THE APPLICATION OF SMALL-MAMMAL ANALYSES IN TERRESTRIAL ECOLOGICAL RISK ASSESSMENT, FORMER YANKEE GIRL MINE, YMIR, B.C.

J.H. Sevigny, Ph.D.[1]
J. Dulisse, R.P.Bio.[2]
M. Tinholt, P.Eng.[3]
G. Stewart, P.Geo.[4]
G. Sinnett, P.Geo.[4]

[1]Iridium Consulting Inc.
812 Victoria Street
Nelson, BC V1L 4L5

[2]Masse & Miller Consulting Ltd.
513 Victoria Street
Nelson, BC V1L 4K7

[3]Morrow Environmental Consultants Inc.
Member of the SNC-Lavalin Group
385D Baker Street
Nelson, BC V1L 4H6

[4]Ministry of Agriculture and Lands
Crown Contaminated Sites Branch
PO Box 9361 Stn Prov Govt
Victoria, BC V8W 9M2

ABSTRACT

A small mammal study was undertaken at the former Yankee Girl Mine, Ymir, B.C. (the "Site") to determine if metals contaminated tailings and surface soil have resulted in adverse health effects to the terrestrial ecosystem and would require remediation to protect the environment. A screening level Tier I ecological risk assessment conducted by a previous consultant yielded hazard quotients above the regulatory limit for the most sensitive terrestrial receptor at the Site (i.e., field mouse), suggesting the potential for adverse, population-level health effects. The screening level model was calibrated here using new data collected as part of a Site-specific small mammal study (e.g., surface soil and deer mice tissue concentrations). Despite orders of magnitude variations in soil concentrations, deer mice tissue concentrations were similar at all locations (1 control; 3 contaminated), and soil to deer mouse bioaccumulation factors were inversely correlated to soil concentration. The calibrated model yielded hazard quotients well below the regulatory limit, suggesting that deer mice have not been adversely affected. The significance of these findings with respect to remedial and/or management decisions at the Site will be discussed.

INTRODUCTION

Theoretical exposure models that predict hazard quotients (HQs) are one technique used in the weight-of-evidence approach in ecological risk assessment (Golder Associates, 2006; Hull and Swanson, 2006). Screening level models that have not been calibrated using empirical, site-specific data are commonly inaccurate due to inappropriate assumptions and input parameters. Calibration involves refining assumptions and input parameters in an effort to return a more accurate risk prediction. In order to make confident risk-based decisions that support sound remedial and/or management strategies, the screening level ecological model should be calibrated using site-specific data.

The purpose of a screening level assessment is twofold (ORNL, 1996). The first is to identify the chemicals of potential concern, and the second is to identify receptors potentially at risk. When a screening assessment predicts the potential for an adverse effect in an ecosystem, such as a hazard quotient (HQ) above a regulatory limit, additional work is required to validate the prediction, especially if remedial decisions will be risk-based. Field-based studies are most commonly used to collect data for calibrating an ecological model.

Metal contaminated tailings and surface soil characterize the former Yankee Girl Mine, Ymir, B.C. (herein called the "Site"). As part of the remediation program for the Site, URS (2005a) used the BCMELP (1998) Tier I methodology to calculate HQs for terrestrial and aquatic receptors. URS (2005a) showed that deer mice were the most sensitive wildlife terrestrial receptor and suggested the potential for Site-wide population levels effects based on arsenic and cadmium HQs (12.3 and 1.5, respectively; Table 1).

Table 1: Deer Mouse Hazard Quotients

Metal	URS (2005a)	This Study			
	Site-Wide	M1	M2	M3	M4
	Uncalibrated, Screening Level Model[1]				
As	**12.3**	0.7	0.6	**13.1**	**12.8**
Pb	0.5	0.1	0.1	0.5	**2.7**
Zn	0.6	0.0	0.0	0.8	0.2
Cd	**1.5**	0.1	0.1	**2.7**	0.5
	Calibrated, Site-Specific Model[2]				
As	----	0.014	0.012	0.016	0.019
Pb	----	0.004	0.008	0.008	0.003
Zn	----	0.022	0.038	0.037	0.030
Cd	----	0.007	0.025	0.020	0.057

[1]Uses 95th percentile soil concentrations and published BAFs.

