APPENDIX E

BIOACCUMULATION MODELS

In association and consultation with: Windward Environmental LLC

Appendix E: Bioaccumulation Models

Final Aquatic Baseline Ecological Risk Assessment—Upper Columbia River

PREPARED FOR
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DATE
July 2026

REFERENCE
0812334

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ACRONYMS AND ABBREVIATIONS

µm	micrometer(s)
ANCOVA	analysis of covariance
BAF	bioaccumulation factor
BERA	baseline ecological risk assessment
BSAF	biota-sediment accumulation factor
COPC	chemical of potential concern
Eco-SSL	ecological soil screening level
EPA	U.S. Environmental Protection Agency
ERA	ecological risk assessment
mg/kg	milligram(s) per kilogram
mm	millimeter(s)
OU	operable unit
RFA	Relict Floodplain A
RFB	Relict Floodplain B
RFC	Relict Floodplain C
RFD	Relict Floodplain D
RFDA	relict floodplain deposition area
Site	Upper Columbia River site
TAI	Teck American Incorporated
TAL	target analyte list
UCR	Upper Columbia River
USGS	U.S. Geological Survey
WSDA	windblown sediment deposition area

1. INTRODUCTION

Teck American Incorporated (TAI) conducted an evaluation to identify existing bioaccumulation models and derive additional bioaccumulation models for use in the baseline ecological risk assessment (BERA) for Operable Unit (OU) 1, OU 2, and the relict floodplain deposition areas (RFDAs) and windblown sediment deposition areas (WSDAs) of the Upper Columbia River (UCR) site (hereinafter, the Site).[1] Bioaccumulation models are used to estimate uptake from sediment or soil into biota (e.g., aquatic plants, aquatic invertebrates, adult flying aquatic emergent insects, terrestrial plants, terrestrial arthropods, terrestrial small mammals) for fish, avian, and mammalian wildlife receptors that are evaluated for the dietary exposure pathway. Past ecological risk assessments (ERAs) for the Site (TAI 2010, 2020) at the screening level did not identify or use bioaccumulation models for terrestrial biota,[2] or used conservative and/or less relevant bioaccumulation estimates for aquatic biota.[3] Therefore, realistic and relevant models are needed for use in the Aquatic BERA.

This appendix presents the ranking of available bioaccumulation model sources, identification of the highest-ranked source for each required model, and the methods used to derive models from raw bioaccumulation data, when available and appropriate. Section 2 of this appendix presents the models and derivation methods for the aquatic (sediment to biota) bioaccumulation models. Section 3 of this appendix presents the models and methods for terrestrial (soil to biota) bioaccumulation.

In this appendix, the terms bioaccumulation factor (BAF) and biota-sediment accumulation factor (BSAF) are used, somewhat interchangeably. These two terms represent the same type of equation to estimate uptake from a substrate to biota; however, the term "BSAF" is specific to sediment substrates whereas "BAF" is more commonly used to refer to soil substrates.

[1] As per the June 2, 2006, Settlement Agreement for Implementation of Remedial Investigation and Feasibility Study at the Upper Columbia River Site (referred to herein as the UCR Site or Site), the Site consists of the areal extent of hazardous substances contamination within the United States in or adjacent to the Upper Columbia River, including the Franklin D. Roosevelt Lake, from the U.S.-Canada border to Grand Coulee Dam, and all suitable areas in proximity to such contamination necessary for implementation of the response actions (Remedial Investigation and Feasibility Study) described therein (USEPA 2006).
[2] In TAI (2010, 2020), the evaluations relied on soil screening benchmarks; therefore, bioaccumulation modeling was not required.
[3] In TAI (2010) and TAI (2020), surrogate data from fish tissue (for non-fish tissue) and/or conservative BAF values (90th percentile rather than median) were used for some food item-analyte pairings.

2. AQUATIC BIOACCUMULATION MODELS

Site-specific biota tissue chemistry data were available for fish, mussels, and crayfish from the 2005 Phase 1 Fish Tissue Sampling (USEPA 2007a), 2009 Fish Tissue Study (TAI 2013), and 2016 Macroinvertebrate Tissue Study (TAI 2018a). These data are available for development of exposure point concentrations within each conceptual site model unit, and thus bioaccumulation models are not needed for these food items. However, bioaccumulation models are needed for all other food items, including aquatic plants, small aquatic invertebrates (such as insect larvae), and adult flying aquatic emergent insects.

Literature containing bioaccumulation models commonly used in Superfund site risk assessments is the primary source for the bioaccumulation models used in the Aquatic BERA. A literature search was conducted for additional metal-specific sediment-to-biota pairings; this search found that, in particular, data were lacking for thallium in small aquatic invertebrate prey. Sources were ranked by considering the following: widely accepted sources commonly used in ERAs, relevance of models to the biota type, availability of models, and availability of raw data that could be used to develop additional models. Bioaccumulation model source rankings for the Aquatic BERA are as follows (with Source 1 as the most preferred and Source 7 the least):

1. Models from commonly used and widely accepted Oak Ridge National Laboratory sources (Bechtel Jacobs 1998a)
2. Models reported in Jackson et al. (1991) for aquatic plants and metals
3. Co-located sediment and small aquatic invertebrate data from southeastern Idaho collected by U.S. Geological Survey (USGS) (Hamilton et al. [2002]; Hamilton and Buhl [2003a,b]; henceforth referred to as the Hamilton data sets)
4. Models reported in Vanier et al. (2001) for aquatic plants and polychlorinated biphenyls
5. Median BSAFs reported in the U.S. Army Corps of Engineers' (2019) online BSAF database for organic analytes and aquatic biota (fish, invertebrates, etc.), prioritizing food-item-specific data where available
6. Median BSAFs reported in USEPA (1999a) for relevant biota
7. Aquatic larvae to adult flying insect correction factors for metals and organic chemicals, as developed in Kraus et al. (2014)

The availability of models and data from the ranked sources varies by chemical of potential concern (COPC)[4] for fish, birds, mammals as well as by biota type, as presented in Table E-1. Models and/or data were selected in order from the ranked sources until a model was available for each of the required COPC-biota type pairings for the Aquatic BERA. Bioaccumulation models and/or data for small aquatic invertebrates were chosen from Sources 1, 3, and 5 above. These models, in conjunction with the correction factors in Source 7, were used to estimate

[4] The COPCs identified for fish and aquatic-dependent birds and mammals in the Aquatic BERA are: aluminum, arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, thallium, vanadium, zinc, bis(2-ethylhexyl)phthalate, total PCB congeners, and dioxins/furans.

bioaccumulation in adult flying aquatic emergent insects. Models for aquatic plants were identified from Sources 2, 4, 5, and 6.

Source 3 presents raw data of paired sediment and biota metal concentrations from southeastern Idaho, from samples collected by USGS. Appropriate bioaccumulation models for small aquatic invertebrates needed to be derived from the raw data in these reports for metals that did not have models from Source 1. This appendix presents the methods used to derive and validate the most reliable and relevant models possible using the information in the Hamilton data sets. Regression modeling and validation was conducted, as reported in this appendix, and used in the Aquatic BERA. The models developed from Source 3 were ranked according to the criteria outlined in the U.S. Environmental Protection Agency's (EPA) ecological soil screening levels (Eco-SSL) guidance (USEPA 2007b); regression models were prioritized over median BAFs or BSAFs when the regression model was significant (slope $p < 0.05$) and met minimum correlation requirements ($R^2 \geq 0.2$). In addition to these criteria from USEPA (2007b), two more criteria were applied to ensure sufficient model performance: a positive slope, and greater than 10 data points. The regression models better account for variable uptake over differing concentrations in soil or sediment than BAFs or BSAFs, which are a static ratio.

Sources 1, 2, and 4 to 7 present their models and any validation work in their respective documentation. Bioaccumulation models selected from Sources 1, 2, and 4 to 7 are taken directly from their documentation without alteration. These models are presented in Section 4.1.2.3 of Volume 1 of the Aquatic BERA and are not discussed further in this appendix.

2.1 DATA AND APPROACH

This section documents the data handling and modeling approach used to derive bioaccumulation models from the Hamilton data sets, for metals that did not have models from Source 1. These metals are: aluminum, barium, iron, manganese, molybdenum, selenium, and vanadium.

2.1.1 SELECTED DATA SET

The Hamilton data sets report the results of an investigation conducted to support the USGS Western US Phosphate Project in southeastern Idaho. Nine stream sites in the Blackfoot River watershed were repeatedly sampled across three seasons (June 2000, September 2000, and May 2001) for surface sediment and aquatic invertebrates. Phosphate mining wastes are of concern in this watershed, particularly trace elements such as selenium.

Aquatic invertebrates were collected from streambed substrates obtained from a D-frame kick net or by removing large stones. The invertebrates were separated from the substrate using forceps or glass tubes with suction bulbs. The aquatic invertebrates collected include the aquatic larval forms of caddisflies, mayflies, damselflies, dragonflies, beetles, midges, Diptera, stoneflies, and craneflies, as well as leeches and gammarids. Collected aquatic invertebrates were pooled into a single sample for each site and seasonal sampling effort. Surface sediment samples were collected from the same nine sites as the aquatic invertebrate samples and analyzed without sieving. Analytes included the following: aluminum, arsenic, barium, beryllium, boron, cadmium, chromium, copper, iron, copper, lead, magnesium, mercury, molybdenum, nickel, selenium, strontium, vanadium, and zinc. Samples from the June 2000 effort were analyzed in two laboratories (Environmental Trace Substances Laboratory at the University of Missouri, Rolla, Missouri, and USGS Geologic Discipline Laboratory at the Denver Federal Center, Denver, Colorado), and inter-laboratory comparisons were conducted. Samples from the September 2000 and May 2001 sampling efforts were analyzed at the Research Triangle Institute at Research Triangle Park, North Carolina.

A summary of the data set used to develop models is presented in Table E-2.

2.1.2 DATA HANDLING

Data were extracted manually from the Hamilton data sets report PDFs, and all data extractions were verified by a second reviewer. Data points were obtained by matching sediment and aquatic invertebrate samples from the same study sites, season, and analytical laboratory. Data points were excluded if 1) either a sediment or biota sample was not available for the given site, season, and laboratory; or 2) concentrations were below detection limits for either the sediment or aquatic invertebrate samples.

Normality testing was performed on the sediment and biota concentrations (Table E-2), and all analytes were identified as either lognormal or as having neither a normal nor lognormal distribution. All sediment and biota concentrations were natural log transformed prior to regression modeling, consistent with the approaches used in other commonly used bioaccumulation model sources, such as those used for EPA's Eco-SSLs (Bechtel Jacobs 1998b; Sample et al. 1998a,b), as well as the bioaccumulation models developed for soil for the Aquatic BERA.

Data were available for metal COPCs for fish, birds, and mammals that did not have a model identified from a higher-ranked source, including: aluminum, barium, iron, manganese, molybdenum, selenium, and vanadium (Tables E-1 and E-2).

2.1.3 MODEL DEVELOPMENT

Bioaccumulation models were developed consistent with approaches used in other commonly used bioaccumulation model sources (Bechtel Jacobs 1998b; Sample et al. 1998a,b), as described in Section 2.1.3.1 below.

2.1.3.1 MODEL TYPES

Bioaccumulation models for ERAs are typically calculated as either a linear regression model on log-transformed data or as BSAFs. Regression models better account for variable (nonlinear) uptake over differing concentrations in soil or sediment than BAFs or BSAFs, which are static ratios that assume linear accumulation (Sample et al. 1998a). Thus, regression models are preferred over BAFs or BSAFs as long as the regression models meet minimum acceptability requirements as described below.

Regression models are calculated using Equation 1:

EQUATION 1: BIOACCUMULATION REGRESSION MODEL

$$\ln(C_{biota}) = a * \ln(C_{soil\ or\ sediment}) + b$$

Where:	a	=	Slope of the model
	b	=	y-intercept of the model
	C_{biota}	=	Concentration of the analyte in biota tissue (mg/kg dry weight)
	$C_{soil\ or\ sediment}$	=	Concentration of the analyte in soil or sediment (mg/kg dry weight)

BAFs and BSAFs are calculated using Equation 2:

EQUATION 2: BAF AND BSAF MODEL

$$\text{BAF or BASF} = \frac{C_{biota}}{C_{soil\ or\ sediment}}$$

Where:	C_{biota}	=	Concentration of the analyte in biota tissue (mg/kg dry weight)
	$C_{soil\ or\ sediment}$	=	Concentration of the analyte in soil or sediment (mg/kg dry weight)

EPA's Eco-SSL guidance (USEPA 2007b) outlines acceptance criteria for regression models of a statistically significant slope ($p < 0.05$) and a minimum correlation ($R^2 \geq 0.2$). In addition, two further acceptance criteria were identified: 1) a positive slope, indicating that biota tissue concentrations increase with sediment concentrations; and 2) a data size requirement of > 10 to ensure that regression models were not well correlated simply due to a small number of data points. Thus, the regression models derived from the Hamilton data sets must meet all four of the above acceptance criteria to be selected for use over BSAFs.

For COPC-biota type combinations where the regression model fails the acceptance criteria, a BAF or BSAF calculated from the same data is used instead. Consistent with EPA's Eco-SSL methodology (USEPA 2007b), the summary statistic used for the BAF is the median value.

Regression models and median BAFs were computed using R statistical software (R Core Team 2020).

2.1.3.2 PREDICTION LIMIT CALCULATION

A prediction interval provides the range in which a new data point would be expected to fall, with a given level of certainty, based on the current data set. The 90 percent prediction interval is comprised of the 5th (lower) prediction limit and the 95th (upper) prediction limit for each value of x (sediment concentration), and is commonly used as a standard reference range. Thus, at a given sediment concentration, the bioaccumulation regression models' 90 percent prediction interval predicts with 90 percent certainty the range in which a new data point would fall.

These prediction intervals for regression models were calculated to support uncertainty analyses for receptors consuming aquatic invertebrates. The 5th and 95th prediction limits were calculated as described below. Prediction limits were calculated for regression models derived from the Hamilton data sets, as well as for the Bechtel Jacobs (1998a) data set, using the information provided in Appendix A of Bechtel Jacobs (1998a). Prediction limits are calculated using Equation 3[5]:

EQUATION 3: PREDICTION LIMIT

$$\hat{y}_0 \pm t_{\frac{\alpha}{2},n-2} * RMSE * \sqrt{1 + \frac{1}{n} + \frac{(x_{soil\ or\ sediment} - \bar{x})^2}{\sum x_i^2 - \frac{1}{n}\left(\sum x_i\right)^2}}$$

Where:	$\hat{y}_0$	=	Predicted log-transformed concentration of the analyte in biota tissue (mg/kg dry weight)
	$t_{\frac{\alpha}{2},n-2}$	=	t-statistic for 95 percent one-tailed limits or 90 percent two-tailed intervals with n-2 degrees of freedom
	n	=	Sample size for regression model
	RMSE	=	Root mean square error for regression model
	$x_{soil\ or\ sediment}$	=	Log-transformed concentration of the analyte in soil or sediment (mg/kg dry weight)
	$\bar{x}$	=	Mean log-transformed concentration of the analyte in soil or sediment from the regression model (mg/kg dry weight)
	$\sum x_i^2$	=	Sum of squared log-transformed concentrations of the analyte in soil or sediment from the regression model (mg/kg dry weight)
	$\sum x_i$	=	Sum of log-transformed concentrations of the analyte in soil or sediment from the regression model (mg/kg dry weight)

After calculating $\hat{y}_0$ and adding or subtracting the product in Equation 3, back transforming the result yields the upper or lower prediction limits.

2.1.3.3 MODEL VALIDATION

A series of model validation procedures were used to confirm the reliability of the model-estimated linear relationships between biota and substrate (sediment or soil) concentrations. The goal was to assess the sensitivity and variability of the model estimates. Two model validation methods were conducted: 1) data truncation of extremes and 2) bootstrap resampling. Regression

[5] Prediction limit formula follows Appendix A of Bechtel Jacobs (1998a) but with replacement of the sum of squared differences from the mean, defined as $\sum x^2 - 1/n (\sum x)^2$ (Sxx) with $\sum x_i^2 - \frac{1}{n}(\sum x_i)^2$ to reflect variance of soil or sediment concentrations from the regression model. The formula for Sxx presented in Appendix A of Bechtel Jacobs (1998a) is incorrect compared to the formula in Dowdy and Wearden (1983).

models were validated using both methods, where data permitted. BSAFs were validated using only bootstrap resampling.

For data truncation validation, substrate concentrations in the top 20 percent were treated as the validation data set, and linear models were fit to the remaining data. Prediction intervals were produced from the linear models and the number of validation data points falling outside of the prediction intervals were tallied. The fitted lines and prediction intervals for both the full data set and truncated data set were compared to assess the sensitivity of the linear relationships to removal of high data extremes. The same procedure was applied to substrate concentrations in the bottom 20 percent.

For bootstrap resampling validation, bootstrap samples (repeatedly sampling the original data set with replacement) of the same size as the original data set were produced, and linear regression models were fit to each bootstrap sample. The variability in the bootstrap model parameters was assessed using histograms and scatterplots. Similarly, median BSAFs were computed for each bootstrap sample, and the variability of the bootstrap sample median BSAFs was assessed using histograms. For this analysis, 100 bootstrap samples were used.

2.2 RESULTS

This section presents the validation results and selected bioaccumulation models for use in the Aquatic BERA.

2.2.1 MODEL DEVELOPMENT

Regression models and median BSAFs were calculated using the data set described above in Section 2 of this appendix for each of the COPC-biota type pairings specified under Source 3 in Table E-1. Calculated model parameters and summary statistics are reported in Table E-3. Estimates for calculating prediction limits around regression models are presented in Table E-4.

2.2.2 MODEL VALIDATION

Results for the validation techniques are presented in Figures E-1 and E-2 (data truncation low and data truncation high), and Figures E-3 through E-5 (bootstrap resampling). Where appropriate, fitted regressions and 90-percent prediction intervals using the training data set, as well as the entire data set, are shown.

