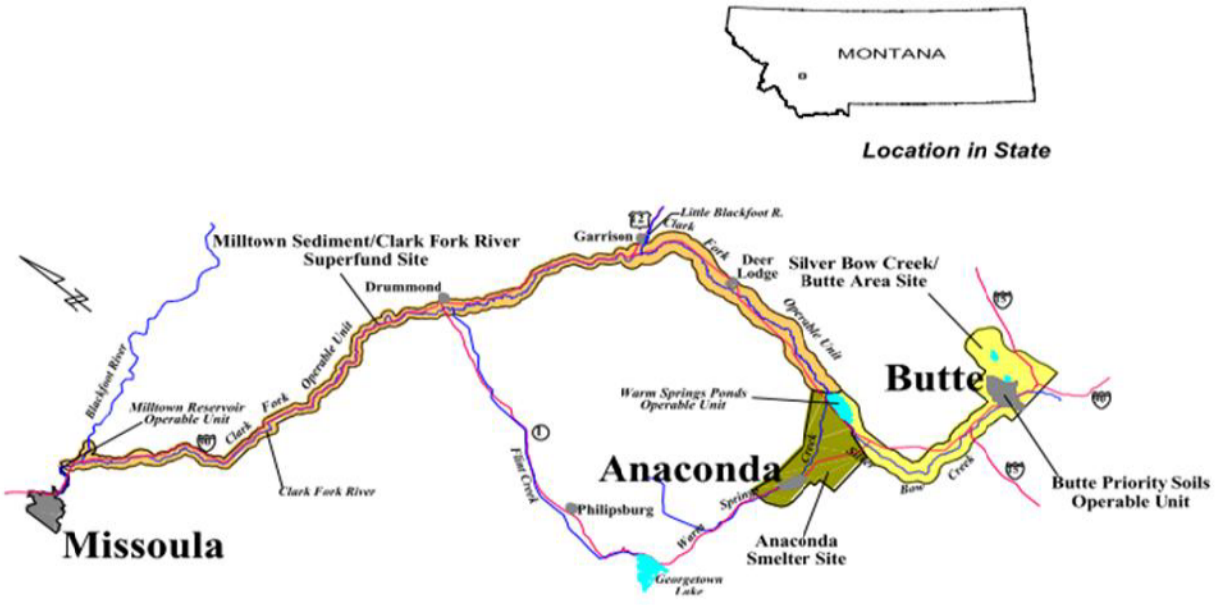


Figure 1. The Upper Clark Fork River Basin Superfund Site, about 140 km (approximately 140 miles) long. The Milltown Sediment/Clark Fork River Superfund site is indicated in orange, the Anaconda Smelter is in green, and the Silver Bow Creek/Butte Area site is in yellow (Alexander, 2006).

Restoration and remediation methods were used throughout the Superfund site. Within the Silver Bow Creek/Butte Area site, the Butte Priority Soil Operable Unit (BPSOU) area was formed in 1987 (Figure 2). Remediation was used to protect the immediately adjacent residential properties (Nagisetty et al. 2022). More than 161 ha (400 ac) of land have been remediated in this area (Figure 3). This land was remediated using vegetated soil caps consisting of a base layer of limestone (calcium carbonate) about 5 cm (2 in) and a minimum of 45 cm (18 in) of EPA-approved topsoil and seeding. These areas are remediated to secure mine waste that has increased levels of metals such as arsenic (As), cadmium (Cd), copper (Cu), gold (Au), iron (Fe), lead (Pb), manganese (Mn), molybdenum (Mo), silver (Ag), and zinc (Zn), (Alexander, 2006).

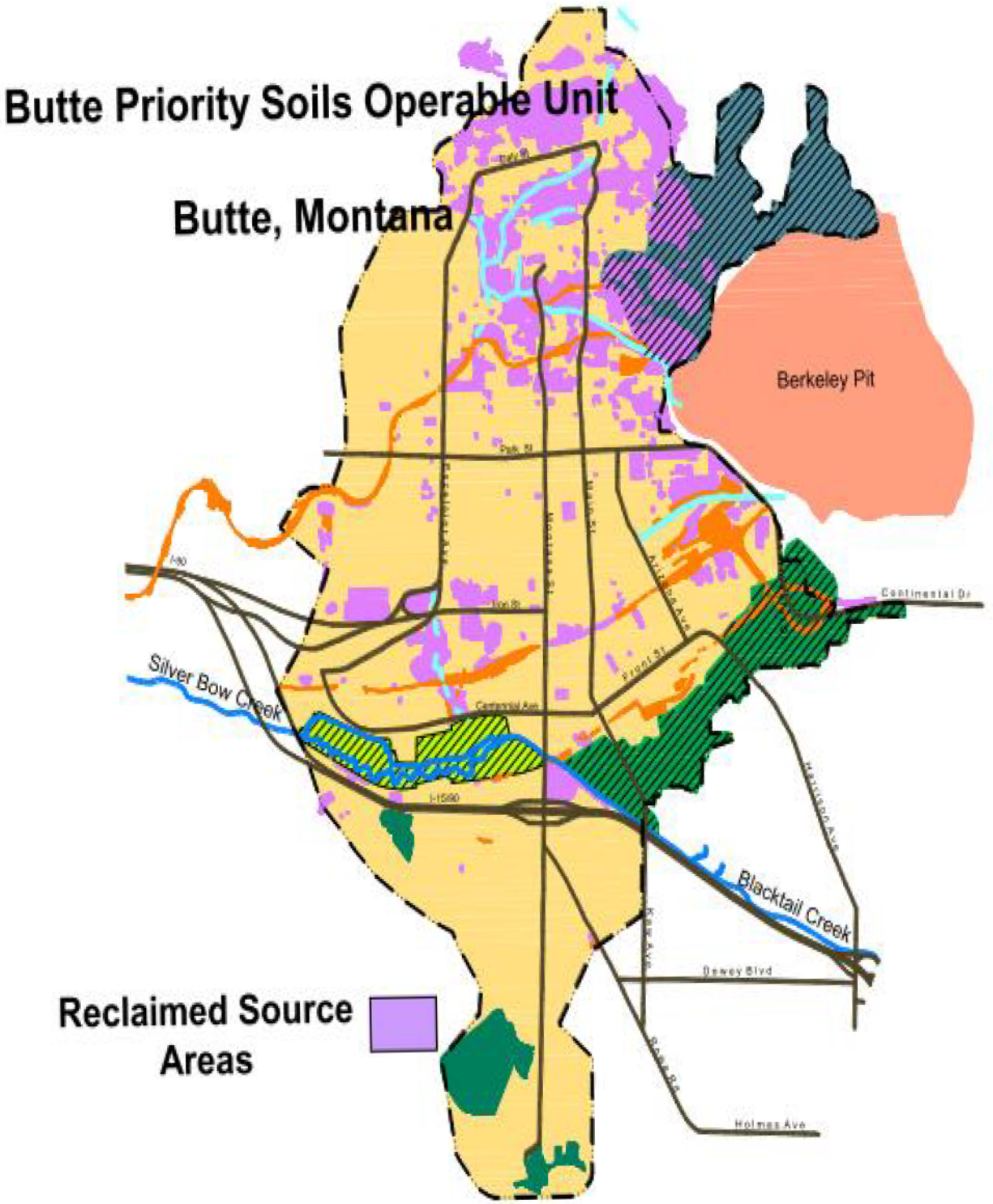


Figure 2. The Butte Priority Soil Operable Unit (BPSOU) within the Silver Bow Creek/Butte Area site. The reclaimed/remediated sites, shown in purple, cover approximately 161 ha (400 acres) of land within Butte (Alexander, 2006).