[2]Uses median soil concentrations and Site-specific soil to mouse BAFs.

12.3 = bolded values exceed the regulatory limit (i.e., 1.0).

---- = not applicable.

M1 = control location; M2–M4 = contaminated locations.

This paper presents the results of a field-based small mammal study undertaken at the Site to refine earlier risk-based predictions using the screening level BCMELP (1998) Tier I methodology (URS, 2005a). This study illustrates that despite orders of magnitude variations in soil concentrations, the metals

concentration in deer mouse tissue was similar at the control and contaminated locations. Soil to mouse bioaccumulation factors (BAFs) varied 2–3 orders of magnitude and were inversely correlated to soil concentration. HQs predicted using the calibrated, Site-specific model were similar to the control and below the regulatory limit of 1 (Table 1). These results were especially important for one location where remedial action was not required to protect human health, but may have been considered using the uncalibrated, screening level model.

BACKGROUND

Historic land use and surface soil metals analyses (URS, 2005b; Morrow, 2007) were used to subdivide the Site into nine Areas of Concern. Morrow (2007) identified remnant tailings and elevated metals along a former access road located in mature cedar-hemlock forest extending north of the Main Tailings.

The small-mammal trapping program was conducted between 28–30 June, 2006. Trapping locations are shown in Figure 1 and include:

- M1 - Northeast Tailings Area (control site);
- M2A/B - former access road north of the Northwest Tailings Area;
- M3A/B - remnant tailings in the Northwest Tailings Area; and
- M4 - Former Mill Area.

Median measured concentrations of Pb, Zn, As, and Cd at the four trapping locations are illustrated in Figure 2.