Overall, all COPCs had linear regression models with some variability and sensitivity. COPCs with bimodal distributions of sediment concentrations (i.e., samples with low or high concentrations with few or none in between: aluminum, barium, iron, and to a lesser extent, selenium) had greater variability and sensitivity than COPCs with a more even distribution of sediment concentrations (manganese and vanadium). COPCs with relatively even distributions of sediment concentrations performed better for each of the validation activities, and thus confidence in these regression models is higher. For all biota types, the medians of bootstrap sample median BAFs were similar in value to the median BAFs computed from all the data, which suggests that median BAF calculations are not highly sensitive to varying the underlying data set. Confidence in median BAFs from the data is thus increased due to the bootstrap resampling validation results.

Specific uncertainties with models for particular COPC-biota type pairings are discussed in Section 2.3 of this appendix.

2.2.3 FINAL SELECTED MODELS

The models selected for use in the Aquatic BERA from the Hamilton data sets are highlighted in bold in Table E-3. The final regression models based on the full data sets, along with a statement as to whether the regression models meet acceptance criteria or not, are presented visually in Figure E-6.

COPCs with regression models that met the acceptance criteria are aluminum, iron, manganese, selenium, and vanadium (Figure E-6). These regression models were selected for use in the Aquatic BERA to estimate uptake into small aquatic invertebrates. For all other COPCs evaluated from the Hamilton data sets (barium and molybdenum), the median BSAF was selected for use.

2.3 UNCERTAINTIES

Uncertainties associated with development of the aquatic invertebrate bioaccumulation models are discussed below. Uncertainties associated with other bioaccumulation models, dietary exposure pathways, and the use of bioaccumulation models for hazard quotient calculations are discussed in the fish, bird, and mammal risk characterization sections of the Aquatic BERA.

2.3.1 UNCERTAINTIES ASSOCIATED WITH MODEL TYPES

There is higher uncertainty in BAFs or BSAFs than in regression models that meet the acceptance criteria. As a static ratio, BAFs and BSAFs do not account for nonlinear bioaccumulation and assume that there is no threshold to concentrations in biota (Sample et al. 1998a). If metals are regulated by the biota, such as essential nutrients (e.g., copper or zinc) that are actively metabolized, sequestered, or excreted as compared to non-essential metals that may not be regulated (e.g., cadmium, mercury, or lead), these assumptions may not hold. Regression models that meet acceptance criteria better account for variable bioaccumulation across different soil or sediment concentrations (e.g., in situations where bioaccumulation rates are higher at lower soil or sediment concentrations or where bioaccumulation rates are lower at higher soil or sediment concentrations), and thus have less uncertainty than BAFs or BSAFs calculated from the same data set.

2.3.2 UNCERTAINTIES FOR THE AQUATIC INVERTEBRATE MODELS

Uncertainties related to the aquatic invertebrate models and underlying data set are discussed below.

- **Small to moderate sample sizes.** Sample sizes for the bioaccumulation models ranged from four (molybdenum) to 23 to 25 (aluminum, barium, iron, manganese, selenium, and vanadium). Models derived from small data sets, particularly molybdenum, have higher uncertainty and may over- or under-estimate bioaccumulation into aquatic invertebrates.
- **Size of prediction intervals.** The upper and lower bounds of the bioaccumulation model prediction intervals may be of different orders of magnitude depending on the variability and sample size of the data. The predicted value of an individual sample can have very high

uncertainty and fall within a wide range being much higher or lower than the average estimated bioaccumulation in aquatic invertebrates. Models with wider prediction intervals have higher uncertainty. Analytes with regression models with 5th and 95th prediction limits greater than one order of magnitude above or below the fitted model are cadmium and lead (see Bechtel Jacobs 1998a and Figure E-6). Further evaluation of the upper and lower bounds to the aquatic invertebrate bioaccumulation models and potential uncertainty associated with HQs is conducted in the receptor-specific uncertainty discussions in Volumes 2 and 3.

- **Empirical range of sediment concentrations.** Uncertainty is introduced if the empirical range of sediment concentrations in the model data set does not encompass the range of sediment concentrations at the Site. The Hamilton data sets is representative of the range of sediment concentrations at the UCR Site with the following exceptions (see Table E-2 and Table 4-7a of Volume 1 of the Aquatic BERA): 1) the UCR Site has some higher aluminum, barium, iron, and manganese concentrations than the maximum concentrations in the Hamilton data sets, 2) concentrations of molybdenum in all UCR Site samples are higher than the highest Hamilton data sets' molybdenum concentrations, and 3) vanadium concentrations in the Hamilton data sets are representative of the mid-range of UCR Site concentrations but lack coverage at the lower and higher concentrations. Thus, there is high uncertainty in the applicability of the molybdenum models to the UCR Site, and uncertainty for higher sediment concentrations of metals at the UCR Site for aluminum, barium, iron, manganese, and vanadium.
- **Relevance of data set species and life stages to receptor dietary items.** Species in the aquatic invertebrate modeling data set include the aquatic larval forms of caddisflies, mayflies, damselflies, dragonflies, beetles, midges, Diptera, stoneflies, and craneflies, as well as leeches and gammarids. This represents a variety of species that are the same or closely related to species expected to be consumed by UCR Site receptors that prey on small aquatic invertebrates. Additionally, this broad range of species is expected to encompass many species-specific differences in life history characteristics and metal regulation mechanisms that may modify bioaccumulation. Thus, the species and life stages in the data set have good relevance overall to the UCR Site and this is not expected to be a major source of uncertainty.
- **Different trophic levels of biota species.** The aquatic invertebrate modeling data set contains data representing different trophic levels of aquatic invertebrates. For some COPCs, such as mercury, that may bio-magnify in higher trophic levels, predaceous invertebrates (e.g., dragonfly larvae) may have higher bioaccumulation than invertebrates that are primarily herbivorous or filter feeding (e.g., mayfly and cranefly larvae). The bioaccumulation models developed by TAI aggregate the different trophic levels. Therefore, the models may underestimate bioaccumulation into predaceous biota and overestimate bioaccumulation into herbivorous or filter feeding biota. However, the models are representative of bioaccumulation across different trophic levels. These models are thus relevant to the UCR Site aquatic-dependent receptor diets because the invertivores (e.g., spotted sandpipers, water shrews, prickly sculpin, longnose dace) eat a wide range of small aquatic invertebrate prey.
- **Environmental relevance of the underlying data set.** The aquatic invertebrate modeling data set contains bioaccumulation data from sediments of the Blackfoot River watershed in southeastern Idaho. Surface waters and sediments in this area may have been impacted by

runoff from tailings piles, ponds, landfills, and dumps used in open-pit surface mining. The sample sites are representative of creeks and rivers within riparian, grassland, pine forest, and sagebrush habitats, some of which had been grazed. This data set is considered to have good environmental relevance, in that it is from the Pacific Northwest, in an area with mining activities, and encompasses similar habitat types as those found near the UCR Site. However, this data set may not be representative of the exact conditions of the UCR Site. Depending on the physical sediment characteristics and bioavailability of metals in Site sediment, the bioaccumulation models may over- or under-estimate bioaccumulation into aquatic invertebrates.

2.3.3 CONTEXT PROVIDED BY THE VALIDATION ACTIVITIES ON THE FINAL SELECTED MODELS

Aluminum, iron, manganese, selenium, and vanadium regression models met the acceptance criteria. These each have sample sizes ranging from 23 to 25. Across the different validation methods, each of these models showed some sensitivity and variability (Figures E-1 through E-5).

- **Aluminum.** The regression model for aluminum showed sensitivity in all validation methods (truncation high, truncation low, and bootstrap resampling), associated with the bimodality of the sediment concentrations. The model shows the highest variability in the low end of the sediment concentration range. There are fewer samples located in the cluster at the lower end of the sediment concentration range than the cluster at the higher end of the sediment concentration range.
- **Iron.** Similar to aluminum, the regression model for iron shows sensitivity and variability in all validation methods. Iron has a similar bimodality as aluminum, and similar higher variability at the low end of the sediment concentration range.
- **Manganese.** The regression model for manganese performed the best of all COPCs evaluated, with the lowest amount of sensitivity and variability. This model was relatively robust across the full range of sediment concentrations in the Hamilton data sets.
- **Selenium.** The linear regression model for selenium performed relatively well in the bootstrap resampling, indicating that this model is robust to random variation. However, due to the small number of samples in the cluster at the high end of the sediment concentration range, the selenium model showed sensitivity in the truncation (high) validation method. This model thus has higher uncertainty for sediment concentrations above approximately 10 milligrams per kilogram (mg/kg) (Figure E-2).
- **Vanadium.** The vanadium regression model performed relatively well in the truncation validation steps, indicating that this model is robust to variation at the high and low end of the sediment concentration range. However, this model showed sensitivity in the bootstrap resampling, indicating that this model is less robust to random variation.

The selected models for barium and molybdenum are median BSAFs. Median BSAFs were validated using bootstrap resampling (Figure E-5).

- **Barium.** The median of the bootstrap samples' median BSAF for barium is nearly identical to the median BSAF calculated for all data (Figure E-5). Uncertainty in the median BSAF value itself is low; however, confidence in BSAFs is lower than for linear regression models as these model types do not account for variable uptake across variable sediment concentrations.

- **Molybdenum.** The median BSAF for molybdenum is highly uncertain, as the data set is limited to four samples. The bootstrap resampling validation indicates that this value may be robust to random variation (Figure E-5); however, this finding is likely an artifact of the low sample size.

3. TERRESTRIAL BIOACCUMULATION MODELS

Literature containing bioaccumulation models commonly used in Superfund site risk assessments is the primary source for the terrestrial bioaccumulation models used in the Aquatic BERA. A literature search was conducted for additional metal-specific soil-to-biota pairings; this search found that, in particular, data were lacking for molybdenum. Sources were ranked by considering the following: Site-specificity, widely accepted sources commonly used in ERAs, availability of models, and availability of raw data that could be used to develop additional models. Terrestrial bioaccumulation model source rankings for the Aquatic BERA are as follows (with Source 1 as the most preferred and Source 4 the least):

1. Site-specific models developed from co-located soil and plant tissue data from the 2018 Plant Tissue Study (TAI 2019)
2. Models from commonly used and widely accepted Oak Ridge National Laboratory sources (Bechtel Jacobs 1998b; Sample et al. 1998a,b)
3. Database from the U.S. Department of Defense, U.S. Army Center for Health Promotion and Preventative Medicine (USACHPPM 2004)
4. Models reported in peer-reviewed literature (e.g., Hargreaves et al. 2011)

The availability of models and data from the ranked sources varies by COPC[6] for birds or mammals and by biota type, as presented in Table E-5. Models and/or data were selected in order from the ranked sources until a model was available for each of the required COPC-biota type pairings for the Aquatic BERA. Source 1 above has available plant models for all COPCs except molybdenum, but lacks models for terrestrial arthropods, flying insects, earthworms, and small mammals. Thus, models for earthworms and small mammals were selected from Source 2 above. Models for terrestrial arthropods and flying insects were selected from Source 3 above when data were available. Models for molybdenum uptake into terrestrial plants were selected from Source 3 as well. Source 4 was used for models of molybdenum uptake into terrestrial arthropods and flying insects.

Additionally, model types were ranked according to the criteria outlined in Section 2.1.3 of this appendix ($p < 0.05$, $R^2 \geq 0.2$, positive slope, and more than 10 data points). Model selection for each metal was done first by ranking the sources (1 to 4) as above, then by ranking the model type (i.e., regression or BAF). For example, a BAF from model Source 1 above would be selected over a regression from model Source 2.

Sources 1 and 3 present raw data of paired soil and biota metal concentrations. Appropriate bioaccumulation models had to be derived from the raw data in these reports for the COPC-biota pairs identified in Table E-5. This appendix presents the methods used to derive the most reliable and relevant models possible using the information in Source 1 (2018 Plant Tissue Study [TAI 2019]) or Source 3 (USACHPPM 2004 database). Specific invertebrate classes and plant parts that aligned best with UCR Site terrestrial wildlife receptor diets were selected. Regression modeling was conducted and evaluated for reliability using a three-part validation process. The validated

[6] The COPCs identified for terrestrial birds and mammals in the Aquatic BERA are: aluminum, barium, cadmium, chromium, copper, iron, lead, mercury, molybdenum, selenium, thallium, vanadium, and zinc.

models developed from Source 1 and Source 3 and reported in this appendix are used in the Aquatic BERA.

Sources 2 and 4 present their models and any validation work in their respective documentation. Bioaccumulation models selected from Sources 2 and 4 are taken directly from their documentation without alteration. These models are presented in Section 4.1.2.3 of the Aquatic BERA and are not discussed further in this appendix.

3.1 DATA AND APPROACH

This section documents the data set acquisition, data handling, and modeling approach used to derive bioaccumulation models from the 2018 Plant Tissue Study (TAI 2019) data set and the USACHPPM (2004) database.

3.1.1 SELECTED DATA SETS

This subsection presents an overview of the two data sets selected for modeling, the 2018 Plant Tissue Study (TAI 2019) and USACHPPM (2004).

3.1.1.1 2018 PLANT TISSUE STUDY

The 2018 Plant Tissue Study (TAI 2019) data collection was designed to evaluate the concentrations of metals in the tissue of wild upland plants sampled from tribal allotments. TAI collected plant tissue and co-located soil samples during three sampling events in 2018: April, June, and August.

This study was conducted in accordance with the approved Quality Assurance Project Plan (TAI 2018b). Sampling design was focused on characterizing metal concentrations in upland plants that are ingested, mouthed, or otherwise used by Confederated Tribes of the Colville Reservation members with the intent to evaluate the potential human exposure to metals and mercury. Plants and co-located soil samples were collected from 12 sampling areas, located on Confederated Tribes of the Colville Reservation tribal allotments or publicly available areas and designated as either "high lead" or "low lead" sampling areas based on soil lead data collected in the 2014 Soil Study (TAI 2015), 2014 Residential Soil Study (USEPA 2016), and 2016 Residential Soil Study (TAI 2017). A total of six high lead and six lower lead sampling areas were targeted for plant tissue and co-located soil sampling for each plant species and tissue type.

Co-located soil samples were collected next to small plants or below the crown of larger bushes and trees. For individual plant samples, one co-located soil sample was collected. For composite plant samples, a co-located composite soil sample was collected for each individual plant sampled; soil samples were composited in the field in amounts proportional to the weight of the plant tissue from each plant in the composited plant sample.

Data collected for this study included the following:

- A total of 174 plant tissue and 174 co-located soil samples were collected and analyzed for target analyte list (TAL) metals (excluding mercury). A subset of 63 plant tissue and co-located soil samples were also analyzed for mercury, as per TAI (2018a).

- Plant tissue types (plant parts) collected were black tree lichen; camas bulbs; kinnikinnick leaves; lomatium roots; Indian potato corms; willow branches; huckleberry berries; wild rose stems, leaves, and rose hips; chokecherry berries; hazelnuts; ponderosa pine nuts; sarvisberry berries; tule culms; and wild mint leaves.
- Soil samples were collected from 0 to 3 inches below the ground surface. Soil samples were air dried and passed through a No. 100 sieve to isolate the target particle size of less than 150 micrometers (µm). This particle size fraction is intended to represent the fraction expected to adhere to skin via dermal contact (Ruby and Lowney 2012).

Mercury was analyzed in leaf and stem tissues collected from kinnikinnick, wild rose, willows, tule, and wild mint (59 plant tissue samples) and the associated soil samples. Three sarvisberry samples and one wild rosehip sample were also analyzed for mercury. Mercury was only analyzed in stem and leaf tissue following review of research demonstrating that mercury was highest in these tissues (Li et al. 2017), as well as the associated co-located soil samples. Detailed results of the 2018 field sampling effort for the plant tissue study conducted for the UCR Site are presented in TAI (2019).

3.1.1.2 USACHPPM (2004)

USACHPPM (2004) reports the results of a literature search for bioaccumulation data for metals and other contaminants. This literature search was conducted by USACHPPM to fill a gap in the existing literature specific to non-earthworm terrestrial arthropods and different terrestrial plant parts (i.e., seed, fruit, and root). A database was populated with the results of this literature search and is presented in Appendix B of USACHPPM (2004).

Data in the USACHPPM database were restricted to the following:

- Co-located biota and soil samples
- Relevant species for the biota types for which models needed to be developed from this source, including terrestrial arthropods and flying insects (such as insects, spiders, millipedes, centipedes, mollusks, and isopods, and excluding all data on earthworms) or terrestrial plants (such as trees, shrubs, grasses, vegetables, and fruits)
- Whole-body concentrations (terrestrial arthropods) or seed, fruit, stem, leaf, root, and/or whole-plant concentrations (terrestrial plants)
- Data likely to have biota concentrations that were at equilibrium with soil concentrations (i.e., field-collected studies of resident biota or laboratory studies of sufficient duration)
- Total (e.g., concentrated acid extraction) chemical analyses of both soil and biota
- Mean or composite concentration reported for each sampling location, for each species reported

Data are available for metals, including essential nutrients such as sodium and magnesium, with all concentrations reported as mg/kg dry weight. Concentrations reported as wet weight in the original study were converted to dry weight using either a water content reported in the study or an estimated water content percentage from USEPA (1993). In addition, class, order, and family taxonomic data were included where possible in the database. A quality assurance and quality control procedure was followed by USACHPPM (2004) to minimize errors in the database.

The USACHPPM (2004) report calculates summary statistics for BAFs (the ratio of the concentration in biota to the concentration in soil) by class and order for terrestrial arthropods and by plant part for terrestrial plants. No regression modeling was done in the report. Since regression models that meet acceptance criteria are preferred over BAFs (see Section 2.1.3.1 of this appendix), data were extracted from the report to derive regression models for use in the Aquatic BERA.