Butte features diverse landscapes that host a variety of animals inhabiting areas rich in naturally occurring metals. These sites are high in metals due to historic mine waste and have been remediated (Figure 2). After remediation, these areas create space and habitat where animals can reside. Based on their primary habitats, diets, and daily routines, the animals may be exposed to varying concentrations of metals. One animal in and around all these diverse landscapes is the wolf spider (Family Lycosidae).

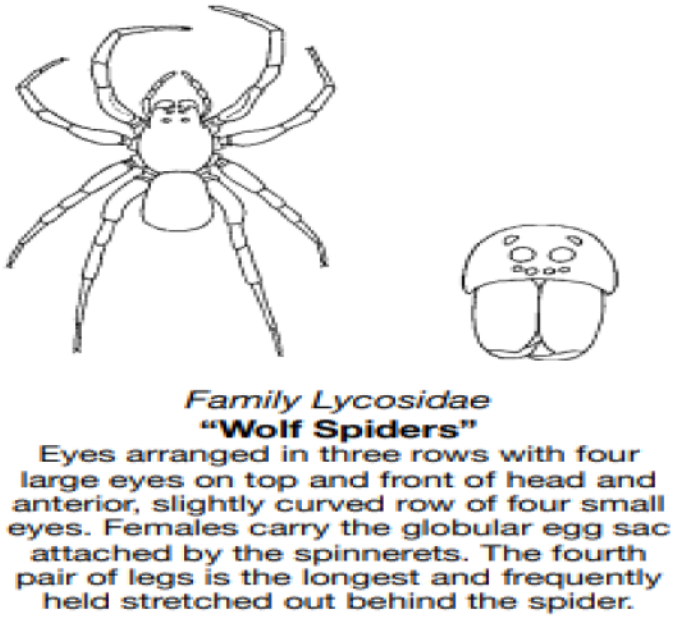


Figure 3. The leg and eye patterns used to identify the wolf spider (Family Lycosidae) (Jensen et al., 2005).

Wolf spiders are distributed worldwide, with 124 genera and more than 2,400 species. They are identified and characterized by the specific arrangement of their eight eyes, which form three rows. The front row consists of four small eyes, and the two back rows with two larger eyes (Figure 3) (Nyffeler & Benz, 1988). In Montana, 52 species of wolf spiders have been recorded to inhabit the state (Table 1) (MTNHP, 2025). They range from the smallest at 1.27 cm (0.5 in) to

the largest at 5.08 cm (2 in). The spiders have large legs specialized for running and are usually hairy and colored from brown to black. These spiders are some of the largest spider species found in Montana (Jensen et al., 2005).

Table 1. The genus, species, and common name of the 52 wolf spiders inhabiting the Montana region, adapted from MTNHP (2025).

Genus	Species	Common Name
Acantholycosa	A. solituda	solitary prickly wolf spider
Alopecosa	A. aculeata	spinyrib wolf spider
	A. kochi	koch's wolf spider
Arctosa	A. alpigena	hilltop wolf spider
	A. emertoni	emerton's wolf spider
	A. insignita	marked wolf spider
	A. littoralis	shoreline wolf spider
	A. perita	eurasian wolf spider
	A. raptor	raptor wolf spider
	A. rubicunda	redlined wolf spider
Geolycosa	G. missouriensis	missouri burrowing wolf spider
Hogna	H. carolinensis	carolina wolf spider
	H. frondicola	broad-banded wolf spider
Pardosa	P. altamontis	gaitred thin-legged wolf spider
	P. anomala	irregular thin-legged wolf spider
	P. bucklei	buckle's thin-legged wolf spider
	P. coloradensis	colorado thin-legged wolf spider
	P. concinna	graceful thin-legged wolf spider
	P. distincta	pale thin-legged wolf spider
	P. dorsalis	mountain leopard spider
	P. dorsuncata	western leopard spider
	P. furcifera	treeline wolf spider
	P. fuscula	snowbank wolf spider
	P. glacialis	glacier wolf spider
	P. groenlandica	greenland wolf spider
	P. labradorensis	labrador thin-legged wolf spider
Pardosa	P. lapidicina	stoned thin-legged wolf spider
	P. mackenziana	mackenzie's wolf spider
	P. metlakatla	metlakatla thin-legged wolf spider
	P. modica	little banded wolf spider
	P. moesta	shiny wolf spider
	P. mulaiki	mulaik's thin-legged wolf spider
	P. ontariensis	ontario thin-legged wolf spider
	P. ourayensis	a thin-legged wolf spider
	P. sternalis	forceps thin-legged wolf spider
	P. steva	toadstool thin-legged wolf spider
	P. tesquorum	northern wolf spider
	P. tetonensis	a thin-legged wolf spider
	P. uintana	boreal wolf spider
	P. uncata	a thin-legged wolf spider
	P. utahensis	a thin-legged wolf spider
	P. wasatchensis	a thin-legged wolf spider
	P. wyuta	wyuta thin-legged wolf spider
	P. xerampelina	forest wolf spider
Pirata	P. piraticus	common pirate wolf spider
	P. sedentarius	spiny-legged pirate wolf spider
Piratula	P. insularis	lonely wolf spider
Schizocosa	S. avida	avid split wolf spider
	S. mccooki	mccook's split wolf spider
	S. minnesotensis	minnesota split wolf spider
Tigrosa	T. grandis	a wolf spider
Trochosa	T. terricola	turf wolf spider

Most lycosids prefer open habitats, but a few inhabit forested areas (Piacentini & Ramírez, 2019). These spiders are aggressive predators and do not use a web to catch prey like many other spiders. They prey on smaller arthropod species, including other wolf spiders. They are generalist predators of small, soft-bodied arthropods and play a beneficial role as a natural control against arthropod pests (Nyffeler & Benz, 1988). Lycosid species prey on and ingest mostly species of Diptera, Hemiptera, and Araneae but also prey on Lepidoptera (adults and

larvae), Phalangida, Hymenoptera, Collembola, and Plecoptera, with prey range varying throughout the year (Edgar, 2009).

Limited research has been conducted on metal accumulation in spiders, and a sentinel species should be selected to monitor these metal impacts. Sentinel species can indicate information about environmental or ecosystem components without devoting scarce resources to monitoring (Clark-Wolf et al., 2024). The wolf spiders' feeding behavior and presence in many areas of Butte with high metal levels make them suitable sentinel species for the region. Their predatory feeding behavior is very aggressive because they hunt on foot instead of using a web. In Butte, the areas with high metals are covered with topsoil, but prey can dig down and infiltrate the mine waste layer. This behavior of their prey places them in direct contact with contaminated soil and leads to the ingestion of metal-contaminated organic material (Butt & Aziz, 2016).