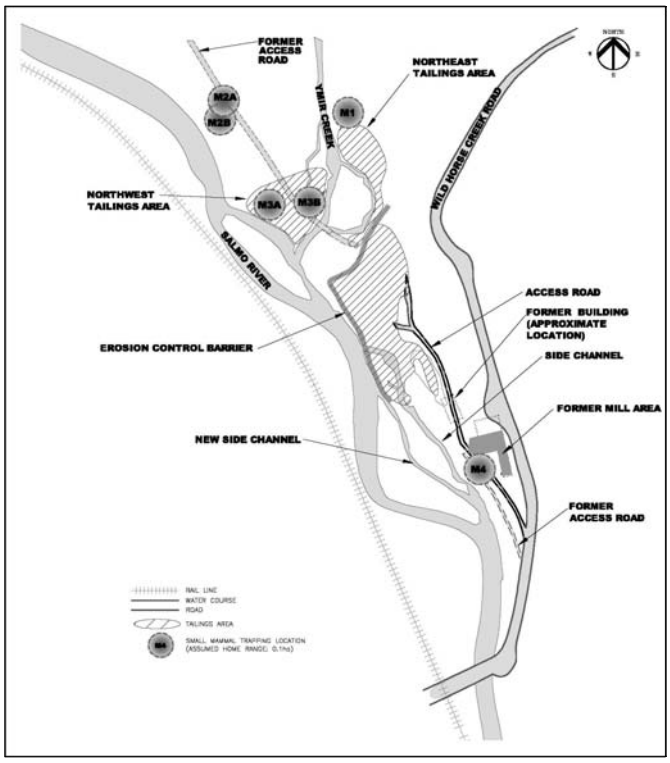

Figure 1: Small-Mammal Trapping Locations

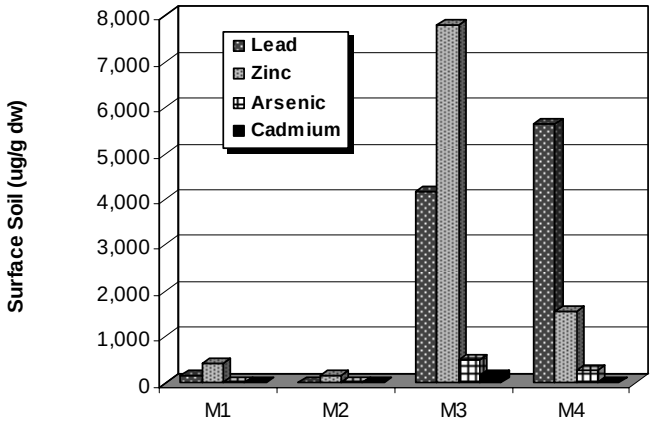

Figure 2: Median Surface Soil Concentrations at the Small-Mammal Trapping Locations

FIELD PROGRAM

Methodology

Deer mice and shrew were the target small mammals. Only deer mice data will be discussed in this paper[1]. Deer mice are sensitive indicators of exposure because their daily food ingestion rate is high relative to their body weight. Deer mice are opportunistic and omnivorous, with a widely varying diet that consists primarily of plant matter (seeds, roots, fruits, fungi) and insects (arthropods) (Johnson, 1961). Home range of the deer mouse is variable and is related to food supply (Stickel, 1968; Banfield, 1974). Deer mice population densities vary dramatically, and have been shown to be correlated with food abundance (Taitt, 1981), plant moisture contents (Bowers and Smith, 1979), vegetation cover (van Horne, 1982), and season (Montgomery, 1989).

Twelve Bolton Traps were used at each sample site (Masse & Miller, 2006). Frozen deer mice were provided to Iridium for inventory and processing. Deer mice were submitted whole to the laboratory, with each animal submitted in a separate zip locked bag. Tissue samples were placed on ice and couriered to ALS Laboratory in Vancouver, B.C. for analyses of moisture content and ICP-MS metals.

Results

Thirty-three deer mice (*Peromyscus maniculatus*) were captured over three nights of trapping. The capture rate was 0.18 animals/trap night (i.e., 33 animals/180 trap nights). Adult and sub-adult deer mice were collected with the number of females and males being approximately equal. Average deer mice weights were similar and ranged from 16.5 ± 2.9 g (station M4) to 19.4 ± 3.6 g (station M3). Deer mice were most abundant at station M4, as a result of favorable habitat (Masse & Miller, 2006). Six deer mice

[1] Only 1 shrew was captured due to poor shrew habitat at the Site.

were collected from each station (except for 7 mice at station M2), and three were submitted for metals analyses.

Metals concentrations in deer mouse tissue are summarized in Appendix I. Tissue concentrations are reported on a wet weight basis (mg/kg ww). The concentration of Zn, expressed as the average ± 1SD (one standard deviation) at each trapping location is illustrated in Figure 3. Zn was used as an example because it is one of the metals showing the largest variation (Figure 2). When expressed at one standard deviation, there is no difference in Zn, Pb, As, or Cd concentrations in field mice tissue at stations M2–M4 relative to the control (M1).

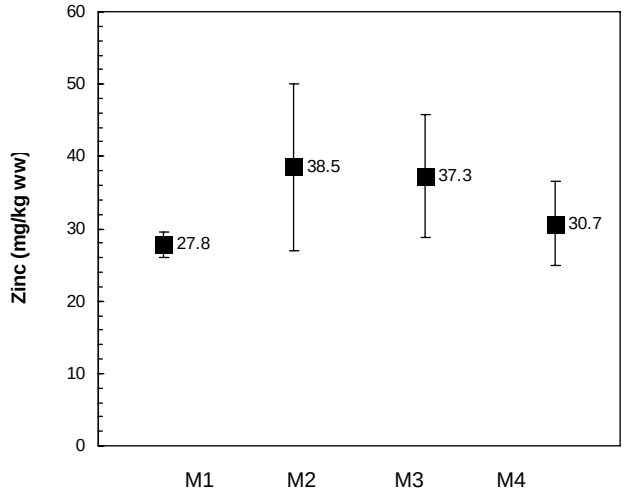

Figure 3: Zinc Tissue Concentrations in Deer Mouse

Soil to deer mouse bioaccumulation factors (BAFs) were calculated for each metal on a dry weight basis as follows:

$$BAF = \frac{[C_{DM}\ (mg/kg\ ww) \times 3.4]}{[C_S\ (mg/kg\ dw)]}$$

where:

BAF = soil to mouse bioaccumulation factor (unitless); C_{DM} = average deer mouse tissue metal concentration at each trapping location expressed on a wet weight basis (mg/kg ww), 3.4 = wet weight to dry weight (dw) conversion factor; and C_S = median metal concentration in soil within an assumed 0.1 ha deer mouse home range centered on a trapping location and expressed on a wet weight basis (mg/kg dw).

The soil to deer mouse BAFs calculation is illustrated using arsenic at location M3 (Northwest Tailings Area) as an example:

$$0.00023 = \frac{[0.036\ (mg/kg\ ww) \times 3.4]}{517\ (mg/kg\ dw)}$$

Soil to deer mouse BAFs for trapping locations M1–M4 are summarized in Table 2, and are reported relative to the published BAF (calculated here as a single BAF using the assumed dietary composition). A log-log plot showing deer mouse bioaccumulation factors for Zn, Pb, As, and Cd and as a function of soil concentration is shown in Figure 4.

Table 2: Soil to Mouse Bioaccumulation Factors[1]

Metal	USEPA (1993)	Measured (this study)			
	Published	M1	M2	M3	M4
As	1.0E-01	4.0E-03	5.6E-03	2.3E-04	5.1E-04
Pb	5.5E-02	1.9E-02	1.4E-01	1.7E-03	4.4E-04
Zn	3.6E-01	1.9E-01	8.1E-01	1.6E-02	6.6E-02
Cd	7.4E-01	1.1E-01	1.6E+00	1.2E-02	5.7E-01

[1]Expressed on a dry weight basis.

This study assumed a deer mouse home range of 0.1 ha (Figure 1), which is on the lower end of reported ranges. The measured BAFs are not sensitive to this assumption at M3 and M4 due to habitat considerations and soil sample size, but are sensitive to the home range assumption at M1 and M2.

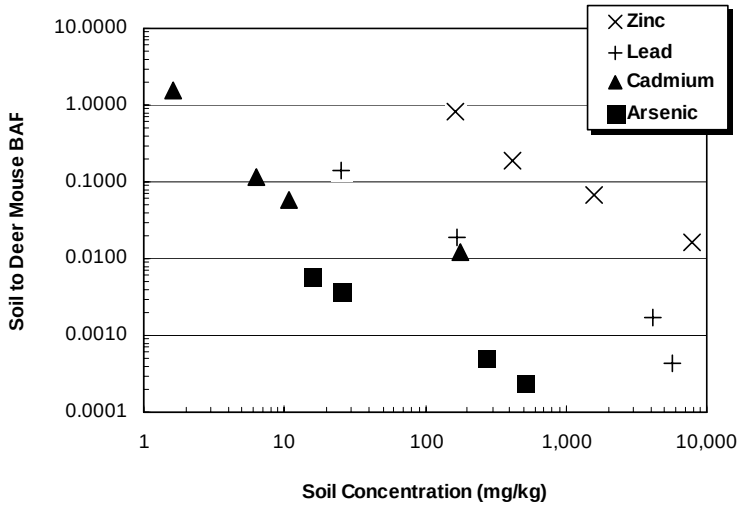

Figure 4: Soil to Deer Mouse BAF vs. Soil Concentration

EXPOSURE MODELLING

Screening Level

The screening level model used by URS (2005a) followed the BCMELP (1998) Tier I methodology and used wildlife parameters from USEPA (1993), BAFs from the USEPA (1999), and toxicity reference values from ORNL (1996). The model assumed that deer mice:

- were exposed to soil concentrations at the upper 95th percent confidence limit;
- dietary composition was 2% soil, 37% plant, and 61% soil invertebrates;
- soil to plant and soil to invertebrate uptake was linear over a range of metals concentrations; and

- metals bioavailability was 100%.