3.1.2 DATA HANDLING

This subsection describes how data were handled in deriving bioaccumulation models from the 2018 Plant Tissue Study (TAI 2019) and USACHPPM (2004) database for use in the Aquatic BERA.

3.1.2.1 2018 PLANT TISSUE STUDY

Fines-bulk correction factors, exclusions, transformations, and data groupings are described for the data from the 2018 Plant Tissue Study (TAI 2019).

Fines-Bulk Correction

Soil data collected as part of the 2018 Plant Tissue Study (TAI 2019) are limited to the fines soil fraction (< 150 µm) because the data were intended for evaluation of human exposure. Since soil data used in the Aquatic BERA are based on the < 2-millimeter (mm) soil fraction, the soil data from the 2018 Plant Tissue Study had to be corrected to represent the < 2-mm fraction that is relevant to ecological organisms. Fines-bulk correction factors were developed using co-located fines and bulk soil data from the 2014 UCR Upland Soil Study data set (TAI 2015).

The steps used to develop the fines-bulk correction factors consisted of the following:

1. Paired fines-bulk soil data from the 2014 UCR Upland Soil Study (TAI 2015) were compiled. Samples for the 2014 UCR Upland Soil Study were collected using the incremental composite sampling method. Samples were collected from decision units in the aerial deposition areas and RFDAs. Duplicates from split samples and field duplicate samples were averaged. Paired data without detect-detect pairs were excluded.
2. An analysis of covariance (ANCOVA) determined the aerial deposition areas and RFB/RFC could be pooled as they were not significantly different ($p > 0.05$). However, RFA and RFD were consistently different ($p < 0.05$) from other areas and were removed from the data set (Figure E-7 and Table E-6).
3. Fines-bulk data were plotted for each COPC and tested for the following.
   a. A statistically significant linear relationship
   b. Whether the relationships are statistically significantly different than a 1:1 relationship
4. Correction factors were then determined in the following way.
   a. If the relationship between fines and bulk data for a COPC is statistically significant and significantly different than a 1:1 relationship, then a linear correction was used as a correction on the fines.

b. If the relationship between fines and bulk data for a COPC is statistically significant and not significantly different than a 1:1 relationship, no correction factor was applied to the fines data.

c. If the relationship between fines and bulk data for a COPC is not statistically significant, no correction factor was applied to the fines data.

The fines-bulk data for each COPC are shown in Figure E-8. Table E-7 summarizes the model parameters and the decision to apply a correction factor to fines data. The following COPCs had fines-bulk correction factors applied to the soil data from the 2018 Plant Tissue Study (TAI 2019): barium, cadmium, chromium, copper, iron, lead, mercury, molybdenum, selenium, thallium, and vanadium.

Exclusions

Data from the 2018 Plant Tissue Study (TAI 2019) were excluded if concentrations were below detection limits or plant tissue types were not relevant. Two plant tissue types were excluded (black tree lichen and willow inner bark) because the lichen is not exposed to soil and the willow inner bark samples are unlikely to be a common aboveground food item for the herbivorous terrestrial receptors evaluated in the Aquatic BERA (e.g., California quail, meadow vole, deer mouse; see Section 2 of Volume 4 of the Aquatic BERA for information on receptor dietary composition).

Data Transformations

Normality testing was performed, which confirmed that the data were log-normally distributed for most of the analytes. Therefore, all soil and biota concentrations were natural log transformed prior to regression modeling. This is consistent with the approaches used in other commonly used bioaccumulation model sources, such as those used for EPA’s Eco-SSLs (Bechtel Jacobs 1998b; Sample et al. 1998a,b).

Selected Plant Groups and Metals for Modeling

Plant part types were grouped into two categories: aboveground plant parts and belowground plant parts. Aboveground plant parts include berries, hips, nuts, culms, leaves, and stems. Belowground plant parts include bulbs, corms, and roots. Initial data exploration showed no improvements by evaluating more data groupings (e.g., separating fruits from nuts).

Data are available for modeling all COPCs except for:

- Molybdenum in aboveground and belowground plant parts
- Mercury in belowground plant parts

3.1.2.2 USACHPPM (2004)

Details of data handing for the USACHPPM (2004) report are provided below.

Database Extraction

The database was extracted electronically from the PDF file of the USACHPPM (2004) report. Extraction was performed using the R package pdf tools, version 2.3.1 (Ooms 2020). Table B-1 (terrestrial arthropods) and Table B-2 (terrestrial plants) were extracted from the PDF of the USACHPPM database.

Page 36 of Table B-1 (page 550 of the PDF file) is blank. While the report does not list the total number of data points, it appears that this potential error in the PDF file results in a loss of approximately 50 data points in the database specific to terrestrial arthropods. The total available data points for terrestrial arthropods for all reported metals is 1,901. No blank pages were identified for terrestrial plants; the total number of data points for all reported metals is 2,082. Uncertainty associated with the loss of data points is discussed later in Section 3.3 of this appendix.

Exclusions

Data points without concentration values for both soil and biota were excluded from the modeling data set. In addition, data points with nondetected concentrations for either soil or biota were excluded. Nondetected concentrations were identified as those values reported as 0 or those values qualified with a "U"[7] in the database.

Terrestrial Arthropods

Mollusks were considered from the USACHPPM (2004) database for invertebrate prey but were excluded from the modeling data set because mollusks (i.e., snails and slugs) are not anticipated to be a major food source for UCR Site terrestrial invertivorous receptors (i.e., tree swallow, American robin, little brown bat, and masked shrew; see Section 2 of Volume 4 of the Aquatic BERA for information on receptor dietary composition), and therefore only terrestrial arthropods were considered from the remaining data. This exclusion resulted in a negligible decrease in data points because limited data (one sample for six analytes) were available for mollusks in the USACHPPM (2004) database. Data on spiders, insects, millipedes, centipedes, and isopods were all retained for the terrestrial arthropod modeling data set.

Aerial Insects

A subset of the terrestrial arthropod modeling data set was used to generate models specific to aerial insects, the preferred prey for aerial insectivore receptors such as the tree swallow and the little brown bat. Given the differences in life history characteristics and degree of exposure to soil, it is reasonable to assume that uptake may be different for flying aerial insects than for ground-dwelling arthropods. To generate this subset of data, available taxonomic information for each data point was scrutinized to assess whether the species was an aerial insect or not, as reported in Table E-8. Spiders, millipedes, centipedes, isopods, and some insects (such as specific beetle, weevil, ant, grasshopper, and cockroach species that cannot or generally do not fly) were excluded from the aerial insect modeling data set. Insects that fly, such as most beetles, weevils, flies, aphids, moths, grasshoppers, and crickets, were included in the aerial insect modeling data set. Where specified in the database, aerial insect species that were labeled as a ground-dwelling larval form (such as caterpillars) were excluded from the aerial insect modeling data set. For data

[7] The "U" qualifier means that the analyte was not detected at a concentration higher than the quantitation limit.

points with limited taxonomic information that precluded categorization (e.g., “chewing insect” or “non-spider”), it was assumed that the species was not an aerial insect.

Terrestrial Plants

Data were reported in the USACHPPM (2004) database for both aboveground and belowground plant parts.

A review of the terrestrial plant data for molybdenum was performed as it was the only COPC that did not have an available model or data in ranked Sources 1 and 2 (see Table E-5). This review indicated that all data points were based on terrestrial species with co-located soil samples. Therefore, no exclusions were made.

Outlier Evaluation and Corrections

Data from the USACHPPM database were assumed to be correct and were not independently verified. However, a visual assessment of the database was conducted to identify outliers or data clusters indicating potential errors in concentration reporting. Any outliers were then verified to ensure that the data had been appropriately included and calculated. The following sets of outliers were identified and handled as described:

- **Watson et al. (1976) soil concentrations.** Visual assessment of the terrestrial arthropod data set identified a study with soil concentrations, particularly for lead, substantially different than all others. This study (Watson et al. 1976) was reviewed and an error in unit conversions for the database was identified. Soil concentrations from this study were corrected to mg/kg, according to the information in the study’s table headings. Database gaps for soil concentration for a limited subset of litter grazer rows were also identified. These gaps were populated according to the soil concentrations reported for each of the Watson et al. (1976) sample locations in the database.
- **Ramirez and Rogers (2000) soil concentrations.** A single grasshopper sample from Ramirez and Rogers (2000) was identified as an outlier for copper. After reviewing the original study, the geometric mean soil concentration of this sample appears to have been calculated in error. The geometric mean was calculated as per the study results and corrected the soil concentration in the terrestrial arthropod data set.

This detailed level of scrutiny was reserved only for visual outliers; no other studies or data points were scrutinized as part of this modeling effort.

Data Transformations

Normality testing was performed, which confirmed that the data were log-normally distributed for the majority of analytes. Therefore, all soil and biota concentrations were natural log transformed prior to regression modeling. This is consistent with the approaches used in other commonly used bioaccumulation model sources, such as those used for EPA’s Eco-SSLs (Bechtel Jacobs 1998b; Sample et al. 1998a,b).

Selected Metals for Modeling

Bioaccumulation models are only necessary for COPCs evaluated through the dietary exposure pathway for wildlife. Models from the USACHPPM (2004) database were only needed for COPC-biota type pairings for which no model from a higher-ranked source was available. Table E-5 delineates which COPC-biota type pairings needed bioaccumulation model calculations from the USACHPPM (2004) data set.

For terrestrial plants, Bechtel Jacobs (1998b) (the second-ranked source for plants) does not present models or data for molybdenum. Thus, the USACHPPM (2004) data set was used to develop terrestrial plant models for molybdenum, as noted in Table E-5.

3.1.3 MODEL DEVELOPMENT

Bioaccumulation models were developed and validated consistent with approaches used in other commonly used bioaccumulation model sources (Bechtel Jacobs 1998b; Sample et al. 1998a,b). The two types of models developed (e.g., regression models, BAFs) and the acceptance criteria for regression models are presented in Section 2.1.3.1 of this appendix.

A series of model validation procedures were used to confirm the reliability of the model-estimated linear relationships between biota and soil concentrations. The goal was to assess the sensitivity and variability of the model estimates. Three model validation methods were conducted, including the following:

1. Data splitting based on studies (similar to methods in Sample et al. [1998a])
2. Data truncation of extremes
3. Bootstrap resampling

Regression models were validated using all three of the methods, where data permitted. BAFs were validated using only the third method, bootstrap resampling. The approach for the second and third methods, data truncation of extremes and bootstrap resampling, is presented in Section 2.1.3.2 of this appendix. The approach for the first method, data splitting based on studies, is presented below.

Similar to validation methods used in Sample et al. (1998a), data were separated into training and validation data sets based on the required sample sizes to achieve approximately an 80/20 split. Studies were assigned as either training or validation so that samples in the same studies were kept together since sampling and analytical variability are likely to be correlated among data from the same study. The assignment of studies and corresponding sample sizes are shown in Table E-9. Aluminum, iron, mercury, and thallium were not included in this validation process for terrestrial arthropods because all samples came from a single study. For all COPCs except for molybdenum, no data from plants were included in the data splitting set since all samples came from the 2018 Plant Tissue Study (TAI 2019). Also, the number of studies used for molybdenum concentrations in plant samples from the USACHPPM (2004) database was not sufficient to conduct a study split; thus, no plant samples were evaluated for molybdenum using this validation method. Wilcoxon signed-rank test and proportional deviation were used to assess how well the biota response in the validation data set was predicted by the training model.

3.2 RESULTS

This section presents the validation results and selected bioaccumulation models used in the Aquatic BERA.

3.2.1 MODEL DEVELOPMENT

Regression models and median BAFs were calculated using the data set described above in Section 3.1 of this appendix for each of the COPC-biota type pairings specified in Table E-5. Calculated model parameters and summary statistics are reported in Table E-10 (terrestrial arthropods and aerial insects) and Table E-11 (aboveground and belowground terrestrial plant parts).

3.2.2 MODEL VALIDATION

Results for the validation techniques are presented in Figures E-9 through E-10 (data splitting), Figures E-12 through E-18 (data truncation low and data truncation high), and Figures E-19 through E-30 (bootstrap resampling). Where appropriate, fitted regressions and 90-percent prediction intervals using the training data set, as well as the entire data set, are shown.

Overall, COPC-biota type pairings with large sample sizes ($n \geq 60$) yielded more robust regression models, and pairings with small sample sizes ($n \leq 30$) yielded more variable and sensitive regression models. If more data were available for the COPC-biota type pairings with small sample sizes ($n \leq 30$), especially data for soil concentrations not represented in the current data set, it is likely that the resulting model relationship would change with the addition of new data. Confidence in regression models with larger sample sizes is thus higher than models with smaller sample sizes. For all biota types, the median of bootstrap sample median BAFs was similar in value to the median BAFs computed from all the data, which suggests that median BAF calculations are not highly sensitive to varying the underlying data set. Confidence in median BAFs from the data is thus increased due to the bootstrap resampling validation results.

Specific uncertainties with models for particular COPC-biota type pairings are discussed in Section 3.3 of this appendix.

3.2.3 FINAL SELECTED MODELS

The models selected for use in the Aquatic BERA are highlighted in bold in Tables E-10 and E-11. The final regression models (based on the full data sets), along with a statement as to whether the models meet acceptance criteria or not, are presented visually in Figures E-31 through E-34.

3.2.3.1 TERRESTRIAL ARTHROPODS

COPCs with regression models that met the acceptance criteria are aluminum, cadmium, and lead (Figure E-31). These regression models were selected for use in the Aquatic BERA. For all other COPCs (barium, chromium, copper, iron, mercury, selenium, thallium, vanadium, and zinc), the median BAF was selected for use. Modeling could not be conducted for molybdenum due to a lack of data in the USACHPPM (2004) database.

3.2.3.2 AERIAL INSECTS

COPCs with regression models that met the acceptance criteria are cadmium, copper, lead, and zinc (Figure E-32). These regression models were selected for use in the Aquatic BERA. For all other COPCs (aluminum, barium, chromium, iron, mercury, selenium, thallium, and vanadium), the median BAF was selected for use. Modeling could not be conducted for molybdenum due to a lack of data in the USACHPPM (2004) database.

3.2.3.3 TERRESTRIAL PLANTS

None of the regression models for aboveground plant parts met the acceptance criteria (Figure E-33). The median BAF for aboveground plant parts was selected for all COPCs (aluminum, barium, cadmium, chromium, copper, iron, lead, mercury, molybdenum, selenium, thallium, vanadium, and zinc).

Chromium and vanadium are the COPCs with regression models for belowground plant parts that met the acceptance criteria (Figure E-34). The median BAF for belowground plant parts was selected for all other COPCs (aluminum, barium, cadmium, copper, iron, lead, molybdenum, selenium, thallium, and zinc).

3.3 UNCERTAINTIES

Uncertainties associated with development of bioaccumulation models are discussed below. Uncertainties associated with dietary exposure pathways and the use of bioaccumulation models for hazard quotient calculations are discussed in the bird and mammal risk characterization sections of the Aquatic BERA.

3.3.1 UNCERTAINTIES ASSOCIATED WITH MODEL TYPES

See discussion of regression models versus BAFs in Section 2.3.1 of this appendix.

3.3.2 UNCERTAINTIES FOR THE PLANT BIOACCUMULATION MODELS

Uncertainties specific to the plant bioaccumulation models derived from 2018 Plant Tissue Study (TAI 2019) data are listed below.

- **Spatial relevance.** The 12 sampling areas where plant tissue samples were collected have limited spatial coverage and poor overlap with locations where soil samples suitable for use in the Aquatic BERA were collected and are not likely to be representative of the range of environmental conditions across the spatial extent of the RFDA and WSDA BERA. The co-located soil samples represent a single point near each collected plant tissue sample, unlike the 2014 UCR Upland Soil Study decision units in the RFDA and WSDA BERA, which represent a composite across approximately 2 to 22 acres, depending on the decision unit. Bioavailability parameters were not measured in these co-located soil samples. However, the range of metal concentrations in the co-located soil samples is similar to the range of metal concentrations seen in the 2014 UCR Upland Soil Study samples in the RFDA and WSDA BERA, with the exception of the RFDA and WSDA BERA have higher concentrations of copper, iron, and zinc in some samples than are represented in the soil samples in the plant tissue data set.

Thus, bioaccumulation models developed from these data have relevance to RFDA and WSDA soil metal concentrations.

- **Relevance to herbivorous wildlife diets.** The specific plants and plant parts sampled were selected for their cultural significance (e.g., inner bark of willow for medicinal tea, kinnikinnick leaves for smoking), during the window of their seasonal availability (April, May, June, and August). While some wildlife species likely include some of the sampled plant parts in their diet (e.g., robins eating rose hips in the early fall), the specific plant samples are unlikely to represent the entire range or the dominant portion of herbivore diets at the UCR Site, which includes many more plant species and plant parts across all four seasons. There is substantial uncertainty in assuming that the sampled plant species and parts are representative of the entirety of the plant material that any one receptor might eat over all four seasons. However, this uncertainty is the same or greater with the Bechtel Jacobs (1998b) plant models commonly used for ERAs.
- **Sieve size correction factors.** Co-located soil samples from the plant tissue sampling were sieved to < 150 µm for evaluation in the human health risk assessment, whereas data sets used in the Aquatic BERA were from soil samples sieved to < 2 mm. Developing relevant bioaccumulation models from these data requires the development of correction factors between < 150-µm and 2-mm soil chemistry data. While TAI was able to develop statistically significant correction factors (with R^2 values above 0.6) between the < 150-µm and < 2-mm soil samples for most COPCs (aluminum, barium, cadmium, chromium, copper, iron, lead, mercury, selenium, thallium, vanadium, and zinc) using the 2014 UCR Upland Soil Study data set (TAI 2015), this correction does add uncertainty.
- **Poor regression model performance.** For most COPCs and tissue type groupings (e.g., aboveground or belowground plant parts), scatterplots of the plant tissue and co-located soil data do not show identifiable direct relationships (see Figures E-33 and E-34); this is supported by the low R^2 values (< 0.1) and non-significant p-values ($p > 0.05$) observed for nearly all regression models (exceptions being chromium and vanadium in belowground plant parts). Models were evaluated by three plant part groups (roots, foliage, and fruits and nuts) as well as individual plant parts (e.g., cherries, berries, nuts, leaves, bulbs) and had similarly poor model performance; a few models had good relationships ($R^2 > 0.1$ and significant p-values [$p < 0.05$]), but these were not consistent across COPCs or plant parts. Terrestrial plant tissue COPC concentrations at the Site are not well predicted by the COPC concentrations in co-located soil. This is likely due to the highly variable uptake, transport, and sequestration mechanisms across different plant species and different plant parts (e.g., roots, leaves, and reproductive parts) and also plant regulation of essential metals (Kabata-Pendias and Pendias 2011). The poor model performance adds uncertainty to the use of bioaccumulation models derived from these data.