Active hunting behavior leads to more frequent feeding on contaminated prey, which causes an increase in the accumulation of higher metal levels compared to other ground-dwelling spider species that utilize passive feeding webs (Jung & Lee, 2011). This phenomenon is known as bioaccumulation, when a substance's concentrations accumulate within an organism's body and cannot be excreted (Rainbow & Luoma, 2011). The spider's metabolism can use certain metals, while others are excreted, and some accumulate without being excreted or used (Jung & Lee, 2011). Evaluating the metal concentrations in these wolf spiders can help monitor the effectiveness of the remediation completed on these sites.

Research Goals and Objectives

My project aims to characterize the levels of metals in lycosid spiders that inhabit sites in Butte. Another objective is to compare the metal levels in lycosid spiders inhabiting remediated sites, native soil sites, and control sites where mine wastes are absent. The last objective is to identify which metal levels are elevated in the lycosid spiders inhabiting the remediated and native soil sites compared to the control site. Other questions that will be addressed include which metals are accumulated by lycosid species and what concentrations of metals accumulate in them over their lifetimes. The metal concentrations will also be compared to body size, which indicates the spider's age. I hypothesize that the spiders that are caught at the remediated sites are going to have higher metal content.

MATERIALS & METHODS

We collected spiders in non-baited pitfall traps at four sites in Butte and Grass Range, MT. These sites were at the Anselmo Historic Mine Yard site, the Travona Historic Mine Yard site, the West Side Soils site in Butte, and a control site in Grass Range. The first site, the Anselmo Historic Mine Yard, has been reclaimed with remediation practices using non-native fill soil. The second site, the Travona Historic Mine Yard site, has been reclaimed with native fill soil. The third site was West Side Soils, an undisturbed area within the Butte area with native soil with elevated heavy metals. The control site in Grass Range was chosen because of the lack of anthropogenic activity in the area.

We placed nine traps at each site, arranged in a three-by-three grid, each trap spaced 20 m apart to ensure that each trap acted independently. The grid was positioned to prevent interference from features such as trails, roads, and vegetation transitions to avoid unwanted

edge effects. Additionally, to minimize edge effects, the grid was centered at each site so that at least 25 m of the dominant vegetation or ground cover surrounded it. The dominant vegetation and ground cover included big sagebrush (*Artemisia tridentata* Nutt.) at the West Side Soils site, sheep fescue (*Festuca ovina* L.) at the Travona Historic Mine Yard site, and crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) at the Anselmo Historic Mine Yard site.

The traps, while non-baited, were filled with ultra-pure water (18.2 MΩ-cm) and 100 µL of soap to disrupt surface tension and ensure capture. These pitfall traps were left on site for one week to ensure an adequate sample size. Once the trap was returned to the lab, the invertebrates caught were sorted and identified as lycosids. The lycosids were identified by eye pattern and abdomen marking specific to species found in the region (MTNHP, 2025). The spiders were washed with ultra-pure DI water and dried in an oven at 50 ºC for 24 hours. After being dried, the spiders were weighed, and their weights were recorded. The spiders were then acid-digested by placing the specimens in 5 mL of 50% nitric acid (1 mL Nitric acid/ 1 mL ultra-pure DI water) and heating them to 60°C for 1 week. After the spiders were acid-digested, the digestion was resuspended in 50% nitric acid and filtered with a 0.2-µg filtration procedure. The equipment was triple rinsed with 2% nitric acid between samples.

The filtered digestion was then heated in a heat block to evaporate 50% nitric acid at 60°C for 1 week. The filter digestion was then resuspended in 5 mL of 2% nitric acid to align with the protocol to analyze for the metal concentrations. The resuspended filtered digestion was then sent to the Montana Bureau of Mines and Geology (MBMG) for metal content analysis. The heavy metal content was analyzed using the EPA method 200.8 on a Thermo Scientific iCAP Q inductively coupled plasma mass spectrometer (ICP-MS) (Long, 1994).

Data Analysis

The data was obtained from the MBMG processing samples through ICP-MS to assess the total metal content accumulated within the spiders. We then analyzed the total metal content in the samples to determine which metals were most prevalent. A relative abundance analysis was conducted using Origin software for data analysis and graphing to ascertain the percentage presence of each metal in the spiders. This analysis aimed to identify which metals accumulated at the highest concentrations across all four sites, helping us identify our metals of interest that were present at the highest concentrations throughout all the study sites. In Origin, these sites and metals of interest were analyzed to determine the range within 1.5 IQR (interquartile range (IQR)), range, median (M), mean ($\bar{x}$), minimum (min), maximum (max), and outliers. The total metals across the sites and the spider weights from all the sites are then compared to evaluate if there is a relationship between spider weight and age. This comparison was also performed with the total amount of metals of interest from all the sites and the weights of all the caught spiders. The mean was calculated for total metals (nmol) and spider weights (g) for individual sites and combined sites; then, the average total metal per spider weight was determined (nmol/g). From these data, the Standard Deviation (SD) was calculated for all the individual sites and combined totals for metals and spider weight.

RESULTS

The pitfall traps caught 51 lycosid spiders over the period they were placed on site. The Anselmo Mine Yard site had 13, the Trevona Mine Yard site had 11, the West Side Soils site had 11, and the Control site had 16.

Total Metal Analysis

The results from the ICP-MS analysis indicated that lycosid spiders from all sites contained metal isotopes aluminum (Al), arsenic (As), barium (Ba), boron (B), cadmium (Cd), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), molybdenum (Mo), silver (Ag), rubidium (Rb), strontium (Sr), and zinc (Zn). The total amount of each metal isotope identified during the ICP-MS analysis was reported in ppb and then converted to nmol. The total of each metal (nmol) for all four sites was calculated to determine which metal was at the highest accumulation within the spiders (Table 2).

Table 2. The total amount of metals (nmol) in lycosid spiders caught on the Anselmo Mine Yard Site, Trevona Mine Yard Site, West Side Soils Site, and Control Site.

Metal Isotopes	Total metals (nmol)
silver (Ag)	4.83
lead (Pb)	5.34
arsenic (As)	6.04
molybdenum (Mo)	12.77
rubidium (Rb)	15.21
cadmium (Cd)	38.88
barium (Ba)	73.81
strontium (Sr)	77.44
boron (B)	152.94
manganese (Mn)	929.50
copper (Cu)	964.93
zinc (Zn)	5812.63
iron (Fe)	8289.18
aluminum (Al)	14010.97

Relative Abundance Analysis

We ran a relative abundance analysis to determine the percentage of each metal at each site (Figure 4).