Metals dose to the deer mouse from incidental ingestion of soil and ingestion of plants and soil invertebrates in the diet were calculated as follows:

$$EXP_{soil} = (FIR \div BW) \times C_S \times 0.02$$

$$EXP_{plant} = (FIR \div BW) \times C_S \times BAF \times 0.37$$

$$EXP_{invertebrate} = (FIR \div BW) \times C_S \times BAF \times 0.61$$

where:

$EXP_{pathway}$ = exposure dose via the different pathways (mg/kg bw day); FIR = food ingestion rate (kg/day); BW = deer mouse body weight (kg); C_S = 95th percentile metal concentration in soil across the Site (mg/kg)[2]; $BAF_{pathway}$ = bioaccumulation factors for plants and soil invertebrates expressed on a dry weight basis (unitless); and 0.02, 0.37, and 0.61 = assumed dietary fractions for soil, plants, and soil invertebrates.

As an example, exposure doses were calculated as follows for soil, plant, and soil invertebrates, respectively, using arsenic at location M3 (Northwest Tailings Area):

$$3.54\ (mg/kg\ bw\ day) = \left[0.004\ (kg/day) \div 0.021\ (kg\ bw)\right] \times 929\ (mg/kg) \times 0.02\ (unitless)$$

$$2.36\ (mg/kg\ bw\ day) = \left[0.004\ (kg/day) \div 0.021\ (kg\ bw)\right] \times 929\ (mg/kg) \times 0.036 \times 0.37\ (unitless)$$

$$11.87\ (mg/kg\ bw\ day) = \left[0.004\ (kg/day) \div 0.021\ (kg\ bw)\right] \times 929\ (mg/kg) \times 0.11 \times 0.61\ (unitless)$$

The HQ was calculated as follows using arsenic at location M3 (Northwest Tailings Area):

$$HQ = \frac{\sum EXP_{soil} + EXP_{plant} + EXP_{invertebrate}}{TRV}$$

$$13.1 = \frac{\sum 3.54 + 2.36 + 11.87 (mg/kg\ bw\ day)}{1.36\ (mg/kg\ bw\ day)}$$

where:

HQ = hazard quotient (unitless); $EXP_{pathway}$ = exposure dose via the different pathways (mg/kg bw day); and TRV = toxicity reference value expressed at the lowest-observed-adverse-effects-level (LOAEL; mg/kg bw day).

[2] The Site-wide metals concentrations was dominated by the Main Tailings.

Screening level HQs calculated on a Site-wide basis (URS, 2005a), and at locations M1–M4 for comparison, are summarized in Table 1.

Model Calibration

The screening level model described above was calibrated as follows using (listed in order of importance) the following:

- soil to deer mouse BAFs;
- median soil concentrations; and
- measured deer mouse weight (0.0163 kg; n=25 animals) along with the corresponding food ingestion rate (0.003 kg/day) calculated using the Nagy (1987) allometric equation for rodents.

The calibrated model is a simpler version because it uses a single, empirical BAF for all routes of exposure. This BAF accounts for all exposure routes, including those not considered in the screening level model (e.g., dermal, water ingestion), and accounts for metals bioavailability (assumed to be 100% in the screening level model).