Uncertainties specific to the plant bioaccumulation models derived from data in the USACHPPM (2004) database are listed below.

- **Relevance of database species, life stages, and plant parts to receptor dietary items.** Species in the terrestrial plant modeling data set include terrestrial grasses, berries, and forbs. This represents a limited range of species and may not encompass many species-specific differences in soil exposure and metal regulation mechanisms that may modify bioaccumulation.

- **Environmental relevance of the underlying data set.** The USACHPPM (2004) database contains bioaccumulation data from soils across North America, South America, Europe, and Asia. None of the studies were conducted with soils from Washington State. The bioaccumulation models thus have broad relevance to a variety of different soil types but are not specifically relevant to soils at the Site. Depending on the physical soil characteristics and bioavailability of metals in Site soils, the bioaccumulation models may over- or under-estimate bioaccumulation into terrestrial arthropods and plants.

3.3.3 UNCERTAINTIES FOR THE TERRESTRIAL ARTHROPOD AND AERIAL INSECT MODELS

Uncertainties specific to the bioaccumulation modeling conducted by TAI using the USACHPPM (2004) database are discussed below.

- **Loss of data points.** Approximately 50 data points for terrestrial arthropods may have been lost due to a blank page in the publicly available PDF file of the USACHPPM (2004) database. Through comparison of the summary statistics in the USACHPPM (2004) report and the extracted data set, the loss of the following 48 data points was identified: aluminum (6), antimony (2), arsenic (5), lead (1), sodium (1), thallium (9), vanadium (12), and zinc (12). It is unclear in the report if this was done intentionally or inadvertently. The loss of these data points is irrelevant for antimony, arsenic, and sodium because these metals are not COPCs for which bioaccumulation modeling was conducted for the Aquatic BERA. The loss of these data points is negligible for lead and zinc, for which a large data set of over 250 samples remains. However, the missing samples for aluminum, thallium, and vanadium represent a substantial portion of the data sets for these three COPCs, which have remaining sample sizes of 24, 14, and 19, respectively, for terrestrial arthropods. It is unknown how the missing samples for aluminum, thallium, and vanadium might have changed the results of the bioaccumulation modeling.
- **Relevance of database species and life stages to receptor dietary items.** The biota included in the USACHPPM (2004) database represent a variety of global species, many of which are not likely to be the exact species consumed by UCR Site terrestrial receptors. However, the database includes classes, orders, and families related to dietary species for UCR Site terrestrial receptors. The bioaccumulation models are broadly relevant to terrestrial arthropods and aerial insects.
  - **Terrestrial arthropods.** Species in the terrestrial arthropod modeling data set include spiders, centipedes, millipedes, beetles, termites, weevils, flies, true bugs, sawflies, ants, hornets, moths, butterflies, lacewings, grasshoppers, cockroaches, crickets, woodlice, and isopods. This represents a broad range of species that is expected to encompass many species-specific differences in life history characteristics and metal regulation mechanisms that may modify bioaccumulation.
  - **Aerial insects.** Species in the aerial insect modeling data set include beetles, weevils, flies, true bugs, sawflies, hornets, moths, butterflies, lacewings, grasshoppers, and

crickets. Data points specific to larval stages of these species were not included. The restriction of the aerial insect data set to just flying adults increases the relevance of the aerial insect models to the UCR Site terrestrial aerial insectivorous receptors (tree swallow and little brown bat). These insect species have undergone metamorphosis to reach the flying adult stage, and metal concentrations may decrease after metamorphosis (Kraus et al. 2014). Additionally, aerial insects may have less exposure to soil, which can further decrease metal bioaccumulation.

- **Different trophic levels of biota species.** The USACHPPM (2004) database contains data representing different trophic levels of terrestrial arthropods. For some COPCs, such as mercury, that may bio-magnify in higher trophic levels, predaceous arthropods (e.g., spiders) may have higher bioaccumulation than herbivorous or detritivorous arthropods (e.g., millipedes). The bioaccumulation models developed by TAI aggregate the different trophic levels. Therefore, the models may underestimate bioaccumulation into predaceous biota and overestimate bioaccumulation into herbivorous or detritivorous biota. However, the models are representative of bioaccumulation across different trophic levels. These models are thus relevant to the UCR Site terrestrial receptor diets because the invertivores (i.e., tree swallow, American robin, little brown bat, and shrew) eat a wide range of invertebrate prey.
- **Environmental relevance of the underlying data set.** See bullet listed above, in Section 3.3.2 of this appendix, for terrestrial plant models developed using data from the USACHPPM (2004) database.

3.3.4 CONTEXT PROVIDED BY THE VALIDATION ACTIVITIES ON THE FINAL SELECTED MODELS

Interpretation and discussion of the validation activities is provided below, for the bioaccumulation models developed for terrestrial arthropods, aerial insects, and plants.

- Terrestrial arthropods
  - Cadmium and lead regression models, which meet the acceptance criteria and have sample sizes between 250 and 300 observations, have the lowest uncertainty of the terrestrial arthropod models developed for the Aquatic BERA. For most of the validation methods, the models for the training data and all data are similar, which indicates that the models are robust. For cadmium, training models for terrestrial arthropods are more sensitive to the removal of the lowest 20 percent of soil concentrations as compared to the highest 20 percent (Figures E-11 and E-15). This indicates that there is greater uncertainty in predicted biota concentrations from lower soil concentrations relative to higher soil concentrations for cadmium.
  - The aluminum regression model meets the acceptance criteria but has a sample size of 24. In the model validation, the aluminum model shows high sensitivity and variability, particularly in the bootstrap resampling validation (Figure E-23). The aluminum regression model has high uncertainty due to the low sample size and sensitivity of the model to the input data.
  - All other selected models for terrestrial arthropods out of the USACHPPM (2004) database are median BAFs. For copper, lead, mercury, selenium, and vanadium, the median of

bootstrap samples' median BAFs is nearly identical to the median BAF calculated for all data (Figure E-27). But for chromium and zinc, the median of bootstrap samples' median BAFs is not identical to the median BAF calculated for all data. Thus, there is high uncertainty in the median BAF values for chromium and zinc.

- Aerial insects
  - Cadmium, copper, lead, and zinc regression models meet the acceptance criteria and have a sample size ≥ 60. Each of these show sensitivity and variability for all of the model validation techniques. These models have moderate uncertainty due to the moderate sample size.
  - All other selected models for aerial insects out of the USACHPPM (2004) database are median BAFs. For each of these (aluminum, chromium, mercury, selenium, and vanadium), the median of the bootstrap samples' median BAFs is nearly identical to the median BAF calculated for all data (Figure E-28). Uncertainty in the median BAF values for these metals is low.
- Terrestrial plants
  - The only regression models that met the acceptance criteria for terrestrial plants are cadmium and vanadium for belowground plant parts. These models show sensitivity and variability in the truncated and bootstrap resampling validation techniques (Figures E-14, E-18, and E-26) but have moderate sample sizes, thus indicating moderate uncertainty. No regression models met the acceptance criteria for aboveground plant parts. All other selected models are median BAFs. For each of these, the median of the bootstrap samples' median BAFs is very similar to the median BAF calculated for all data (Figures E-29 and E-30), which indicates low uncertainty.

4. SUMMARY

For the Aquatic BERA, realistic and relevant bioaccumulation models were identified from the literature and/or developed from available data sets using the methodology described in this appendix. These models are used to estimate dietary doses of COPCs for fish, birds, and mammals, based on soil or sediment COPC concentrations.

The selected bioaccumulation models used in the Aquatic BERA are summarized in Table E-12.

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TABLES

Table E-1
Available Aquatic Bioaccumulation Models and/or Data from Ranked Sources
Upper Columbia River
Final Aquatic Baseline Ecological Risk Assessment
Appendix E

Dietary COPC for Fish, Birds and/or Mammals	Ranked Sources of Bioaccumulation Models and/or Data						
	1. Oak Ridge National Laboratory Reports (Bechtel Jacobs 1998a)	2. Jackson et al. (1991)	3. Hamilton et al. (2002), Hamilton and Buhl (2003a, 2003b)	4. Vanier et al. (2001)	5. USACE (2019)	6. USEPA (1999)	7. Kraus et al. (2014)
Small Aquatic Invertebrates							
Aluminum	no model or data available	no model or data available	data available (N = 25)	NA	NA	NA	NA
Arsenic	model available	NA	NA	NA	NA	NA	NA
Barium	no model or data available	no model or data available	data available (N = 25)	NA	NA	NA	NA
Cadmium	model available	NA	NA	NA	NA	NA	NA
Chromium	model available	NA	NA	NA	NA	NA	NA
Copper	model available	NA	NA	NA	NA	NA	NA
Iron	no model or data available	no model or data available	data available (N = 25)	NA	NA	NA	NA
Lead	model available	NA	NA	NA	NA	NA	NA
Manganese	no model or data available	no model or data available	data available (N = 25)	NA	NA	NA	NA
Mercury	model available	NA	NA	NA	NA	NA	NA
Molybdenum	no model or data available	no model or data available	data available (N = 4)	NA	NA	NA	NA
Nickel	model available	NA	NA	NA	NA	NA	NA
Selenium	no model or data available	no model or data available	data available (N = 23)	NA	NA	NA	NA
Thallium	no model or data available	no model or data available	no model or data available	no model or data available	no model or data available	no model or data available	no model or data available
Vanadium	no model or data available	no model or data available	data available (N = 25)	NA	NA	NA	NA
Zinc	model available	NA	NA	NA	NA	NA	NA
Bis(2-Ethylhexyl)phthalate	no model or data available	no model or data available	no model or data available	no model or data available	model available	NA	NA
Total PCB congeners	model available	NA	NA	NA	NA	NA	NA
Dioxins/Furans [a]	no model or data available	no model or data available	no model or data available	no model or data available	model available	NA	NA

Table E-1
Available Aquatic Bioaccumulation Models and/or Data from Ranked Sources
Upper Columbia River
Final Aquatic Baseline Ecological Risk Assessment
Appendix E

Dietary COPC for Fish, Birds and/or Mammals	**Ranked Sources of Bioaccumulation Models and/or Data**						
	1. Oak Ridge National Laboratory Reports (Bechtel Jacobs 1998a)	**2. Jackson et al. (1991)**	**3. Hamilton et al. (2002), Hamilton and Buhl (2003a, 2003b)**	**4. Vanier et al. (2001)**	**5. USACE (2019)**	**6. USEPA (1999)**	**7. Kraus et al. (2014)**
Adult Flying Aquatic Emergent Insects							
Metals and Metalloids	no model or data available	no model or data available	no model or data available	no model or data available	no model or data available	no model or data available	correction factor available
Organics	no model or data available	no model or data available	no model or data available	no model or data available	no model or data available	no model or data available	correction factor available
Aquatic Plants							
Aluminum	no model or data available	model available	NA	NA	NA	NA	NA
Arsenic	no model or data available	model available	NA	NA	NA	NA	NA
Barium	no model or data available	model available	NA	NA	NA	NA	NA
Cadmium	no model or data available	model available	NA	NA	NA	NA	NA
Chromium	no model or data available	model available	NA	NA	NA	NA	NA
Copper	no model or data available	model available	NA	NA	NA	NA	NA
Iron	no model or data available	model available	NA	NA	NA	NA	NA
Lead	no model or data available	model available	NA	NA	NA	NA	NA
Manganese	no model or data available	model available	NA	NA	NA	NA	NA
Mercury	no model or data available	model available	NA	NA	NA	NA	NA
Molybdenum	no model or data available	model available	NA	NA	NA	NA	NA
Nickel	no model or data available	model available	NA	NA	NA	NA	NA
Selenium	no model or data available	model available	NA	NA	NA	NA	NA
Thallium	no model or data available	model available	NA	NA	NA	NA	NA

Table E-1
Available Aquatic Bioaccumulation Models and/or Data from Ranked Sources
Upper Columbia River
Final Aquatic Baseline Ecological Risk Assessment
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Dietary COPC for Fish, Birds and/or Mammals	Ranked Sources of Bioaccumulation Models and/or Data						
	1. Oak Ridge National Laboratory Reports (Bechtel Jacobs 1998a)	2. Jackson et al. (1991)	3. Hamilton et al. (2002), Hamilton and Buhl (2003a, 2003b)	4. Vanier et al. (2001)	5. USACE (2019)	6. USEPA (1999)	7. Kraus et al. (2014)
Aquatic Plants (Continued)							
Vanadium	no model or data available	model available	NA	NA	NA	NA	NA
Zinc	no model or data available	model available	NA	NA	NA	NA	NA
Bis(2-Ethylhexyl)phthalate	no model or data available	no model or data available	no model or data available	no model or data available	model available	NA	NA
Total PCB congeners	no model or data available	no model or data available	no model or data available	model available	NA	NA	NA
Dioxins/Furans [a]	no model or data available	no model or data available	no model or data available	no model or data available	no model or data available	model available	NA

Notes:

(grey) No model or data are available for the given biota type, COPC, and source.
(light aqua) Co-located sediment and biota data are available for the given biota type, COPC, and source.
(green) A calculated model is available for the given biota type, COPC, and source.

[a] COPCs include PCB TEQ, dioxin/furan TEQ, and total TEQ.

COPC = chemical of potential concern

N = number of paired detect-detect data points

NA = not applicable; model was chosen in previous source

PCB = polychlorinated biphenyl

TEQ = toxic equivalency

Table E-2
Summary of Aquatic Invertebrate Bioaccumulation Model Data Set
Upper Columbia River
Final Aquatic Baseline Ecological Risk Assessment
Appendix E

Analyte	Number of Paired Detect-Detect Data Points	Sediment Concentration (µg/g dw)						Aquatic Invertebrate Concentration (µg/g dw)					
		Distribution [a]	Minimum	Mean	Standard Deviation	Median	Maximum	Distribution [a]	Minimum	Mean	Standard Deviation	Median	Maximum
Aluminum	25	neither	944	8500	6000	9730	19800	lognormal	49	650	500	429.5	1790
Barium	25	neither	7.8	110	74	111	240	neither	14	64	59	31	215
Iron	25	neither	130	11000	8800	12300	25400	lognormal	59	600	470	388.5	1630
Manganese	25	lognormal	29	1200	1500	790	6630	lognormal	21	420	420	197	1530
Molybdenum	4	neither	0.5	1.2	1.1	0.9	4.7	neither	0.5	0.98	0.62	1	3.5
Selenium	23	neither	0.5	7.4	13	1.8	45.8	lognormal	0.5	18	38	6.95	186
Vanadium	25	neither	15	31	16	24	68	lognormal	1	5.8	9.1	3	46

Notes:
[a] The data set was evaluated for both normal and lognormal distributions. Distributions labeled as "neither" were neither normal nor lognormal.
µg = micrograms
dw = dry weight
g = grams

Table E-3
Results for Aquatic Invertebrate Bioaccumulation Modeling
Upper Columbia River
Final Aquatic Baseline Ecological Risk Assessment
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Analyte	Number of Data Points	Regression Models [a]					BSAF							Final Model Selection
		Intercept	Slope	R^2	p-value	Acceptable Regression Model? [b]	Distribution [c]	Mean	Standard Deviation	Minimum	Median	90th Percentile	Maximum	
Aluminum	25	1.3	0.57	0.48	0.00012	yes	lognormal	0.11	0.086	0.023	0.063	0.25	0.29	regression
Barium	25	4.5	-0.15	0.032	0.39	no	lognormal	1.8	3.2	0.059	0.28	4.0	13	median BSAF
Iron	25	3.2	0.34	0.53	3.4e-05	yes	neither	0.28	0.50	0.016	0.045	1.1	1.6	regression
Manganese	25	1.6	0.61	0.58	8.5e-06	yes	lognormal	0.67	0.63	0.098	0.41	1.6	2.2	regression
Molybdenum	4	NA	NA	NA	NA	no	lognormal	1.4	1.1	0.43	1.1	2.5	2.9	median BSAF
Selenium	23	1.4	0.62	0.55	5.6e-05	yes	lognormal	3.6	2.5	0.28	3.4	6.6	11	regression
Vanadium	25	-1.3	0.73	0.20	0.024	yes	lognormal	0.15	0.12	0.036	0.10	0.33	0.46	regression

Notes:

Bolded values represent the selected model parameters.

[a] Regression model equation is $\ln(C_{biota}) = slope * \ln(C_{sediment}) + intercept$.

[b] Regression model acceptability criteria: $p < 0.05$, $R^2 > 0.2$, positive slope, and number of data points > 10. Regression modeling was not attempted for analytes with insufficient data points (i.e., molybdenum).

[c] Normality testing was conducted on calculated bioaccumulation factors (BAFs) for both normal and lognormal distributions.