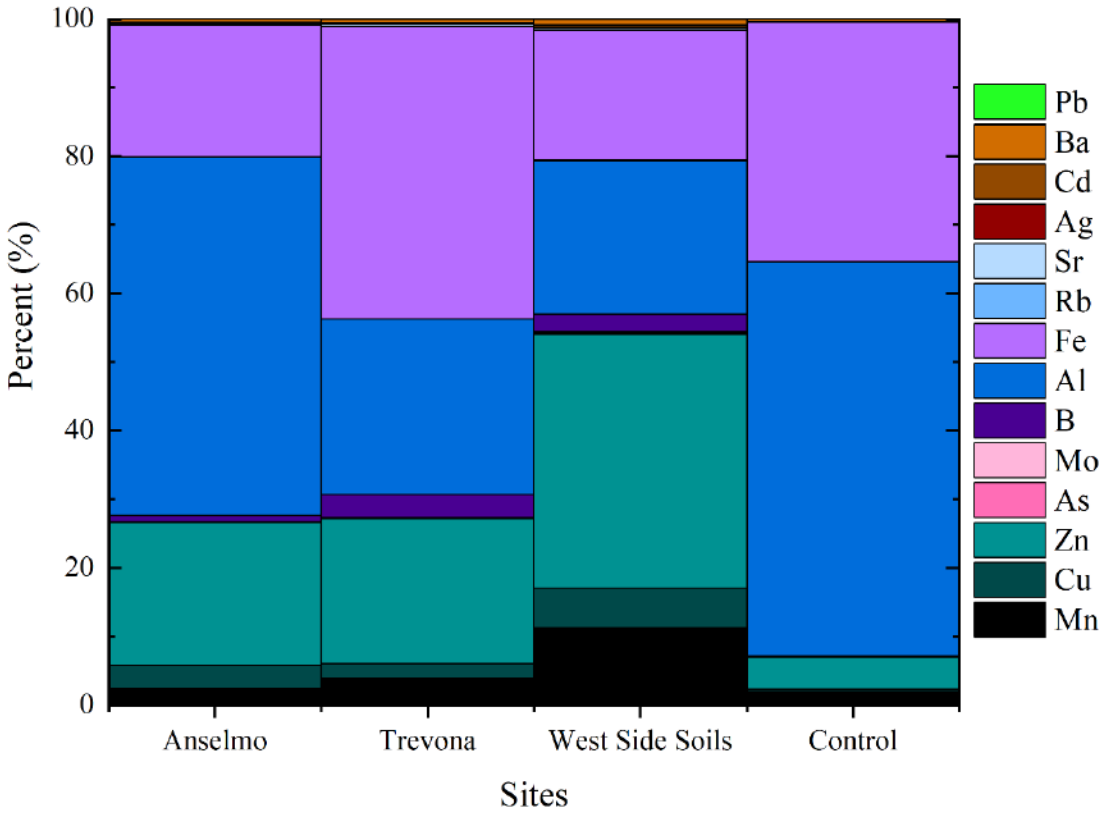


Figure 4. Relative abundance illustrates the percentage of each metal found in lycosid spiders at individual sites. Each metal is represented by a specific color and size in this figure, indicating both its presence and the proportion it contributes to the total amount across all the spiders at a given site. These results reveal the metals that accumulate in lycosid spiders within these sites.

This analysis revealed the percentage of each metal present in the spiders at each site and across all sites combined (Table 3). The analysis identified the percentage of the most prevalent metals accumulated in the spiders at each location. The metals found at the highest levels across all the sites were used to analyze the overall data. The metals identified with the highest concentrations and abundance across all locations are Mn at 3.1%, Cu at 3.17%, Zn at 19.12%, Fe at 27.27%, and Al at 46.10%. These metals will be referred to as the metals of interest through subsequent analyses.

Table 3. Relative abundance of metal percentages in all spiders at the Anselmo Mine Yard Site, Trevona Mine Yard Site, West Side Soils Site, Control Site, and all sites combined.

Metal	All Sites (%)	Anselmo (%)	Trevona (%)	West Side Soils (%)	Control (%)
Al	46.10	48.45	43.45	44.70	48.81
Fe	27.27	24.41	32.42	23.86	24.13
Zn	19.12	18.93	17.00	22.58	21.22
Mn	3.06	3.75	3.30	3.02	1.27
Cu	3.17	3.11	2.71	4.30	3.34
B	0.50	0.62	0.38	0.56	0.51
Ba	0.24	0.26	0.17	0.32	0.32
Sr	0.25	0.20	0.31	0.21	0.28
Cd	0.13	0.12	0.10	0.29	0.08
Mo	0.04	0.07	0.04	0.03	0.02
Pb	0.02	0.03	0.02	0.02	0.01
Rb	0.05	0.03	0.08	0.04	0.03
As	0.02	0.02	0.02	0.04	0.01
Ag	0.02	0.01	0.02	0.02	0.01

Analysis of Accumulation of Metals of Interest

The accumulation of the metals of interest in the lycosid spiders caught at each individual sample site was analyzed in nmol for each site. The samples collected from the individual sites were analyzed using the metals of interest. This analysis was done by indicating and plotting the range within 1.5 IQR (interquartile range (IQR)), range, median (M), mean ($\bar{x}$), minimum (min), maximum (max), and outliers (Figure 6). In Appendix B, there is a statistical analysis of the values for all sites that were analyzed. These values show that at all the sites, the most accumulated metals were Fe, Al, and Zn, while Mn and Cu were at much lower levels.