As an example, the arsenic HQ was calculated as follows at location M3 (Northwest Tailings Area):

$$HQ = \frac{(FIR \div BW) \times C_S \times BAF}{TRV}$$

$$0.016 = \frac{\left[0.003\,(kg/day) \div 0.0163\,(kg\ bw)\right] \times 517\,(mg/kg) \times 0.00023\,(unitless)}{1.36\,(mg/kg\ bw\ day)}$$

where:

HQ = hazard quotient; FIR = food ingestion rate (kg/day); BW = deer mouse body weight (kg); C_S = median metal concentration in soil within an assumed 0.1 ha deer mouse home range centered on a trapping location (mg/kg); BAF = soil to mouse bioaccumulation factor expressed on a dry weight basis (unitless); and TRV = toxicity reference value expressed at the LOAEL (mg/kg bw day).

RESULTS AND DISCUSSION

HQs calculated using the screening level and calibrated models for locations M1–M4 are summarized in Table 1. HQs for the limiting metals As and Cd are illustrated in Figure 5. The calibrated model yielded hazard quotients 1–3 orders of magnitude lower than previous values and below the regulatory limit of 1, suggesting that the deer mouse (and higher tropic level mammals) have not been adversely affected at the population level.

The reasons for the discrepancy between screening and calibrated models are numerous but generally involve the inability of the screening model to account for difference in diet, bioaccumulation, bioavailability, etc[3]. The soil to deer mouse BAF had the strongest influence on the model calibration followed by the use of the median soil concentration.

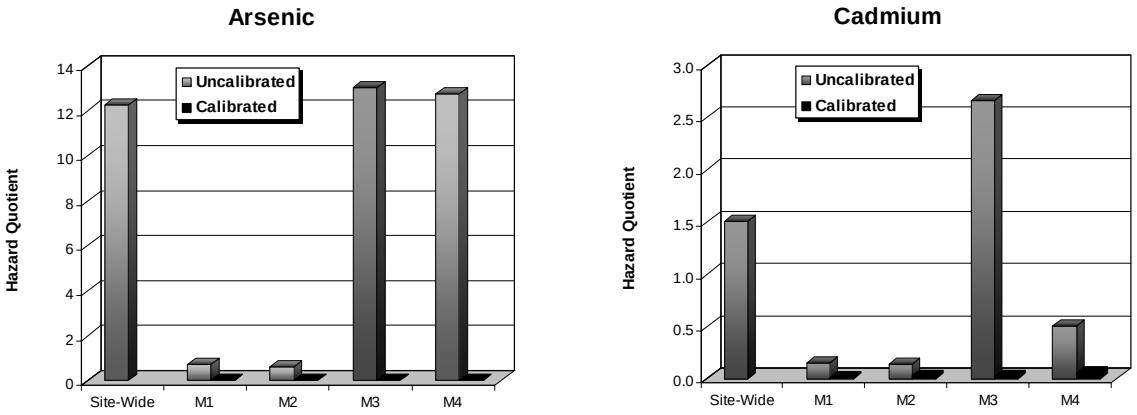

Figure 5: Comparison of Arsenic and Cadmium Hazard Quotients Derived using Screening Level and Calibrated Models

The results of this study are important when viewed with respect to remedial and/or management decisions at the Site. Results from the screening level ecological model could be interpreted to suggest that remediation of the Former Mill Area and the Northwest Tailing Area would be required to protect the terrestrial ecosystem. The human heath risk assessment (Iridium, 2007) suggested that remediation of the Former Mill Area would be required to protect toddlers, but that remediation of remnant tailings at the Northwest Tailing Area would not be required. Results from the calibrated model avoid unnecessary remediation at the Northwest Tailing Area, which is located in mature cedar-hemlock forest.