BSAF = biota-sediment accumulation factor

NA = not applicable

Table E-4
Estimates for Calculation of Aquatic Invertebrate Bioaccumulation Model Prediction Limits
Upper Columbia River
Final Aquatic Baseline Ecological Risk Assessment
Appendix E

Analyte	Data Source	Number of Data Points (n)	Prediction Limit Calculation Estimates for Regression Models					
			$\bar{x}$	Σx	Σx^2	RMSE	Sxx	t statistic (alpha = 0.05, df = n-2)
Aluminum	Hamilton data sets	25	8.724	218.099	1930.832	0.622	28.145	1.711
Arsenic	Bechtel Jacobs (1998a)	55	1.916	105.364	229.370	0.447	27.523	1.674
Cadmium	Bechtel Jacobs (1998a)	120	0.451	54.100	145.153	0.684	120.763	1.658
Chromium	Bechtel Jacobs (1998a)	34	1.812	61.611	117.076	0.298	5.431	1.694
Copper	Bechtel Jacobs (1998a)	112	1.501	168.165	318.839	0.301	66.344	1.659
Iron	Hamilton data sets	25	8.501	212.513	1897.949	0.600	91.484	1.711
Lead	Bechtel Jacobs (1998a)	117	1.462	171.011	281.205	0.568	31.250	1.658
Manganese	Hamilton data sets	25	6.336	158.407	1055.855	0.746	52.143	1.711
Selenium	Hamilton data sets	23	0.957	22.004	53.585	0.674	32.533	1.717
Vanadium	Hamilton data sets	25	3.289	82.217	275.989	0.685	5.605	1.711
Zinc	Bechtel Jacobs (1998a)	112	2.077	232.627	540.751	0.249	57.578	1.659

Notes:
Estimates for arsenic, cadmium, chromium, copper, lead, and zinc taken from Appendix A of Bechtel Jacobs (1998a), except Sxx, which was recalculated because Sxx should be defined as $\Sigma x^2 - 1/n (\Sigma x)^2$ and not $(\Sigma x^2 - (\Sigma x)^2)/n$. This is in agreement with the equation in Dowdy and Wearden (1983), which was referenced by Bechtel Jacobs (1998a).
RMSE = root mean square error
Sxx = sum of squared differences from the mean, defined as $\Sigma x^2 - 1/n (\Sigma x)^2$
t statistic = t-statistic for 95 percent one-tailed limits or 90 percent two-tailed intervals with n-2 degrees of freedom

Table E-5
Available Terrestrial Bioaccumulation Models and/or Data from Ranked Sources
Upper Columbia River
Final Aquatic Baseline Ecological Risk Assessment
Appendix E

Dietary COPC for Birds and/or Mammals	Ranked Sources for Models and/or Data			
	1. Site-Specific (2018 Plant Tissue Study) [a]	2. Oak Ridge National Laboratory Reports (Bechtel 1998b; Sample et al. 1998a,b)	3. USACHPPM (2004) Raw Database (see Appendix C)	4. Other Peer-Reviewed Literature
Terrestrial Plants–Aboveground Plant Parts				
Aluminum	data available (N = 99)	NA	NA	NA
Barium	data available (N = 112)	NA	NA	NA
Cadmium	data available (N = 111)	NA	NA	NA
Chromium	data available (N = 109)	NA	NA	NA
Copper	data available (N = 112)	NA	NA	NA
Iron	data available (N = 112)	NA	NA	NA
Lead	data available (N = 105)	NA	NA	NA
Mercury	data available (N = 49)	NA	NA	NA
Molybdenum	no model or data available	no model or data available	data available (N = 10)	NA
Selenium	data available (N = 32)	NA	NA	NA
Thallium	data available (N = 45)	NA	NA	NA
Vanadium	data available (N = 73)	NA	NA	NA
Zinc	data available (N = 112)	NA	NA	NA
Terrestrial Plants—Belowground Plant Parts				
Aluminum	data available (N = 36)	NA	NA	NA
Barium	data available (N = 36)	NA	NA	NA
Cadmium	data available (N = 36)	NA	NA	NA
Chromium	data available (N = 36)	NA	NA	NA
Copper	data available (N = 36)	NA	NA	NA
Iron	data available (N = 36)	NA	NA	NA
Lead	data available (N = 36)	NA	NA	NA
Mercury	surrogate data available (N = 49)[b]	NA	NA	NA
Molybdenum	no model or data available	no model or data available	data available (N = 8)	NA
Selenium	data available (N = 27)	NA	NA	NA
Thallium	data available (N = 36)	NA	NA	NA
Vanadium	data available (N = 36)	NA	NA	NA
Zinc	data available (N = 36)	NA	NA	NA

Table E-5
Available Terrestrial Bioaccumulation Models and/or Data from Ranked Sources
Upper Columbia River
Final Aquatic Baseline Ecological Risk Assessment
Appendix E

Dietary COPC for Birds and/or Mammals	Ranked Sources for Models and/or Data			
	1. Site-Specific (2018 Plant Tissue Study) [a]	2. Oak Ridge National Laboratory Reports (Bechtel 1998b; Sample et al. 1998a,b)	3. USACHPPM (2004) Raw Database (see Appendix C)	4. Other Peer-Reviewed Literature
Terrestrial Arthropods				
Aluminum	no model or data available	no model or data available	data available (N = 24)	NA
Barium	no model or data available	no model or data available	data available (N = 33)	NA
Cadmium	no model or data available	no model or data available	data available (N = 299)	NA
Chromium	no model or data available	no model or data available	data available (N = 35)	NA
Copper	no model or data available	no model or data available	data available (N = 274)	NA
Iron	no model or data available	no model or data available	data available (N = 30)	NA
Lead	no model or data available	no model or data available	data available (N = 268)	NA
Mercury	no model or data available	no model or data available	data available (N = 30)	NA
Molybdenum	no model or data available	no model or data available	no model or data available	model available
Selenium	no model or data available	no model or data available	data available (N = 22)	NA
Thallium	no model or data available	no model or data available	data available (N = 14)	NA
Vanadium	no model or data available	no model or data available	data available (N = 19)	NA
Zinc	no model or data available	no model or data available	data available (N = 258)	NA
Flying Insects				
Aluminum	no model or data available	no model or data available	data available (N = 17)	NA
Barium	no model or data available	no model or data available	data available (N = 19)	NA
Cadmium	no model or data available	no model or data available	data available (N = 94)	NA
Chromium	no model or data available	no model or data available	data available (N = 21)	NA
Copper	no model or data available	no model or data available	data available (N = 78)	NA
Iron	no model or data available	no model or data available	data available (N = 17)	NA
Lead	no model or data available	no model or data available	data available (N = 64)	NA
Mercury	no model or data available	no model or data available	data available (N = 17)	NA
Molybdenum	no model or data available	no model or data available	no model or data available	model available
Selenium	no model or data available	no model or data available	data available (N = 14)	NA
Thallium	no model or data available	no model or data available	data available (N = 4)	NA
Vanadium	no model or data available	no model or data available	data available (N = 6)	NA
Zinc	no model or data available	no model or data available	data available (N = 60)	NA

Table E-5
Available Terrestrial Bioaccumulation Models and/or Data from Ranked Sources
Upper Columbia River
Final Aquatic Baseline Ecological Risk Assessment
Appendix E

Dietary COPC for Birds and/or Mammals	Ranked Sources for Models and/or Data			
	1. Site-Specific (2018 Plant Tissue Study) [a]	2. Oak Ridge National Laboratory Reports (Bechtel 1998b; Sample et al. 1998a,b)	3. USACHPPM (2004) Raw Database (see Appendix C)	4. Other Peer-Reviewed Literature
Earthworms				
Aluminum	no model or data available	model available	NA	NA
Barium	no model or data available	model available	NA	NA
Cadmium	no model or data available	model available	NA	NA
Chromium	no model or data available	model available	NA	NA
Copper	no model or data available	model available	NA	NA
Iron	no model or data available	model available	NA	NA
Lead	no model or data available	model available	NA	NA
Mercury	no model or data available	model available	NA	NA
Molybdenum	no model or data available	model available	NA	NA
Selenium	no model or data available	model available	NA	NA
Thallium	no model or data available	no model or data available	no model or data available	no model or data available
Vanadium	no model or data available	model available	NA	NA
Zinc	no model or data available	model available	NA	NA
Small Mammals				
Aluminum	no model or data available	model available	NA	NA
Barium	no model or data available	model available	NA	NA
Cadmium	no model or data available	model available	NA	NA
Chromium	no model or data available	model available	NA	NA
Copper	no model or data available	model available	NA	NA
Iron	no model or data available	model available	NA	NA
Lead	no model or data available	model available	NA	NA
Mercury	no model or data available	model available	NA	NA
Molybdenum	no model or data available	no model or data available	no model or data available	no model or data available
Selenium	no model or data available	model available	NA	NA
Thallium	no model or data available	model available	NA	NA

Table E-5
Available Terrestrial Bioaccumulation Models and/or Data from Ranked Sources
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Appendix E

Dietary COPC for Birds and/or Mammals	Ranked Sources for Models and/or Data			
	1. Site-Specific (2018 Plant Tissue Study) [a]	2. Oak Ridge National Laboratory Reports (Bechtel 1998b; Sample et al. 1998a,b)	3. USACHPPM (2004) Raw Database (see Appendix C)	4. Other Peer-Reviewed Literature
Small Mammals (continued)				
Vanadium	no model or data available	model available	NA	NA
Zinc	no model or data available	model available	NA	NA

Notes:

No model or data are available for the given biota type, COPC, and source.

Co-located sediment and biota data are available for the given biota type, COPC, and source.

A calculated model is available for the given biota type, COPC, and source.

[a] Counts of available data points for the 2018 Plant Tissue Study report the number of detected pairs of data between soil and plant parts. Nondetected results were excluded from the analysis.

[b] Belowground plant samples were not analyzed for mercury, because the highest concentrations were expected in aboveground plant parts (TAI 2019). Aboveground plant parts are thus used as conservative surrogate data for belowground plant parts.

COPC = chemical of potential concern

N = number of data points

NA = not applicable; model was chosen in previous source

Table E-6
ANCOVA Coefficients for Fines-Bulk Analysis
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Term	Estimate	Standard Error	Statistic	p-Value	Statistically Significant
Aluminum					
(intercept)	-0.804	0.440	-1.83	0.0693	no
log(fines)	1.07	0.0455	23.5	6.71e-58	yes
area_idRFA	14.6	6.70	2.17	0.0312	yes
area_idRFB	0.387	6.69	0.0579	0.954	no
area_idRFC	1.69	5.02	0.338	0.736	no
area_idRFD	6.89	3.10	2.22	0.0276	yes
log(Fines):area_idRFA	-1.61	0.786	-2.05	0.0416	yes
log(Fines):area_idRFB	-0.0195	0.728	-0.0268	0.979	no
log(Fines):area_idRFC	-0.157	0.540	-0.290	0.772	no
log(Fines):area_idRFD	-0.769	0.353	-2.18	0.0306	yes
Barium					
(intercept)	-0.773	0.177	-4.37	2.02e-05	yes
log(fines)	1.14	0.0313	36.4	3.72e-87	yes
area_idRFA	5.94	4.78	1.24	0.215	no
area_idRFB	2.19	2.02	1.08	0.280	no
area_idRFC	2.44	1.96	1.24	0.216	no
area_idRFD	1.40	2.15	0.651	0.516	no
log(Fines):area_idRFA	-0.935	0.779	-1.20	0.231	no
log(Fines):area_idRFB	-0.395	0.400	-0.986	0.325	no
log(Fines):area_idRFC	-0.429	0.385	-1.11	0.267	no
log(Fines):area_idRFD	-0.341	0.362	-0.942	0.348	no
Cadmium					
(intercept)	0.429	0.0438	9.80	1.40E-18	yes
log(fines)	0.780	0.0285	27.3	2.07e-67	yes
area_idRFA	-1.57	1.62	-0.967	0.335	no
area_idRFB	-0.152	0.337	-0.449	0.654	no
area_idRFC	1.23	0.954	1.29	0.200	no
area_idRFD	1.01	2.28	0.441	0.660	no
log(Fines):area_idRFA	0.433	0.767	0.564	0.573	no
log(Fines):area_idRFB	0.236	0.391	0.604	0.546	no
log(Fines):area_idRFC	-0.460	0.483	-0.953	0.342	no
log(Fines):area_idRFD	-0.710	1.27	-0.561	0.576	no
Chromium					
(intercept)	-0.347	0.112	-3.11	0.00214	yes
log(fines)	1.10	0.0372	29.6	1.29e-72	yes
area_idRFA	4.49	1.75	2.57	0.0110	yes
area_idRFB	0.464	1.48	0.313	0.754	no
area_idRFC	0.453	2.88	0.157	0.875	no
area_idRFD	4.02	2.40	1.67	0.0957	no

Table E-6
ANCOVA Coefficients for Fines-Bulk Analysis
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Term	Estimate	Standard Error	Statistic	p-Value	Statistically Significant
Chromium (continued)					
log(Fines):area_idRFA	-1.26	0.597	-2.12	0.0354	yes
log(Fines):area_idRFB	-0.118	0.462	-0.255	0.799	no
log(Fines):area_idRFC	-0.114	0.913	-0.124	0.901	no
log(Fines):area_idRFD	-1.45	0.857	-1.69	0.0918	no
Copper					
(intercept)	0.647	0.125	5.19	5.52e-07	yes
log(fines)	0.774	0.0406	19.0	9.8e-46	yes
area_idRFA	7.19	2.02	3.55	0.000486	yes
area_idRFB	-0.467	1.32	-0.355	0.723	no
area_idRFC	0.491	1.16	0.424	0.672	no
area_idRFD	-10.4	2.89	-3.62	0.000384	yes
log(Fines):area_idRFA	-1.10	0.425	-2.58	0.0105	yes
log(Fines):area_idRFB	0.220	0.464	0.474	0.636	no
log(Fines):area_idRFC	0.0251	0.251	0.100	0.920	no
log(Fines):area_idRFD	2.87	0.766	3.75	0.000236	yes
Iron					
(intercept)	-2.99	0.583	-5.12	7.42e-07	yes
log(fines)	1.30	0.0596	21.9	1.70E-53	yes
area_idRFA	17.7	3.09	5.72	4.24e-08	yes
area_idRFB	3.25	6.55	0.497	0.620	no
area_idRFC	5.37	7.69	0.698	0.486	no
area_idRFD	-7.88	6.42	-1.23	0.222	no
log(Fines):area_idRFA	-1.64	0.298	-5.49	1.29e-07	yes
log(Fines):area_idRFB	-0.323	0.676	-0.478	0.633	no
log(Fines):area_idRFC	-0.538	0.783	-0.686	0.493	no
log(Fines):area_idRFD	0.790	0.652	1.21	0.227	no
Lead					
(intercept)	0.871	0.143	6.08	6.45e-09	yes
log(fines)	0.839	0.0277	30.3	2.71e-74	yes
area_idRFA	0.552	3.14	0.176	0.861	no
area_idRFB	-0.655	1.35	-0.484	0.629	no
area_idRFC	1.73	1.98	0.873	0.384	no
area_idRFD	5.05	8.72	0.579	0.563	no
log(Fines):area_idRFA	-0.0805	0.524	-0.154	0.878	no
log(Fines):area_idRFB	0.165	0.282	0.584	0.56	no
log(Fines):area_idRFC	-0.230	0.325	-0.709	0.479	no
log(Fines):area_idRFD	-0.865	1.47	-0.589	0.557	no

Table E-6
ANCOVA Coefficients for Fines-Bulk Analysis
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Term	Estimate	Standard Error	Statistic	p-Value	Statistically Significant
Mercury					
(intercept)	-0.601	0.158	-3.81	0.000190	yes
log(fines)	0.756	0.0549	13.8	2.94e-30	yes
area_idRFA	-1.24	0.247	-5.00	1.33e-06	yes
area_idRFB	0.829	1.09	0.761	0.448	no
area_idRFC	0.0473	0.693	0.0683	0.946	no
area_idRFD	-0.747	0.598	-1.25	0.213	no
log(Fines):area_idRFA	-0.796	0.172	-4.63	6.82e-06	yes
log(Fines):area_idRFB	0.260	0.329	0.791	0.430	no
log(Fines):area_idRFC	-0.145	0.370	-0.391	0.696	no
log(Fines):area_idRFD	-0.690	0.351	-1.97	0.0506	no
Molybdenum					
(intercept)	0.0942	0.0173	5.44	1.68e-07	yes
log(fines)	1.15	0.0293	39.2	2.10E-92	yes
area_idRFA	2.54	1.62	1.56	0.120	no
area_idRFB	-0.202	0.363	-0.556	0.579	no
area_idRFC	0.0650	0.0929	0.699	0.485	no
area_idRFD	-0.387	0.186	-2.08	0.0391	yes
log(Fines):area_idRFA	-1.44	0.877	-1.65	0.101	no
log(Fines):area_idRFB	-0.746	0.617	-1.21	0.228	no
log(Fines):area_idRFC	-0.703	0.432	-1.63	0.105	no
log(Fines):area_idRFD	-0.258	0.224	-1.15	0.250	no
Selenium					
(intercept)	-0.0767	0.0614	-1.25	0.213	no
log(fines)	0.868	0.0465	18.7	1.02e-44	yes
area_idRFA	0.236	0.211	1.12	0.264	no
area_idRFB	0.757	0.415	1.83	0.0695	no
area_idRFC	0.0726	0.386	0.188	0.851	no
area_idRFD	0.216	0.753	0.286	0.775	no
log(Fines):area_idRFA	-1.11	0.479	-2.31	0.0220	yes
log(Fines):area_idRFB	0.416	0.302	1.38	0.170	no
log(Fines):area_idRFC	-0.170	0.450	-0.378	0.706	no
log(Fines):area_idRFD	0.309	0.730	0.424	0.672	no
Thallium					
(intercept)	-0.339	0.0504	-6.74	1.92e-10	yes
log(fines)	0.796	0.0371	21.5	1.79e-52	yes
area_idRFA	0.454	0.529	0.857	0.392	no
area_idRFB	0.176	0.699	0.252	0.801	no
area_idRFC	-0.0682	0.463	-0.147	0.883	no
area_idRFD	-0.500	0.704	-0.710	0.478	no