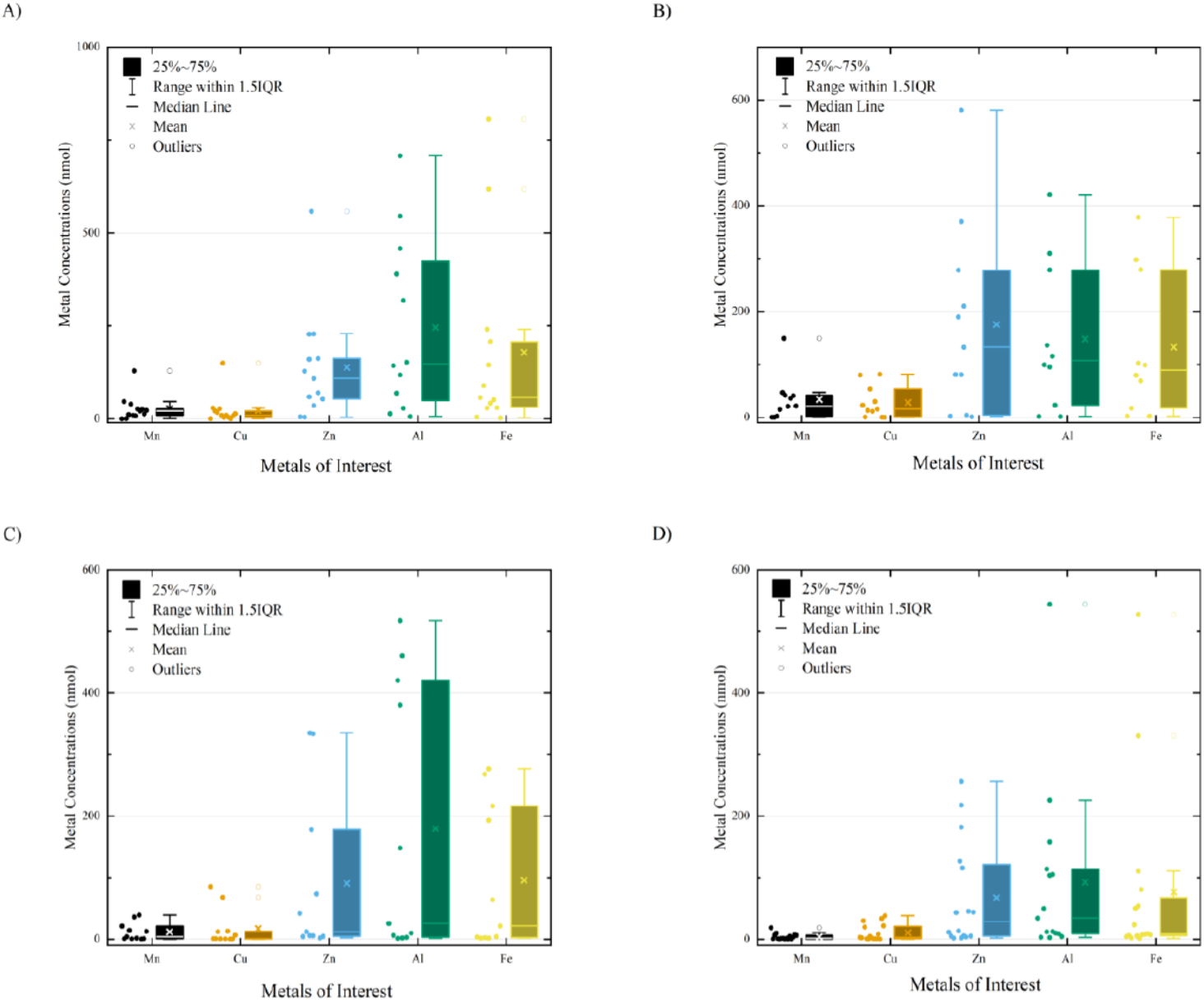


Figure 5a–d. Accumulation of the metals of interest (Mn, Cu, Zn, Al, and Fe) in the lycosid spiders caught at each individual sample site, revealing the range within 1.5 IQR (interquartile range), range, median, mean, and outliers in nmol. The graphs are labeled for each site's data: A. Anselmo Mine Yard Site, B. Travona Mine Yard Site, C. West Side Soils Site, and D. Control Site.

Analysis of Spider Metal Accumulation vs. Spider Weight

We compared the spiders' dry weights (g) to the total metal accumulation (nmol) accumulated throughout the individual sites (Figure 7). The results suggest a relationship between a spider's weight and the total amount of metals it accumulates. The R^2 value for all the sites combined is 0.1537, or 15.37%, indicating a low variance in the spider weight (the dependent variable) that can be attributed to the total amount of metals it accumulates (the independent variable).

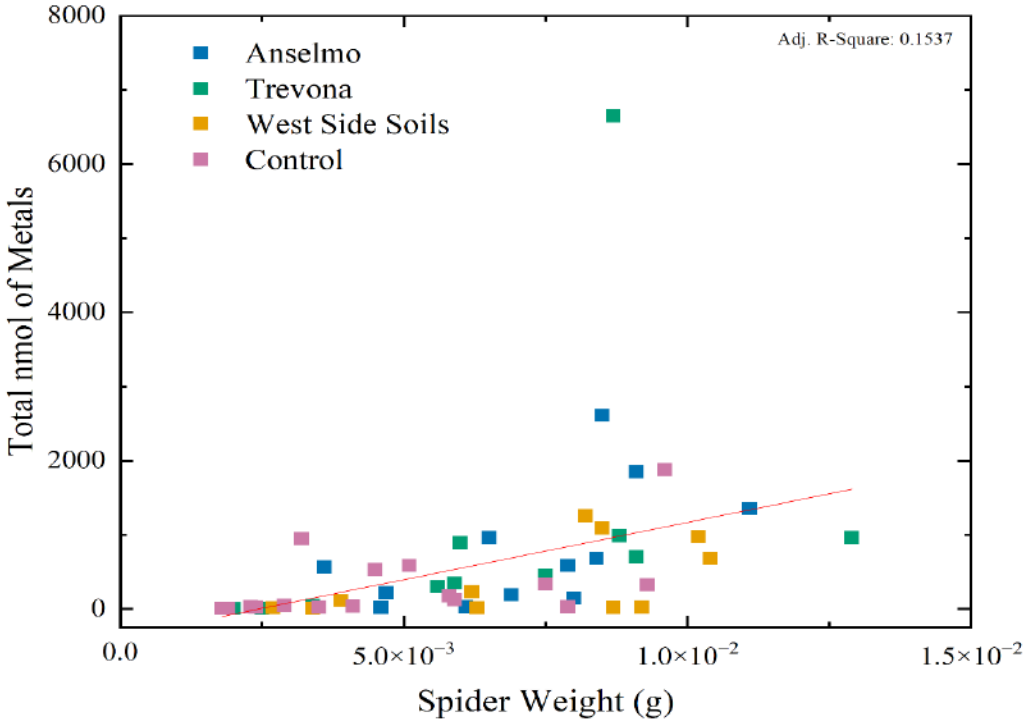


Figure 6. The accumulation of the total amount of metals (nmol) versus spider weight (g) for each site. The R-squared value of 0.1537, or 15.37%, indicates low variation, reflecting a weak relationship between spider weight and total metal accumulated.

Appendix A compares the total amounts of metals of interest across all sites with the total spider weights collected at these locations. Each appendix illustrates different accumulation levels of the metals of interest and spider weights throughout the spiders caught at all the sites. The R^2 value varied among the different metals of interest, with the largest variation indicating the strongest relationship between metal and weight being Zn, which had a value of 0.31 or 31%. The other metals had lower R^2 values, indicating weaker relationships, with Cu at 0.2892 or 28.92%, Al at 0.2424 or 24.24%, Fe at 0.2222 or 22.22%, and Mn at 0.1937 or 19.37%.

We then analyzed the data numerically to determine the standard deviation of total metals and the average weight of the spiders (Table 4). This analysis revealed that the total metal accumulation exhibited high variability, reflected by a high standard deviation (SD) across all sites and combined. In contrast, the SD data for the weights of the spiders indicated low variability, as shown by a low SD across all sites and combined. The average total metal accumulation per gram of spider weight was also analyzed. The spiders collected from Trevona showed the highest metal concentration (nmol) per spider weight (g) at 1.57E+05 nmol/g compared to all other sites. The Anselmo Mine Yard site had the second highest concentration at 1.03E+05 nmol/g, followed by the Control site at 6.56E+04 nmol/g, with the West Side Soils exhibiting the least with 5.69E+04 nmol/g.

Table 4. Average values of total metals (nmol), weight (g), and the average amount of metals accumulated in spiders relative to their weight (nmol/g). The standard deviation (SD) of the average total metal content of the spiders and their weights was calculated to assess the variation within and between the different sites.

Site	Average Total of Metals (nmol) (SD)	Average Weight (g) (SD)	Average nmol/g
Anselmo Mine Yard	7.33E+02 (7.81E+02)	7.15E+03 (2.06E+03)	1.03E+05
Trevona Mine Yard	1.03E+03 (1.90E+03)	6.58E+03 (3.26E+03)	1.57E+05
West Side Soils	4.02E+02 (4.97E+02)	7.06E+03 (2.75E+03)	5.69E+04
Control	3.19E+02 (4.97E+02)	4.86E+03 (2.59E+03)	6.56E+04
All sites	5.96E+02 (1.02E+03)	6.29E+03 (2.74E+03)	9.48E+04

DISCUSSION

Our study supports that wolf spiders may be a suitable sentinel species for efficiently monitoring metal bioaccumulation. We found that the metals Mn, Cu, Zn, Fe, and Al accumulate in high concentrations in the spiders caught on these sites compared to the other metals in the spiders. These metals were at elevated levels across all four sites, with the highest concentrations recorded at the Trevona Mine Yard site. Larger spiders, or those that weighed more, were associated with more mature individuals. There is a trend that smaller spiders accumulate lower metal levels, while their larger counterparts exhibit higher metal accumulations.