CONCLUSIONS

A screening level Tier I ecological risk assessment conducted by a previous consultant yielded hazard quotients above the regulatory limit for the most sensitive terrestrial wildlife receptor at the Site (i.e., field mouse), suggesting the potential for adverse, population-level health effects. The screening level model was calibrated here using new data collected as part of the small mammal study (e.g., surface soil and deer mice tissue concentrations). Despite orders of magnitude variations in soil concentrations, deer mice tissue concentrations were similar at all locations (1 control; 3 contaminated), and soil to deer mouse bioaccumulation factors were inversely correlated to soil concentration. The calibrated model yielded hazard quotients 1–3 orders of magnitude lower than previous values, suggesting that deer mice have not been adversely affected. Results from the calibrated model avoid unnecessary remediation at the Northwest Tailing Area, which is located in mature cedar-hemlock forest.

[3] Bioaccumulation and bioavailability may reflect metabolic controls on the cellular level.

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APPENDIX I: Metals Concentrations in Small Mammal Tissue

ID	Moisture	Arsenic	Cadmium	Chromium	Cobalt	Copper	Lead	Molybdenum	Nickel	Zinc
	(%)	(mg/kg)[1]	(mg/kg)[1]	(mg/kg)[1]	(mg/kg)[1]	(mg/kg)[1]	(mg/kg)[1]	(mg/kg)[1]	(mg/kg)[1]	(mg/kg)[1]
1M1	76.0	0.018	0.08	0.18	<0.020	2.67	0.49	0.217	0.12	29.7
1M2	72.3	0.034	0.27	0.12	<0.020	2.75	1.16	0.194	<0.10	27.2
1M3	76.3	0.033	0.27	0.10	<0.020	2.68	1.16	0.189	<0.10	26.4
average	**74.9**	**0.028**	**0.21**	**0.13**	**----**	**2.70**	**0.94**	**0.20**	**0.12**	**27.8**
±1SD	**2.2**	**0.009**	**0.11**	**0.04**	**----**	**0.04**	**0.39**	**0.01**	**----**	**1.7**
2M1	69.7	0.040	0.39	0.31	0.027	3.53	1.11	0.298	0.27	35.4
2M2	69.1	0.016	0.18	0.20	<0.020	2.92	0.68	0.248	0.17	28.8
2M3	75.9	0.025	1.70	0.27	0.046	3.64	1.31	0.268	0.32	51.4
2S1	69.0	0.043	1.91	0.21	0.032	5.98	2.29	0.197	<0.10	40.7
average[2]	**71.6**	**0.027**	**0.75**	**0.26**	**0.037**	**3.36**	**1.03**	**0.27**	**0.25**	**38.5**
±1SD	**3.8**	**0.012**	**0.83**	**0.06**	**0.013**	**0.39**	**0.32**	**0.03**	**0.08**	**11.6**
3M1	63.5	0.043	0.96	0.24	<0.020	2.93	4.44	0.470	0.19	37.1
3M3	65.9	0.030	0.16	0.19	<0.020	3.07	1.65	0.238	0.14	29.0
3M4	65.1	0.036	0.78	0.25	0.040	3.23	0.22	0.330	0.20	45.9
average	**64.8**	**0.036**	**0.63**	**0.23**	**0.040**	**3.08**	**2.10**	**0.35**	**0.18**	**37.3**
±1SD	**1.2**	**0.007**	**0.42**	**0.03**	**----**	**0.15**	**2.14**	**0.12**	**0.03**	**8.5**
4M2	72.6	0.052	0.25	0.20	0.030	2.74	0.38	0.273	0.24	27.2
4M3	69.1	0.028	0.13	0.19	0.027	3.00	0.59	0.255	0.16	27.5
4M4	73.6	0.042	0.15	0.22	0.054	2.88	1.23	0.332	0.17	37.4
average	**71.8**	**0.041**	**0.18**	**0.20**	**0.037**	**2.87**	**0.74**	**0.29**	**0.19**	**30.7**
±1SD	**2.4**	**0.012**	**0.07**	**0.02**	**0.015**	**0.13**	**0.44**	**0.04**	**0.04**	**5.8**

[1] Concentrations expressed as milligrams per wet kilogram. To convert to dry weight, multiply the metals concentration by 3.40.

[2] Does not include shrew (2S1) concentrations.

---- = not calculated.