Table E-6
ANCOVA Coefficients for Fines-Bulk Analysis
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Term	Estimate	Standard Error	Statistic	p-Value	Statistically Significant
Thallium (continued)					
log(Fines):area_idRFA	0.785	0.473	1.66	0.0984	no
log(Fines):area_idRFB	0.108	0.469	0.229	0.819	no
log(Fines):area_idRFC	-0.219	0.400	-0.549	0.584	no
log(Fines):area_idRFD	-0.418	0.646	-0.646	0.519	no
Vanadium					
(intercept)	-0.608	0.159	-3.81	0.000185	yes
log(fines)	1.17	0.0471	24.8	3.81e-61	yes
area_idRFA	2.46	2.28	1.08	0.282	no
area_idRFB	1.64	1.95	0.84	0.402	no
area_idRFC	1.18	2.89	0.407	0.684	no
area_idRFD	-1.61	16.1	-0.100	0.920	no
log(Fines):area_idRFA	-0.698	0.649	-1.07	0.284	no
log(Fines):area_idRFB	-0.451	0.568	-0.795	0.427	no
log(Fines):area_idRFC	-0.308	0.820	-0.375	0.708	no
log(Fines):area_idRFD	0.417	4.74	0.088	0.930	no
Zinc					
(intercept)	0.273	0.216	1.26	0.208	no
log(fines)	0.947	0.0383	24.7	6.67e-61	yes
area_idRFA	14.2	4.53	3.12	0.00207	yes
area_idRFB	-0.730	2.44	-0.299	0.765	no
area_idRFC	1.08	1.91	0.566	0.572	no
area_idRFD	-4.00	1.93	-2.07	0.0402	yes
log(Fines):area_idRFA	-1.69	0.601	-2.81	0.00542	yes
log(Fines):area_idRFB	0.170	0.467	0.364	0.716	no
log(Fines):area_idRFC	-0.150	0.326	-0.459	0.647	no
log(Fines):area_idRFD	0.599	0.283	2.12	0.0357	yes

Notes:
Statistical significance based on p-value < 0.05.
ANCOVA = analysis of covariance

Table E-7
Correction Factors for Fines-Bulk Analysis
Upper Columbia River
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Appendix E

Analyte	Intercept	Slope	Slope Standard Error	Slope 95% CI Lower Bound	Slope 95% CI Upper Bound	Intercept 95% CI Lower Bound	Intercept 95% CI Upper Bound	p-Value	R^2	Slope = 1	Intercept = 0	Correction Factor Applied
Aluminum	-0.0534	0.995	0.0442	0.907	1.08	-0.894	0.787	< 0.001	0.73	yes	yes	no
Barium	-0.554	1.10	0.0312	1.04	1.16	-0.900	-0.208	< 0.001	0.87	no	no	yes
Cadmium	0.424	0.795	0.0287	0.739	0.852	0.337	0.511	< 0.001	0.80	no	no	yes
Chromium	-0.369	1.11	0.0368	1.04	1.18	-0.588	-0.151	< 0.001	0.83	no	no	yes
Copper	0.212	0.924	0.0337	0.857	0.990	0.00344	0.421	< 0.001	0.80	no	no	yes
Iron	-2.90	1.29	0.0589	1.18	1.41	-4.03	-1.76	< 0.001	0.72	no	no	yes
Lead	0.762	0.863	0.0270	0.810	0.917	0.485	1.04	< 0.001	0.85	no	no	yes
Mercury	-0.442	0.808	0.0466	0.716	0.900	-0.704	-0.180	< 0.001	0.62	no	no	yes
Molybdenum	0.105	1.14	0.0299	1.08	1.20	0.0703	0.139	< 0.001	0.89	no	no	yes
Selenium	-0.0333	0.891	0.0461	0.800	0.982	-0.152	0.0855	< 0.001	0.67	no	yes	yes
Thallium	-0.320	0.805	0.0373	0.731	0.878	-0.420	-0.220	< 0.001	0.71	no	no	yes
Vanadium	-0.630	1.18	0.0474	1.08	1.27	-0.947	-0.313	< 0.001	0.77	no	no	yes
Zinc	0.278	0.948	0.0382	0.873	1.02	-0.146	0.703	< 0.001	0.77	yes	yes	no

Note:
CI = confidence interval

Table E-8
Identification of Non-Larval Aerial Insect Data Points from Terrestrial Arthropod Data in USACHPPM (2004) Database
Upper Columbia River
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Appendix E

Taxa Information as Provided in USACHPPM (2004) Database				Number of Data Points in Database	Included in Aerial Insect Data Set?	Notes
Order	Family	Species	Common Name			
Arachnida						
Araneae	nd	*Alopecosa cuneata*	wolf spider	4	no	NA
Araneae	nd	*Alopecosa trabalis*	wolf spider	16	no	NA
Araneae	nd	*Amaurobius obustus*	wolf spider	4	no	NA
Araneae	nd	*Gonatium rubidium*	lace-webbed spider	4	no	NA
Araneae	nd	*Hahnia ononidum*	dwarf spider	8	no	NA
Araneae	nd	*Harpactea lepida*	dwarf sheet spider	4	no	NA
Araneae	nd	*Histopona torpida*	woodhouse hunting spiders	4	no	NA
Araneae	nd	*Lycosa* sp.	funnel weaver spider	1	no	NA
Araneae	nd	*Macrargus rufus*	wolf spider	8	no	NA
Araneae	nd	*Micaria fulgens*	dwarf spider	8	no	NA
Araneae	nd	*Pardosa alacris*	ground spider	4	no	NA
Araneae	nd	*Pardosa luubris s. Str.*	wolf spider	4	no	NA
Araneae	nd	*Phrurolithus festivis*	wolf spider	4	no	NA
Araneae	nd	spider	araneomorph spider	169	no	NA
Araneae	nd	spider	spider	4	no	NA
Araneae	nd	*Xerolycosa nemoralis*	spider	4	no	NA
Araneae	nd	*Zelotes apricorum*	burnt wolf spider	4	no	NA
Araneae	nd	*Zelotes electus*	ground spider	4	no	NA
Araneae	nd	*Zodarion rubidum*	ground spider	4	no	NA
Opiliones	Opilionidae	*Lacinius ephippiatus*	ant-eating spider	4	no	NA
Opiliones	Opilionidae	*Lophopilio palpinalis*	harvestmen spider	8	no	NA
Opiliones	Opilionidae	*Nelima semproni*	harvestmen spider	4	no	NA
Opiliones	Opilionidae	*Oliolophus tridens*	harvestmen spider	8	no	NA
Opiliones	Opilionidae	*Paranemastoma 4-punctatum*	harvestmen spider	8	no	NA
Opiliones	Opilionidae	*Phalangium opilio*	harvestmen spider	4	no	NA
Araneae	nd	spider	harvestmen spider	40	no	NA
Chilopoda						
nd	nd	centipede	centipede	4	no	NA
nd	nd	*chilopoda - E. grossipes*	centipede	4	no	NA
nd	nd	*chilopoda - L. forficatus*	centipede	8	no	NA
nd	nd	*chilopoda - L. tricuspis*	centipede	4	no	NA

Table E-8
Identification of Non-Larval Aerial Insect Data Points from Terrestrial Arthropod Data in USACHPPM (2004) Database
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Taxa Information as Provided in USACHPPM (2004) Database				Number of Data Points in Database	Included in Aerial Insect Data Set?	Notes
Order	Family	Species	Common Name			
Diplopoda						
nd	Polydesmida	nd	centipede	8	no	NA
nd	nd	*diplopoda-M. mutabilis*	millipede	8	no	NA
nd	nd	*diplopoda-O. pusilla*	millipede	12	no	NA
nd	nd	*diplopoda-P. complanatus*	millipede	4	no	NA
nd	nd	*millepede-1*	millipede	4	no	NA
nd	nd	*millepede-2*	millipede	4	no	NA
nd	nd	*millepede-3*	millipede	4	no	NA
nd	nd	*millipedes*	millipede	3	no	NA
Insecta						
nd	nd	nd	millipede	144	no	Unidentified insect class, excluded from flying
nd	nd	beetles and termite larva	insect	1	no	NA
nd	nd	chewing insects	beetle and termite larva	4	no	Unidentified insect class, excluded from flying
nd	nd	herbivore arthropods	chewing insect	8	no	Unidentified insect class, excluded from flying
nd	nd	litter-grazer	herbivore arthropod	48	no	Unidentified insect class, excluded from flying
nd	nd	non-spider	litter grazer	48	no	Unidentified insect class, excluded from flying
nd	nd	omnivore arthropods	non-spider	8	no	Unidentified insect class, excluded from flying
nd	nd	predatory arthropds	omnivore arthropod	8	no	Unidentified insect class, excluded from flying
nd	nd	predatory insects	predatory arthropod	4	no	Unidentified insect class, excluded from flying
nd	nd	sucking insects	predatory insect	4	no	Unidentified insect class, excluded from flying
Coleoptera	nd	*Amphimallon solstitiale*	sucking insect	1	yes	NA
Coleoptera	nd	beetle	european june beetle	115	yes	NA
Coleoptera	nd	beetle	beetle	45	yes	NA
Coleoptera	nd	carnivore arthropods	beetle	6	yes	NA
Coleoptera	nd	*Geotrupes stercorarious*	carnivore arthropod	1	yes	NA
Coleoptera	nd	herbivore arthropods	earth-boring dung beetle	6	yes	NA
Coleoptera	nd	*Lagrea hirta*	herbivore arthropod	1	yes	NA
Coleoptera	nd	*Phyllobius arborator*	beetle	1	yes	NA
Coleoptera	nd	*Phyllobius sinuatus*	broad-nosed weevil	1	yes	NA

Table E-8
Identification of Non-Larval Aerial Insect Data Points from Terrestrial Arthropod Data in USACHPPM (2004) Database
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Taxa Information as Provided in USACHPPM (2004) Database				Number of Data Points in Database	Included in Aerial Insect Data Set?	Notes
Order	Family	Species	Common Name			
Insecta (continued)						
Coleoptera	nd	*Psylliodes chrysocephala*	weevil	1	yes	NA
Coleoptera	nd	*Pterostichus oblongopuntatus*	leaf beetle	1	yes	NA
Coleoptera	nd	*Rhagium sycophanta (larvae)*	ground beetle	1	no	NA
Coleoptera	nd	*Rhagium sycophanta (pupae)*	longhorn beetle larvae	1	no	NA
Coleoptera	nd	*Strangalia maculata*	longhorn beetle pupae	1	yes	NA
Coleoptera	carabidae	*Molops piceus*	longhorn beetle	1	no	This family is generally unable or reluctant to fly
Coleoptera	Carabidae	*Abax parallelepipedus*	ground beetle	1	no	This family is generally unable or reluctant to fly
Coleoptera	Carabidae	*carabidae*	ground beetle	4	no	This family is generally unable or reluctant to fly
Coleoptera	Carabidae	*carabidae-A. lunicollis*	ground beetle	4	no	This family is generally unable or reluctant to fly
Coleoptera	Carabidae	*carabidae-C. erratus*	ground beetle	4	no	This family is generally unable or reluctant to fly
Coleoptera	Carabidae	*carabidae-C. hortensis*	ground beetle	8	no	This family is generally unable or reluctant to fly
Coleoptera	Carabidae	*carabidae-H. rufipes*	ground beetle	4	no	This family is generally unable or reluctant to fly
Coleoptera	Carabidae	*carabidae-P. metallicus*	ground beetle	4	no	This family is generally unable or reluctant to fly
Coleoptera	Carabidae	*carabidae-P. oblongopunctatus*	ground beetle	8	no	This family is generally unable or reluctant to fly
Coleoptera	Carabidae	*carabidae-P. versicolor*	ground beetle	8	no	This family is generally unable or reluctant to fly
Coleoptera	Carabidae	*carabidae ad*	ground beetle	3	no	This family is generally unable or reluctant to fly
Coleoptera	Carabidae	*Carabus coriaceus*	ground beetle	1	no	This family is generally unable or reluctant to fly
Coleoptera	Cerambycidae	*A villosoviridescens*	ground beetle	6	yes	NA
Coleoptera	Coccinelidae	*C septempunctata*	longhorn beetle	32	yes	NA
Coleoptera	Coccinellidae	*Calvia decemguttata*	ladybug	1	yes	NA
Coleoptera	Curculionidae	*curculionidae-H. abietus*	beetle	4	no	Adults can fly, but is a rarity for this order; assumed not flying
Coleoptera	Curculionidae	*curculionidae-O. crategi*	true weevil	4	no	Adults cannot fly
Coleoptera	Curculionidae	*curculionidae-O. ovatus*	true weevil	8	no	Adults cannot fly
Coleoptera	Curculionidae	*curculionidae-O. raucus*	true weevil	4	no	Adults cannot fly
Coleoptera	Curculionidae	*Neochetina eichhornae*	true weevil	18	no	Adults cannot fly
Coleoptera	Curculionidae	*Neochetina eichhorniae*	true weevil	9	no	Adults cannot fly
Coleoptera	Scolytidae	bark beetle larvae	true weevil	8	no	NA
Coleoptera	silphidae	*Necrophorus vespilloides*	bark beetle larvae	1	yes	NA
Coleoptera	Staphylinidae	*staphylinid ad*	burying beetle	3	yes	NA
Coleoptera	Staphylinidae	*staphylinidae-G. circellaris*	rove beetle	4	yes	NA
Coleoptera	Staphylinidae	*staphylinidae-P. fossor*	rove beetle	12	yes	NA

Table E-8
Identification of Non-Larval Aerial Insect Data Points from Terrestrial Arthropod Data in USACHPPM (2004) Database
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Taxa Information as Provided in USACHPPM (2004) Database				Number of Data Points in Database	Included in Aerial Insect Data Set?	Notes
Order	Family	Species	Common Name			
Insecta (continued)						
Coleoptera	Staphylinidae	*staphylinidae-Q. fuliginosus*	rove beetle	8	yes	NA
Coleoptera	Staphylinidae	*staphylinidae-X. linearis*	rove beetle	4	yes	NA
Coleoptera	Staphylinidae	*staphylinidae-Z. humeralis*	rove beetle	4	yes	NA
Coleoptera	Sylphidae	*carrion beetles*	rove beetle	8	yes	NA
Collembola	nd	*Orchesella cincta*	carrion beetle	22	no	NA
Diptera	nd	*diptera*	springtail	6	yes	NA
Diptera	Calliphoridae	*dip. Calliphoridae*	true flies	4	yes	NA
Diptera	Sarcophagidae	*dip. Sarcophagidae*	bow flies	4	yes	NA
Diptera	Syrphidae	*Syrphidae*	fresh fly	1	yes	NA
Hemiptera	nd	*Acanthosoma haemorrhoidale*	hoverfly	1	yes	NA
Hemiptera	Pentatomidae	*Pentatoma rufipes*	hawthorn shield bug	1	yes	NA
Homoptera	Aphididae	*Aphididae*	forest bug	1	yes	NA
Homoptera	Aphididae	*Aphis fabae*	aphid	6	yes	NA
Hymenoptera	Diprionidae	*D. pini (adult)*	black bean aphid	3	yes	NA
Hymenoptera	Diprionidae	*Diprion pini (larvae)*	sawflies	3	no	NA
Hymenoptera	Diprionidae	*Dolerus nigratus (larvae)*	sawflies larvae	3	no	NA
Hymenoptera	formicidae	*Araschnia levana (larvae)*	sawflies larvae	1	no	NA
Hymenoptera	formicidae	*Myrmicinae*	map butterfly larvae	1	no	Some adults do fly, but expected to be insignificant portion of diets for aerial insectivores
Hymenoptera	Formicidae	*Camponitus ligniperda*	ants	12	no	Some adults do fly, but expected to be insignificant portion of diets for aerial insectivores
Hymenoptera	Formicidae	*Camponitus vagus*	biting ant	4	no	Some adults do fly, but expected to be insignificant portion of diets for aerial insectivores
Hymenoptera	Formicidae	*Formica fusca*	carpenter ant	5	no	Some adults do fly, but expected to be insignificant portion of diets for aerial insectivores
Hymenoptera	Formicidae	*Formica rufa*	wood ant	1	no	Some adults do fly, but expected to be insignificant portion of diets for aerial insectivores
Hymenoptera	Formicidae	*Formica sanguinea*	wood ant	1	no	Some adults do fly, but expected to be insignificant portion of diets for aerial insectivores
Hymenoptera	Formicidae	*Lasius platythorax*	wood ant	12	no	Some adults do fly, but expected to be insignificant portion of diets for aerial insectivores
Hymenoptera	Formicidae	*Leptohorax acervorum*	formicine ant	4	no	Some adults do fly, but expected to be insignificant portion of diets for aerial insectivores
Hymenoptera	Formicidae	*Myrmica sabuleti*	ant	24	no	Some adults do fly, but expected to be insignificant portion of diets for aerial insectivores