Metal Concentration Analysis by Site

The total metal concentrations were highest in lycosids at the Trevona Mine Yard site, likely due to the reclaimed native fill soil containing naturally occurring metals that cover mine waste. The Anselmo Mine Yard site followed, being a reclaimed area with non-native fill soil that still contained mine waste beneath it. The next lowest was the West Side Soils site, an

undisturbed region in the Butte area with native soil and elevated heavy metals. The control site, situated in an undisturbed area with no mining history, recorded the lowest metal concentrations.

Size-Related Metal Accumulation

These results indicate that as the spiders grow larger- implying they are older- they accumulate more metal. The spiders tend to accumulate these metals of interest more than the other analyzed metals, demonstrating an unsurprising upward trend: As the spiders' weight increases, metal accumulation also increases (Appendix A). This trend was observed across all study sites, including the control site with the lowest metal concentrations. These results are limited because the sample contained several species of lycosid spiders, which may each have different weights and maturities.

Environmental Implications

Our results demonstrate a connection between the mine waste beneath the remediated areas and surface-dwelling animals. The data show that these spiders have higher concentrations of some metals than those not exposed to high metal levels. These metals could affect trophic levels and lead to their bioaccumulation in larger animals that are higher in the food chain. Although possible, our study did not demonstrate this because of the lack of larger animal data. The data and results indicate that the current remediation practices can allow the environment and the animals inhabiting it to interact with mine waste with a high metal content. The connection between mine waste and the environment is shown by the elevated concentrations of metals found in higher trophic levels, such as the wolf spider.

Future Research

For future research, I recommend increasing the sample size across all sites and adding a site in Butte where no mining history has occurred. These changes would provide a broader range of data, demonstrating more evidence of metal accumulation. The prey species could be tested for what metals they have in them to see what concentrations the wolf spiders ingest. The Identification of the lycosid species individually and observing how the metal concentrations differ among the various species. The wolf spider's guts could be dissected to show that the metals are accumulated from just ingesting the prey. An XRF (X-ray fluorescence) metal analysis of each site would be beneficial, revealing which metals are at different levels and where the mine waste is. This would give a baseline for the metal content of the soil for each site.

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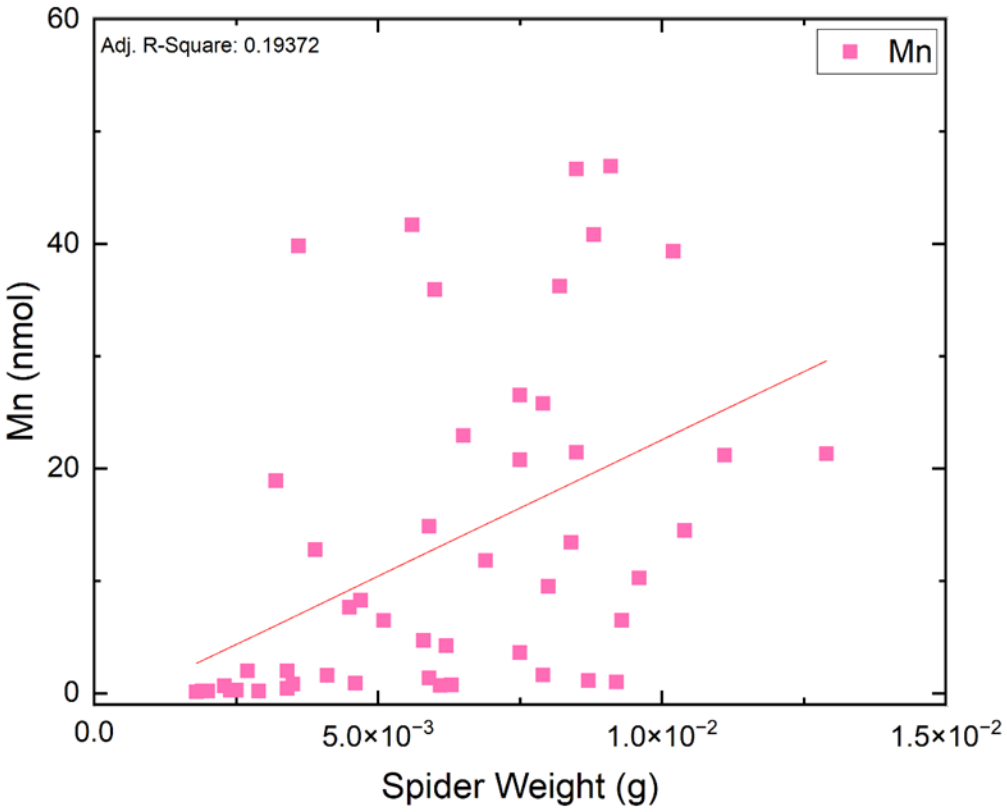
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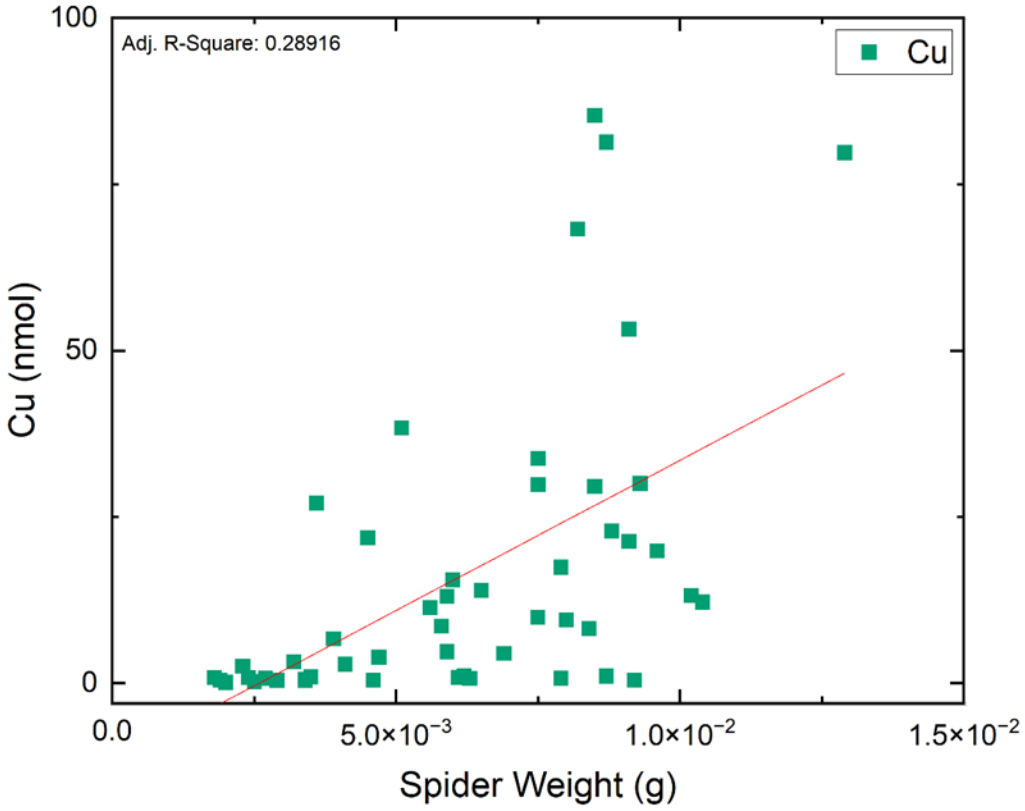
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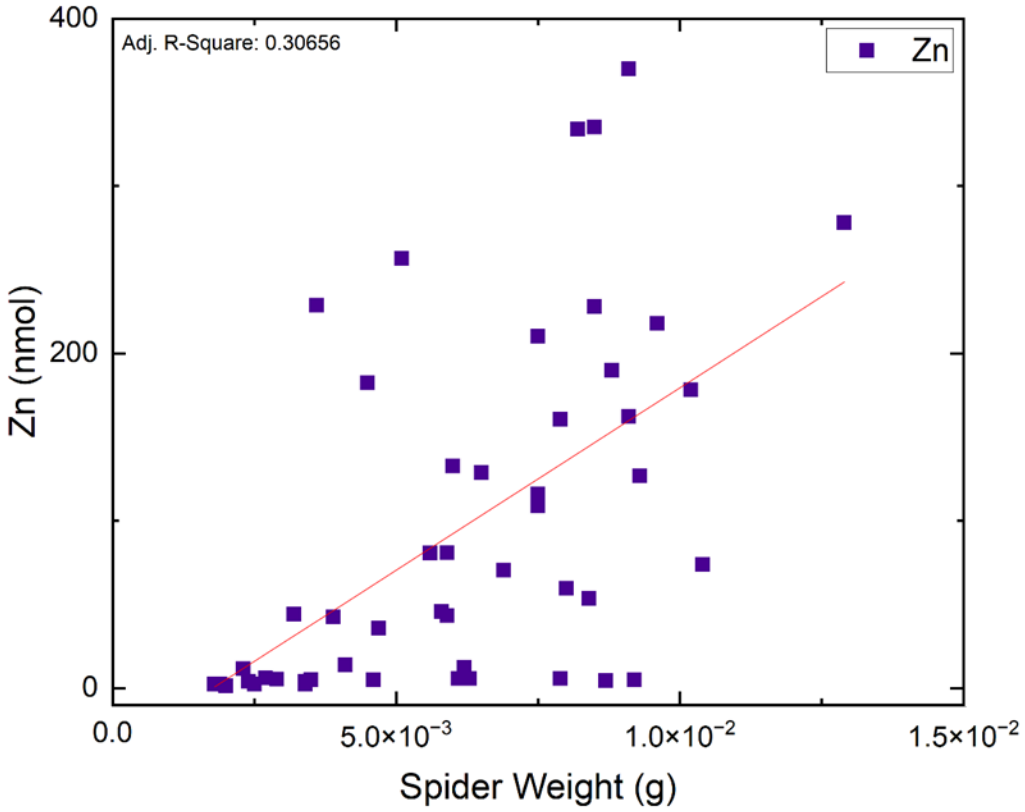
APPENDICES

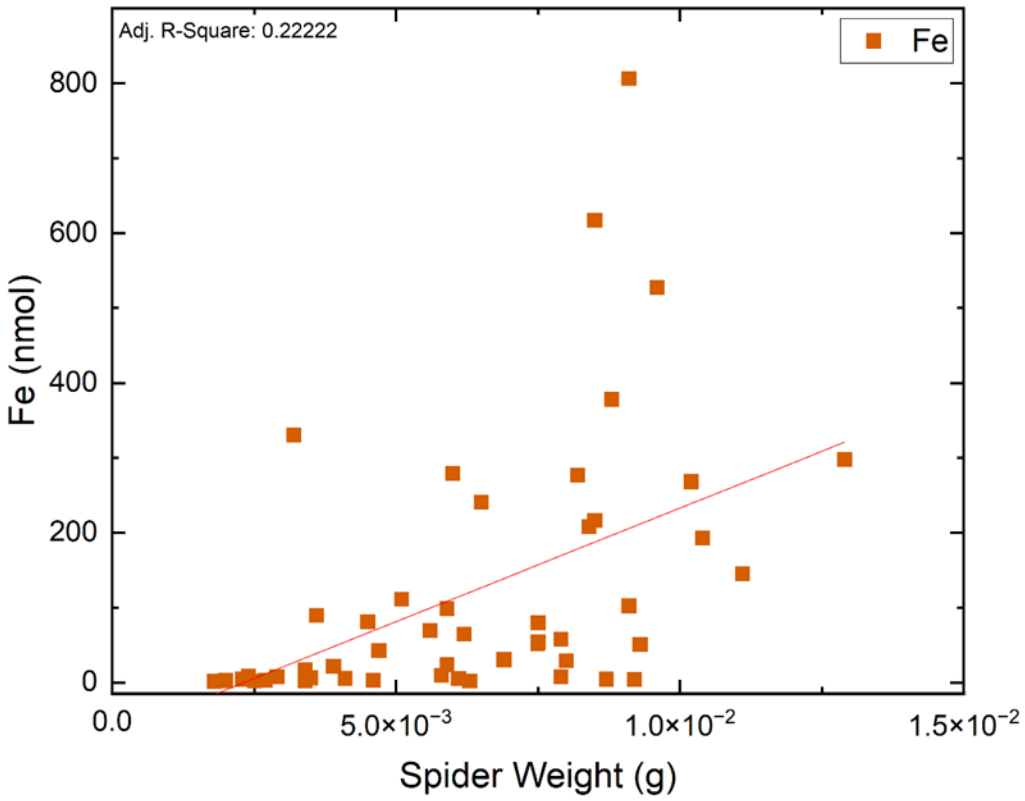
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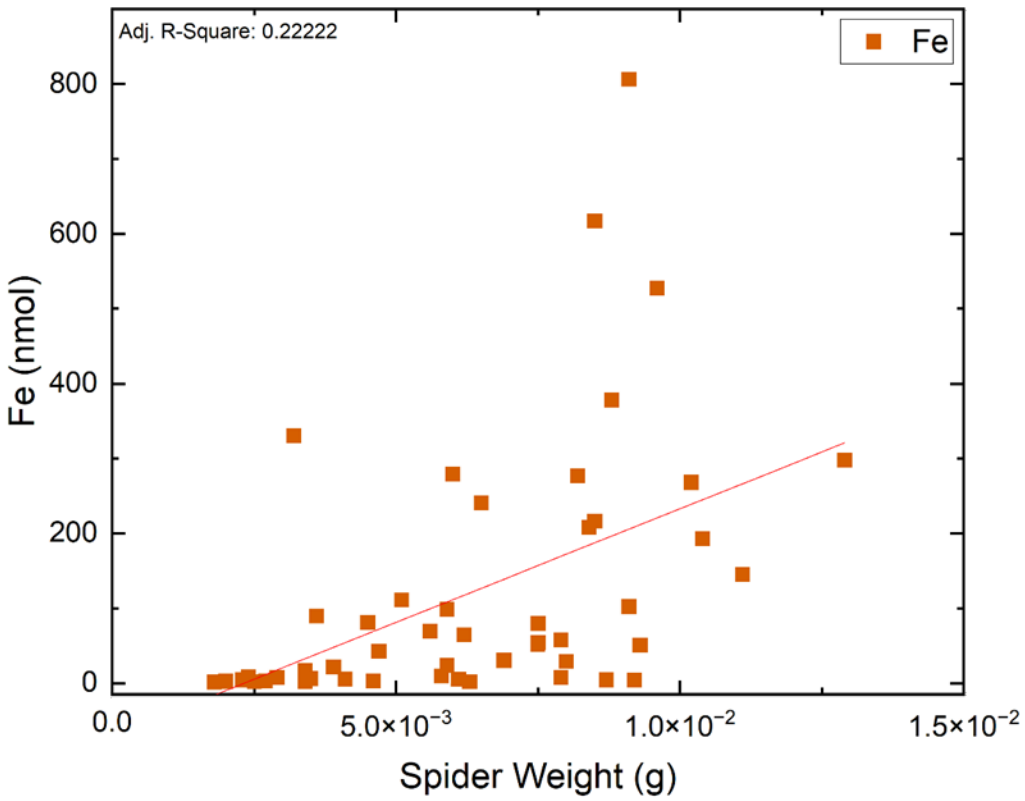
METALS OF INTEREST ACCUMULATION (NMOL) VS. SPIDER WEIGHT