Table E-8
Identification of Non-Larval Aerial Insect Data Points from Terrestrial Arthropod Data in USACHPPM (2004) Database
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Taxa Information as Provided in USACHPPM (2004) Database				Number of Data Points in Database	Included in Aerial Insect Data Set?	Notes
Order	Family	Species	Common Name			
Insecta (continued)						
Hymenoptera	Formicidae	*Tapinoma ambigumm*	ant	4	no	Some adults do fly, but expected to be insignificant portion of diets for aerial insectivores
Hymenoptera	Formicidae	*Tetramorium caespitum*	ant	4	no	Some adults do fly, but expected to be insignificant portion of diets for aerial insectivores
Hymenoptera	Tenthedinidae	*D. nigratus (adult)*	ant	3	yes	NA
Hymenoptera	Tenthedinidae	*E. baltica (adult)*	sawflies	3	yes	NA
Hymenoptera	Tenthedinidae	*Empria baltica (larvae)*	sawflies	3	no	NA
Hymenoptera	Vespidae	hornets	sawflies larvae	4	yes	NA
Lepidoptera	nd	catapillar	hornet	161	no	NA
Lepidoptera	nd	*Eilema deplana*	caterpillar	1	yes	NA
Lepidoptera	nd	*Eilema lurideiola*	scarce footman moth	1	yes	NA
Lepidoptera	nd	*Scotia exlamationis*	common footman moth	1	yes	NA
Lepidoptera	Arctiidae	*Halisidota and spilosoma*	heart and dart moth	4	yes	NA
Lepidoptera	Arctiidae	*lep. H. tessellaris*	moth	4	yes	NA
Lepidoptera	Lasiocampidae	*lep. M. americanum*	moth	4	yes	NA
Lepidoptera	Limacodidae	*Apoda limacodes*	lappet moth	1	yes	NA
Lepidoptera	Lymantriidae	*lep. P. dispar*	cup moth	7	yes	NA
Lepidoptera	Lymantriidae	*lep. P. dispar*	tussock moth	1	yes	NA
Lepidoptera	Noctuidae	*lep. A. pyramidoides*	tussock moth	8	yes	NA
Lepidoptera	Noctuidae	*lep. C. paleogama*	owlet moth	8	yes	NA
Lepidoptera	Noctuidae	*lep. L. unipuncta*	owlet moth	8	yes	NA
Lepidoptera	Noctuidae	*lep. N. c-nigrum*	owlet moth	8	yes	NA
Lepidoptera	Noctuidae	*lep. P. excaecatus*	owlet moth	4	yes	NA
Lepidoptera	Nymphalidae	*A. urticae (adult)*	owlet moth	3	yes	NA
Lepidoptera	Nymphalidae	*Tortrix viridana (larvae)*	true butterfly	3	no	NA
Lepidoptera	Tortricidae	*Aglais urticae (larvae)*	true butterfly larvae	3	no	NA
Lepidoptera	Tortricidae	*T. viridana (adult)*	tortix moth larvae	3	yes	NA
Neuroptera	Chrysopidae	*Chrysopidae*	tortix moth	1	yes	NA
Orthoptera	Acrididae	*Aiolopus thalassinus*	green lacewings	26	yes	NA
Orthoptera	Acrididae	*Chorthippus brunneus*	grasshopper	12	yes	NA
Orthoptera	Acrididae	*Eyprepocnemis plorans*	grasshopper	28	yes	NA
Orthoptera	Acrididae	grasshopper	grasshopper	239	yes	NA

Table E-8
Identification of Non-Larval Aerial Insect Data Points from Terrestrial Arthropod Data in USACHPPM (2004) Database
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Taxa Information as Provided in USACHPPM (2004) Database				Number of Data Points in Database	Included in Aerial Insect Data Set?	Notes
Order	Family	Species	Common Name			
Insecta (continued)						
Orthoptera	Acrididae	grasshopper	grasshopper	40	yes	NA
Orthoptera	Acrididae	grasshopper	grasshopper	8	yes	NA
Orthoptera	Acrididae	grasshopper	grasshopper	17	yes	NA
Orthoptera	Acrididae	*Orthoptera-C. montanus*	grasshopper	4	no	NA
Orthoptera	Blattodidae	*Blattodea-E. sylvestris*	grasshopper	4	no	NA
Orthoptera	Gryllidae	*Acheta domesticus*	cockroach	6	yes	NA
Orthoptera	Gryllidae	*P. fasciatus*	true cricket	1	yes	NA
Isopoda						
nd	nd	*isopoda-P. scaber*	true cricket	4	no	NA
nd	nd	*isopoda-T. rathkei*	rough woodlouse	4	no	NA
nd	nd	*isopoda-T. ratzeburgi*	woodlouse	12	no	NA
nd	nd	isopods	woodlouse	7	no	NA
nd	nd	*O. asellus, P. scaber*	isopods	1	no	NA
nd	nd	*P. pictus, P. scaber, T. rathkei*	woodlouse	2	no	NA
nd	nd	*P. scaber*	woodlouse	8	no	NA
nd	nd	*P. scaber, P. picuts*	woodlouse	1	no	NA
nd	nd	*Porcellio larvis*	woodlouse	5	no	NA
nd	nd	*Porcellio scaber*	woodlouse	10	no	NA
nd	nd	*Tracheoniscus rathkei*	woodlouse	1	no	NA
nd	nd	*Tracheoniscus rathkei, P. pictus*	woodlouse	2	no	NA

Notes:
NA = not applicable
nd = no data populated in database cell
UCACHPPM = United States Army Center for Health Promotion and Preventive Medicine

Table E-9
Study Assignment for Single-Split Validation
Upper Columbia River
Final Aquatic Baseline Ecological Risk Assessment
Appendix E

Analyte	Studies Assigned to the Training Data Set [a]	Studies Assigned to the Validation Data Set [a]	Number of Data Points in Training Data Set	Number of Data Points in Validation Data Set
Terrestrial Arthropods				
Aluminum	PTI (1995)	NA	24	NA
Barium	PTI (1995)	Hope et al. (1996); Ramirez and Rogers (2000)	30	3
Cadmium	Beyer et al. (1985); Carter (1983); Hemminga et al. (1989); Hunter and Johnson (1982); Knutti et al. (1988); Pascoe et al. (1996); Posthuma (1990); PTI (1995); Rabitsch (1995a); Rabitsch (1995c); Ramirez and Rogers (2000); Van Hook and Yates (1975); Watson et al. (1976)	Dmowski and Karolewski (1979); Rabitsch (1995b); PTI (1994)	248	51
Chromium	PTI (1995)	Beyer et al. (1990)	30	5
Copper	Beyer et al. (1985); Beyer et al. (1990); Carter (1983); Hemminga et al. (1989); Hunter and Johnson (1982); Pascoe et al. (1996); PTI (1995); Rabitsch (1995a); Rabitsch (1995c); Ramirez and Rogers (2000); Watson et al. (1976); Wieser et al. (1976); Wieser et al. (1977)	Rabitsch (1995b); PTI (1994)	232	42
Iron	PTI (1995)	NA	30	NA
Lead	Andrews et al. (1989a); Beyer et al. (1985); Beyer et al. (1990); Price et al. (1974); PTI (1995); Rabitsch (1995a); Rabitsch (1995c); Watson et al. (1976)	Dmowski and Karolewski (1979); Rabitsch (1995b); PTI (1994)	218	50
Mercury	PTI (1995)	NA	30	NA
Selenium	PTI (1995)	Beyer et al. (1990); Ramirez and Rogers (2000)	19	3
Thallium	PTI (1995)	NA	14	NA
Vanadium	PTI (1995)	Ramirez and Rogers (2000)	18	1
Zinc	Andrews et al. (1989b); Beyer et al. (1985); Beyer et al. (1990); Carter (1983); Pascoe et al. (1996); Posthuma (1990); PTI (1995); Rabitsch (1995a); Rabitsch (1995c); Ramirez and Rogers (2000); Watson et al. (1976)	Dmowski and Karolewski (1979); Rabitsch (1995b); PTI (1994)	210	48

Table E-9
Study Assignment for Single-Split Validation
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Analyte	Studies Assigned to the Training Data Set [a]	Studies Assigned to the Validation Data Set [a]	Number of Data Points in Training Data Set	Number of Data Points in Validation Data Set
Flying Insects				
Aluminum	PTI (1995)	NA	17	NA
Barium	PTI (1995)	Ramirez and Rogers (2000)	17	2
Cadmium	Beyer et al. (1985); Carter (1983); Knutti et al. (1988); Pascoe et al. (1996); PTI (1995); Van Hook and Yates (1975); PTI (1994)	Hemminga et al. (1989); Hunter and Johnson (1982); Rabitsch (1995a); Ramirez and Rogers (2000)	75	19
Chromium	PTI (1995)	Beyer et al. (1990)	17	4
Copper	Beyer et al. (1985); Beyer et al. (1990); Carter (1983); Pascoe et al. (1996); PTI (1995); PTI (1994)	Hemminga et al. (1989); Hunter and Johnson (1982); Rabitsch (1995a); Ramirez and Rogers (2000)	59	19
Iron	PTI (1995)	NA	17	NA
Lead	Andrews et al. (1989a); Beyer et al. (1985); Beyer et al. (1990); PTI (1995); PTI (1994)	Rabitsch (1995a)	56	8
Mercury	PTI (1995)	NA	17	NA
Selenium	PTI (1995)	Beyer et al. (1990); Ramirez and Rogers (2000)	11	3
Thallium	PTI (1995)	NA	4	NA
Vanadium	PTI (1995)	Ramirez and Rogers (2000)	5	1
Zinc	Andrews et al. (1989b); Beyer et al. (1985); Beyer et al. (1990); Carter (1983); Pascoe et al. (1996); PTI (1995); PTI (1994)	Rabitsch (1995a); Ramirez and Rogers (2000)	50	10

Notes:
[a] Studies as cited in USACHPPM (2004).
NA = not applicable
USACHPPM = United States Army Center for Health Promotion and Preventive Medicine

Table E-10
Results for Terrestrial Arthropod and Aerial Insect Bioaccumulation Modeling
Upper Columbia River
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Analyte	Number of Studies	Number of Data Points	Regression Models [a]					BAF							Final Model Selection
			Intercept	Slope	R^2	p-Value	Acceptable Regression Model? [b]	Distribution [c]	Mean	Standard Deviation	Minimum	Median	90th Percentile	Maximum	
Terrestrial Arthropods															
Aluminum	1	24	-33.5	3.88	0.203	0.0272	yes	lognormal	0.00499	0.00696	0.000749	0.00266	0.00988	0.0271	regression
Barium	3	33	1.52	0.0375	0.00017	0.943	no	neither	0.0558	0.0599	0.0126	0.0315	0.130	0.302	median BAF
Cadmium	16	299	0.506	0.588	0.512	3.10E-48	yes	neither	3.03	7.95	0.0206	0.723	7.60	92.7	regression
Chromium	2	35	1.38	-0.112	0.00513	0.683	no	lognormal	0.149	0.191	0.0100	0.0643	0.492	0.741	median BAF
Copper	15	274	3.33	0.192	0.0722	6.44E-06	no	lognormal	3.220	7.50	0.00495	0.942	8.23	78.6	median BAF
Iron	1	30	9.09	-0.390	0.0100	0.599	no	lognormal	0.0134	0.0198	0.00165	0.00612	0.0278	0.102	median BAF
Lead	11	268	-1.49	0.799	0.460	1.78E-37	yes	neither	0.294	0.676	0.000314	0.0672	0.627	5.54	regression
Mercury	1	30	-3.08	-0.149	0.106	0.0787	no	neither	1.18	1.59	0.0581	0.729	2.02	6.67	median BAF
Selenium	3	22	0.270	0.145	0.0488	0.323	no	normal	1.94	1.61	0.0183	1.61	4.11	6.06	median BAF
Thallium	1	14	-0.265	3.34	0.118	0.230	no	neither	0.0885	0.0741	0.0513	0.0556	0.213	0.263	median BAF
Vanadium	2	19	0.195	-0.392	0.0319	0.465	no	lognormal	0.0116	0.00883	0.00345	0.00977	0.0217	0.0358	median BAF
Zinc	14	258	5.38	0.0997	0.0534	0.000181	no	lognormal	4.04	9.49	0.0103	0.827	10.5	74.1	median BAF
Aerial Insects															
Aluminum	1	17	-30.3	3.53	0.180	0.0899	no	lognormal	0.00413	0.00607	0.000749	0.00197	0.00832	0.0255	median BAF
Barium	3	19	-0.480	0.386	0.0224	0.541	no	neither	0.0402	0.0386	0.0126	0.0238	0.101	0.156	median BAF
Cadmium	16	94	-0.311	0.601	0.600	5.35E-20	yes	lognormal	1.60	4.43	0.0206	0.522	2.68	37.1	regression
Chromium	2	21	0.360	0.0951	0.00622	0.734	no	lognormal	0.0912	0.123	0.0100	0.0561	0.144	0.600	median BAF
Copper	15	78	1.52	0.469	0.573	1.11E-15	yes	lognormal	0.841	0.972	0.0492	0.485	1.95	5.07	regression
Iron	1	17	1.97	0.273	0.0113	0.685	no	lognormal	0.00621	0.00602	0.00165	0.00444	0.00998	0.0270	median BAF
Lead	11	64	-2.28	0.687	0.345	3.38E-07	yes	lognormal	0.0581	0.0957	0.000675	0.0238	0.147	0.585	regression
Mercury	1	17	-3.05	-0.0629	0.118	0.177	no	neither	0.764	0.618	0.0581	0.556	1.76	2.00	median BAF
Selenium	3	14	0.112	0.0996	0.0204	0.627	no	normal	1.53	1.34	0.0183	1.39	3.55	4.15	median BAF
Thallium	1	4	-3.91	0	NA	NA	no	lognormal	0.0554	0.00376	0.0526	0.0541	0.0591	0.0606	median BAF
Vanadium	2	6	0.874	-0.559	0.112	0.516	no	lognormal	0.0117	0.00953	0.00345	0.00813	0.0230	0.0279	median BAF
Zinc	14	60	3.98	0.234	0.412	3.28E-08	yes	lognormal	0.756	0.857	0.0123	0.368	1.68	3.52	regression

Notes:
Bolded values represent the selected model parameters.
[a] Regression model equation is $\ln(C_{biota}) = slope * \ln(C_{soil}) + intercept$.
[b] Regression model acceptability criteria: $p < 0.05$, $R^2 > 0.2$, positive slope, and number of data points > 10.
[c] Normality testing was conducted on calculated bioaccumulation factors (BAFs) for both normal and lognormal distributions.
NA = not applicable; all flying insect concentrations were the same, so no values could be calculated for R^2 and p-value

Table E-11
Results for Terrestrial Plants Bioaccumulation Modeling
Upper Columbia River
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Analyte	Number of Data Points	Regression Models [a]					BAF							Final Model Selection
		Intercept	Slope	R^2	p-Value	Acceptable Regression Model? [b]	Distribution [c]	Mean	Standard Deviation	Minimum	Median	90th Percentile	Maximum	
Aboveground Plant Parts														
Aluminum	99	13.2	-1.12	0.119	0.000461	no	lognormal	0.00304	0.00825	0.0000170	0.000948	0.00527	0.0760	median BAF
Barium	112	-1.05	0.718	0.0305	0.0654	no	neither	0.153	0.145	0.000492	0.124	0.352	0.677	median BAF
Cadmium	111	-3.75	0.577	0.0704	0.00490	no	neither	0.0254	0.0388	0.000144	0.0128	0.0597	0.222	median BAF
Chromium	109	1.13	-0.606	0.0308	0.0678	no	neither	0.119	0.198	0.000927	0.0203	0.417	1.02	median BAF
Copper	112	1.29	0.101	0.00351	0.535	no	neither	0.279	0.910	0.0131	0.110	0.427	9.53	median BAF
Iron	112	9.48	-0.601	0.101	0.000658	no	neither	0.00364	0.00663	0.000282	0.00171	0.00665	0.0585	median BAF
Lead	105	-1.93	0.0589	0.00138	0.707	no	neither	0.00388	0.0105	5.57E-06	0.000984	0.00939	0.0949	median BAF
Mercury	49	-6.01	-0.206	0.0351	0.197	no	neither	0.171	0.273	0.0108	0.0694	0.506	1.09	median BAF
Molybdenum	10	-1.42	2.10	0.828	0.000260	no	lognormal	1.75	1.81	0.0826	1.25	3.51	5.56	median BAF
Selenium	32	-2.47	-0.366	0.140	0.0346	no	lognormal	0.130	0.154	0.00779	0.0917	0.234	0.645	median BAF
Thallium	25	-4.70	0.0952	0.0353	0.369	no	lognormal	0.231	0.480	0.00522	0.0475	0.719	2.09	median BAF
Vanadium	73	0.937	-1.08	0.337	7.26E-08	no	neither	0.00380	0.00944	0.000334	0.00154	0.00783	0.0755	median BAF
Zinc	112	2.83	0.0695	0.00162	0.674	no	lognormal	0.141	0.175	0.00293	0.0637	0.422	0.710	median BAF
Belowground Plant Parts														
Aluminum	36	1.79	0.446	0.0243	0.364	no	lognormal	0.0435	0.0384	0.00248	0.0327	0.0970	0.176	median BAF
Barium	36	-0.457	0.801	0.0417	0.232	no	neither	0.321	0.267	0.0138	0.261	0.780	0.949	median BAF
Cadmium	36	2.30	-0.208	0.0174	0.444	no	lognormal	0.670	0.648	0.0399	0.491	1.31	3.27	median BAF
Chromium	36	-7.50	2.28	0.369	8.62E-05	yes	lognormal	0.0730	0.0927	0.00580	0.0272	0.181	0.378	regression
Copper	36	1.59	0.0942	0.00933	0.575	no	lognormal	0.154	0.0975	0.0186	0.123	0.291	0.371	median BAF
Iron	36	-2.21	0.819	0.0588	0.154	no	lognormal	0.0264	0.0231	0.00194	0.0208	0.0479	0.103	median BAF
Lead	36	-0.551	0.646	0.191	0.00767	no	neither	0.0934	0.0656	0.00600	0.0895	0.174	0.307	median BAF
Molybdenum	8	-0.892	2.33	0.787	0.00331	no	lognormal	10.4	18.3	0.111	1.70	31.7	51.4	median BAF
Selenium	27	-2.56	0.629	0.0633	0.206	no	neither	0.122	0.126	0.0293	0.0714	0.350	0.476	median BAF
Thallium	34	-2.05	-0.0372	0.00586	0.667	no	lognormal	0.327	0.307	0.0359	0.278	0.586	1.51	median BAF
Vanadium	36	-9.65	2.46	0.352	0.000138	yes	lognormal	0.0320	0.0393	0.00171	0.0187	0.0757	0.169	regression
Zinc	36	4.60	0.134	0.0113	0.537	no	lognormal	0.635	0.564	0.0542	0.479	1.20	2.61	median BAF

Notes:
Bolded values represent the selected model parameters.
[a] Regression model equation is $\ln(C_{biota}) = slope * \ln(C_{soil}) + intercept$.
[b] Regression model acceptability criteria: $p < 0.05$, $R^2 > 0.2$, positive slope, and number of data points > 10.
[c] Normality testing was conducted on calculated bioaccumulation factors (BAFs) for both normal and lognormal distributions.