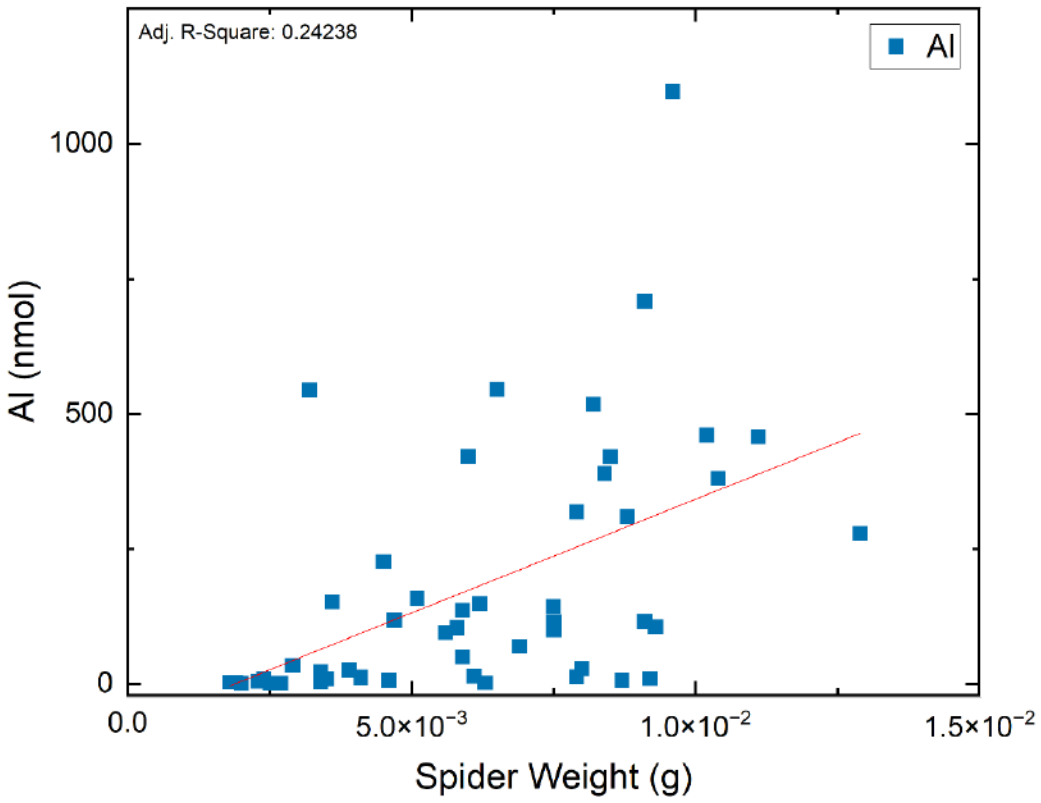

Adj. R-Square: 0.19372
Mn
Mn (nmol)
60
40
20
0
0.0
5.0×10⁻³
1.0×10⁻²
1.5×10⁻²
Spider Weight (g)


Adj. R-Square: 0.28916
Cu
Cu (nmol)
100
50
0
0.0
5.0×10⁻³
1.0×10⁻²
1.5×10⁻²
Spider Weight (g)


Adj. R-Square: 0.30656
Zn
Zn (nmol)
400
200
0
0.0
5.0×10⁻³
1.0×10⁻²
1.5×10⁻²
Spider Weight (g)


Adj. R-Square: 0.22222
Fe
800
600
400
200
0
Fe (nmol)
0.0
5.0×10⁻³
1.0×10⁻²
1.5×10⁻²
Spider Weight (g)


Adj. R-Square: 0.22222
Fe
800
600
400
200
0
Fe (nmol)
0.0
5.0×10⁻³
1.0×10⁻²
1.5×10⁻²
Spider Weight (g)


Adj. R-Square: 0.24238
Al
1000
500
0
Al (nmol)
0.0
5.0×10⁻³
1.0×10⁻²
1.5×10⁻²
Spider Weight (g)

APPENDIX B

STATISTICAL ANALYSIS OF SITE-SPECIFIC METAL ACCUMULATION

THESE VALUES SHOW THE STATISTICAL ANALYSIS FOR THE METAL CONCENTRATIONS IN THE SPIDERS CAUGHT AT EACH INDIVIDUAL SITE.

Anselmo Mine Yard Site					
	Al	Fe	Zn	Mn	Cu
IQR	374.89	177.48	108.90	17.05	16.84
Range	701.50	803.59	553.32	128.75	1449.61
M	147.72	57.42	108.90	21.20	9.93
$\bar{x}$	245.90	178.92	138.74	27.45	22.83
min	6.25	2.79	4.76	0.68	0.44
max	707.76	806.38	558.08	129.44	150.06
Trevona Mine Yard Site					
	Al	Fe	Zn	Mn	Cu
IQR	255.52	261.92	274.01	39.71	52.64
range	419.70	375.88	579.64	149.13	81.22
M	107.39	89.12	132.45	21.31	15.52
$\bar{x}$	148.15	132.60	175.41	34.02	27.99
min	1.37	2.06	1.14	0.21	0.12
max	421.07	377.95	580.78	149.34	81.34
West Side Soils Site					
	Al	Fe	Zn	Mn	Cu
IQR	417.13	213.78	173.26	20.41	12.47
range	515.75	274.75	332.80	38.92	84.96
M	25.54	21.59	12.29	4.20	1.12
$\bar{x}$	179.67	95.92	90.74	12.15	17.29
min	1.54	2.02	2.22	0.41	0.40
max	517.29	276.77	335.02	39.34	85.37
Control Site					
	Al	Fe	Zn	Mn	Cu
IQR	105.09	61.65	116.23	6.03	20.04
range	541.26	526.24	254.50	18.78	37.96
M	34.42	8.68	28.48	1.60	3.04
$\bar{x}$	92.71	76.86	67.59	4.04	10.63
min	2.89	1.41	2.15	0.11	0.40
max	544.15	527.65	256.65	18.90	38.36
*Values reported in nmol					