Table E-12
Bioaccumulation Models Used in the Aquatic BERA
Upper Columbia River
Final Aquatic Baseline Ecological Risk Assessment
Appendix E

COPC	Model Type	Model Equation [a]	Variable A	Variable B	Model Source	Regression Model R^2	Notes
Aquatic Plants							
Aluminum	regression	$\log10(C_{tissue}) = A * \log10(C_{sed}) + B$	0.9	-0.08	Jackson et al. (1991)	0.75	regression on averages for 39 elements
Arsenic	regression	$\log10(C_{tissue}) = A * \log10(C_{sed}) + B$	0.9	-0.08	Jackson et al. (1991)	0.75	regression on averages for 39 elements
Barium	regression	$\log10(C_{tissue}) = A * \log10(C_{sed}) + B$	0.9	-0.08	Jackson et al. (1991)	0.75	regression on averages for 39 elements
Cadmium	regression	$\log10(C_{tissue}) = A * \log10(C_{sed}) + B$	0.9	-0.08	Jackson et al. (1991)	0.75	regression on averages for 39 elements
Chromium	regression	$\log10(C_{tissue}) = A * \log10(C_{sed}) + B$	0.9	-0.08	Jackson et al. (1991)	0.75	regression on averages for 39 elements
Copper	regression	$\log10(C_{tissue}) = A * \log10(C_{sed}) + B$	0.9	-0.08	Jackson et al. (1991)	0.75	regression on averages for 39 elements
Lead	regression	$\log10(C_{tissue}) = A * \log10(C_{sed}) + B$	0.9	-0.08	Jackson et al. (1991)	0.75	regression on averages for 39 elements
Iron	regression	$\log10(C_{tissue}) = A * \log10(C_{sed}) + B$	0.9	-0.08	Jackson et al. (1991)	0.75	regression on averages for 39 elements
Manganese	regression	$\log10(C_{tissue}) = A * \log10(C_{sed}) + B$	0.9	-0.08	Jackson et al. (1991)	0.75	regression on averages for 39 elements
Mercury	regression	$\log10(C_{tissue}) = A * \log10(C_{sed}) + B$	0.9	-0.08	Jackson et al. (1991)	0.75	regression on averages for 39 elements
Molybdenum	regression	$\log10(C_{tissue}) = A * \log10(C_{sed}) + B$	0.9	-0.08	Jackson et al. (1991)	0.75	regression on averages for 39 elements
Nickel	regression	$\log10(C_{tissue}) = A * \log10(C_{sed}) + B$	0.9	-0.08	Jackson et al. (1991)	0.75	regression on averages for 39 elements
Selenium	regression	$\log10(C_{tissue}) = A * \log10(C_{sed}) + B$	0.9	-0.08	Jackson et al. (1991)	0.75	regression on averages for 39 elements
Vanadium	regression	$\log10(C_{tissue}) = A * \log10(C_{sed}) + B$	0.9	-0.08	Jackson et al. (1991)	0.75	regression on averages for 39 elements
Zinc	regression	$\log10(C_{tissue}) = A * \log10(C_{sed}) + B$	0.9	-0.08	Jackson et al. (1991)	0.75	regression on averages for 39 elements
Bis(2-ethylhexyl)phthalate	OC-normalized BAF	$C_{tissue}/f_{lipid} = A * C_{sed}/f_{OC}$	1	NA	USACE (2019)	NA	median of reported BSAFs (3 values reported, all for fish) from Teil et al. (2012)
Total PCB congeners [b]	OC-normalized BAF	$C_{tissue}/f_{lipid} = A * C_{sed}/f_{OC}$	3.74	NA	Vanier et al. (2001)	NA	lipid/OC-normalized BSAF based on data from one lake in Ontario, Canada
PCB TEQs, dioxin/furan TEQs, total TEQs	BAF	$C_{tissue} = A * C_{sed}$	0.0011	NA	USEPA (1999b)	NA	median of recommended BSAFs for all dioxins/furans, based on equation using octanol-water partition coefficients
Small Aquatic Invertebrates [c]							
Aluminum	regression	$\ln(C_{tissue}) = A * \ln(C_{sediment}) + B$	0.57	1.3	Hamilton et al. 2002; Hamilton and Buhl (2003a,b)	0.48	regression from raw data
Arsenic	regression	$\log10(C_{tissue}) = A * \log10(C_{sed}) + B$	0.754	-0.292	Bechtel Jacobs (1998b)	0.6	regression model
Barium	BAF	$C_{tissue} = A * C_{sed}$	0.28	NA	Hamilton et al. 2002; Hamilton and Buhl (2003a,b)	NA	BSAF calculated from raw data - median
Cadmium	regression	$\log10(C_{tissue}) = A * \log10(C_{sed}) + B$	0.692	0.0395	Bechtel Jacobs (1998b)	0.51	regression model
Chromium	regression	$\log10(C_{tissue}) = A * \log10(C_{sed}) + B$	0.365	0.2092	Bechtel Jacobs (1998b)	0.20	regression model
Copper	regression	$\log10(C_{tissue}) = A * \log10(C_{sed}) + B$	0.278	1.089	Bechtel Jacobs (1998b)	0.34	regression model
Iron	regression	$\ln(C_{tissue}) = A * \ln(C_{sediment}) + B$	0.34	3.2	Hamilton et al. 2002; Hamilton and Buhl (2003a,b)	0.53	regression from raw data
Lead	regression	$\log10(C_{tissue}) = A * \log10(C_{sed}) + B$	0.801	-0.776	Bechtel Jacobs (1998b)	0.35	regression model
Manganese	regression	$\ln(C_{tissue}) = A * \ln(C_{sediment}) + B$	0.61	1.6	Hamilton et al. 2002; Hamilton and Buhl (2003a,b)	0.58	regression from raw data
Mercury	BAF	$C_{tissue} = A * C_{sed}$	1.136	NA	Bechtel Jacobs (1998b)	NA	median reported BSAF
Molybdenum	BAF	$C_{tissue} = A * C_{sed}$	1.1	NA	Hamilton et al. 2002; Hamilton and Buhl (2003a,b)	NA	BSAF calculated from raw data - median
Nickel	BAF	$C_{tissue} = A * C_{sed}$	0.486	NA	Bechtel Jacobs (1998b)	NA	median reported BSAF
Selenium	regression	$\ln(C_{tissue}) = A * \ln(C_{sediment}) + B$	0.62	1.4	Hamilton et al. 2002; Hamilton and Buhl (2003a,b)	0.55	regression from raw data
Vanadium	regression	$\ln(C_{tissue}) = A * \ln(C_{sediment}) + B$	0.73	-1.3	Hamilton et al. 2002; Hamilton and Buhl (2003a,b)	0.20	regression from raw data
Zinc	regression	$\log10(C_{tissue}) = A * \log10(C_{sed}) + B$	0.208	1.8	Bechtel Jacobs (1998b)	0.27	regression model

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Small Aquatic Invertebrates [c] (continued)							
Bis(2-ethylhexyl)phthalate	OC-normalized BAF	C_{tissue}/f_{lipid} = A * C_{sed}/f_{OC}	1	NA	USACE (2019)	NA	median of reported BSAFs (only 3 values reported, all for fish) from Teil et al. (2012)
Total PCB congeners [d]	regression	log10(C_{tissue}/f_{lipid}) = A * log10(C_{sed}/f_{OC}) + B	1.11	0.59	Bechtel Jacobs (1998b)	0.65	regression model for benthos data set; after input of the f_{lipid} value from footnote d and the OC-normalized concentration, and further algebraic rearrangement, this equation becomes C_{tissue} = 10^(A * $log_{10}(C_{orgsed})$ + B - log_{10}(0.125))
PCB TEQs, dioxin/furan TEQs, total TEQs [d]	OC-normalized BAF	C_{tissue}/f_{lipid} = A * C_{sed}/f_{OC}	0.3	NA	USACE (2019)	NA	median of reported BSAFs for small benthic invertebrates, for all dioxins/furans
Adult Flying Aquatic Emergent Insects [e]							
All metal/metalloids	correction factor	C_{adult} = C_{larval} / A	3.1	NA	Kraus et al. (2014)	NA	correction factor for COPC loss after metamorphosis
All organic compounds	correction factor	C_{adult} = C_{larval} * A	1.2	NA	Kraus et al. (2014)	NA	correction factor for COPC gain after metamorphosis; in the case of TEQs, after input of the f_{lipid} value from footnote d and the OC-normalized concentration and further algebraic rearrangement, this equation becomes C_{tissue} = A * C_{orgsed} * 0.125 * 1.2
Aboveground Terrestrial Plant Parts							
Aluminum	BAF	C_{tissue} = A * C_{soil}	0.0009	NA	2018 UCR Plant Tissue Study (TAI 2019)	NA	median BAF using fines-bulk corrected soil chemistry
Barium	BAF	C_{tissue} = A * C_{soil}	0.1244	NA	2018 UCR Plant Tissue Study (TAI 2019)	NA	median BAF using fines-bulk corrected soil chemistry
Cadmium	BAF	C_{tissue} = A * C_{soil}	0.0128	NA	2018 UCR Plant Tissue Study (TAI 2019)	NA	median BAF using fines-bulk corrected soil chemistry
Chromium	BAF	C_{tissue} = A * C_{soil}	0.0203	NA	2018 UCR Plant Tissue Study (TAI 2019)	NA	median BAF using fines-bulk corrected soil chemistry
Copper	BAF	C_{tissue} = A * C_{soil}	0.1103	NA	2018 UCR Plant Tissue Study (TAI 2019)	NA	median BAF using fines-bulk corrected soil chemistry
Iron	BAF	C_{tissue} = A * C_{soil}	0.0017	NA	2018 UCR Plant Tissue Study (TAI 2019)	NA	median BAF using fines-bulk corrected soil chemistry
Lead	BAF	C_{tissue} = A * C_{soil}	0.0010	NA	2018 UCR Plant Tissue Study (TAI 2019)	NA	median BAF using fines-bulk corrected soil chemistry
Mercury	BAF	C_{tissue} = A * C_{soil}	0.0694	NA	2018 UCR Plant Tissue Study (TAI 2019)	NA	median BAF using fines-bulk corrected soil chemistry
Molybdenum	BAF	C_{tissue} = A * C_{soil}	1.25	NA	USACHPPM (2004)	NA	median BAF; developed from raw data
Selenium	BAF	C_{tissue} = A * C_{soil}	0.0917	NA	2018 UCR Plant Tissue Study (TAI 2019)	NA	median BAF using fines-bulk corrected soil chemistry
Thallium	BAF	C_{tissue} = A * C_{soil}	0.0164	NA	2018 UCR Plant Tissue Study (TAI 2019)	NA	median BAF using fines-bulk corrected soil chemistry
Vanadium	BAF	C_{tissue} = A * C_{soil}	0.0015	NA	2018 UCR Plant Tissue Study (TAI 2019)	NA	median BAF using fines-bulk corrected soil chemistry
Zinc	BAF	C_{tissue} = A * C_{soil}	0.0637	NA	2018 UCR Plant Tissue Study (TAI 2019)	NA	median BAF using fines-bulk corrected soil chemistry
Belowground Terrestrial Plant Parts							
Aluminum	BAF	C_{tissue} = A * C_{soil}	0.0327	NA	2018 UCR Plant Tissue Study (TAI 2019)	NA	median BAF using fines-bulk corrected soil chemistry
Barium	BAF	C_{tissue} = A * C_{soil}	0.2608	NA	2018 UCR Plant Tissue Study (TAI 2019)	NA	median BAF using fines-bulk corrected soil chemistry
Cadmium	BAF	C_{tissue} = A * C_{soil}	0.4915	NA	2018 UCR Plant Tissue Study (TAI 2019)	NA	median BAF using fines-bulk corrected soil chemistry
Chromium	regression	ln(C_{tissue}) = A * ln(C_{soil}) + B	2.2830	-7.4983	2018 UCR Plant Tissue Study (TAI 2019)	0.369	used fines-bulk corrected soil chemistry
Copper	BAF	C_{tissue} = A * C_{soil}	0.1229	NA	2018 UCR Plant Tissue Study (TAI 2019)	NA	median BAF using fines-bulk corrected soil chemistry
Iron	BAF	C_{tissue} = A * C_{soil}	0.0208	NA	2018 UCR Plant Tissue Study (TAI 2019)	NA	median BAF using fines-bulk corrected soil chemistry
Lead	BAF	C_{tissue} = A * C_{soil}	0.0895	NA	2018 UCR Plant Tissue Study (TAI 2019)	NA	median BAF using fines-bulk corrected soil chemistry
Mercury	BAF	C_{tissue} = A * C_{soil}	0.0694	NA	2018 UCR Plant Tissue Study (TAI 2019)	NA	median BAF using fines-bulk corrected soil chemistry
Molybdenum	BAF	C_{tissue} = A * C_{soil}	1.7030	NA	USACHPPM (2004)	NA	median BAF; developed from raw data
Selenium	BAF	C_{tissue} = A * C_{soil}	0.0714	NA	2018 UCR Plant Tissue Study (TAI 2019)	NA	median BAF using fines-bulk corrected soil chemistry
Thallium	BAF	C_{tissue} = A * C_{soil}	0.2783	NA	2018 UCR Plant Tissue Study (TAI 2019)	NA	median BAF using fines-bulk corrected soil chemistry
Vanadium	regression	ln(C_{tissue}) = A * ln(C_{soil}) + B	2.4603	-9.6464	2018 UCR Plant Tissue Study (TAI 2019)	0.352	used fines-bulk corrected soil chemistry
Zinc	BAF	C_{tissue} = A * C_{soil}	0.4788	NA	2018 UCR Plant Tissue Study (TAI 2019)	NA	median BAF using fines-bulk corrected soil chemistry

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Terrestrial Arthropods							
Aluminum	regression	$\ln(C_{tissue}) = A * \ln(C_{soil}) + B$	3.8816	-33.549	Appendix B-1 of USACHPPM (2004)	0.203	developed from raw data
Barium	BAF	$C_{tissue} = A * C_{soil}$	0.0310	NA	Appendix B-1 of USACHPPM (2004)	NA	median BAF; developed from raw data
Cadmium	regression	$\ln(C_{tissue}) = A * \ln(C_{soil}) + B$	0.5884	0.506	Appendix B-1 of USACHPPM (2004)	0.512	developed from raw data
Chromium	BAF	$C_{tissue} = A * C_{soil}$	0.0643	NA	Appendix B-1 of USACHPPM (2004)	NA	median BAF; developed from raw data
Copper	BAF	$C_{tissue} = A * C_{soil}$	0.9416	NA	Appendix B-1 of USACHPPM (2004)	NA	median BAF; developed from raw data
Iron	BAF	$C_{tissue} = A * C_{soil}$	0.0060	NA	Appendix B-1 of USACHPPM (2004)	NA	median BAF; developed from raw data
Lead	regression	$\ln(C_{tissue}) = A * \ln(C_{soil}) + B$	0.7985	-1.494	Appendix B-1 of USACHPPM (2004)	0.46	developed from raw data
Mercury	BAF	$C_{tissue} = A * C_{soil}$	0.7292	NA	Appendix B-1 of USACHPPM (2004)	NA	median BAF; developed from raw data
Molybdenum	BAF	$C_{tissue} = A * C_{soil}$	0.9800	NA	Hargreaves et al. (2011)	NA	mean BAF (median BAF not reported)
Selenium	BAF	$C_{tissue} = A * C_{soil}$	1.6129	NA	Appendix B-1 of USACHPPM (2004)	NA	median BAF; developed from raw data
Thallium	BAF	$C_{tissue} = A * C_{soil}$	0.0560	NA	Appendix B-1 of USACHPPM (2004)	NA	median BAF; developed from raw data
Vanadium	BAF	$C_{tissue} = A * C_{soil}$	0.0098	NA	Appendix B-1 of USACHPPM (2004)	NA	median BAF; developed from raw data
Zinc	BAF	$C_{tissue} = A * C_{soil}$	0.8269	NA	Appendix B-1 of USACHPPM (2004)	NA	median BAF; developed from raw data
Aerial Insects of Terrestrial Origin							
Aluminum	BAF	$C_{tissue} = A * C_{soil}$	0.0020	NA	Appendix B-1 of USACHPPM (2004)	NA	median BAF; developed from raw data
Barium	BAF	$C_{tissue} = A * C_{soil}$	0.0240	NA	Appendix B-1 of USACHPPM (2004)	NA	median BAF; developed from raw data
Cadmium	regression	$\ln(C_{tissue}) = A * \ln(C_{soil}) + B$	0.6006	-0.311	Appendix B-1 of USACHPPM (2004)	0.600	developed from raw data
Chromium	BAF	$C_{tissue} = A * C_{soil}$	0.0561	NA	Appendix B-1 of USACHPPM (2004)	NA	median BAF; developed from raw data
Copper	regression	$\ln(C_{tissue}) = A * \ln(C_{soil}) + B$	0.469	1.521	Appendix B-1 of USACHPPM (2004)	0.573	developed from raw data
Iron	BAF	$C_{tissue} = A * C_{soil}$	0.004	NA	Appendix B-1 of USACHPPM (2004)	NA	median BAF; developed from raw data
Lead	regression	$\ln(C_{tissue}) = A * \ln(C_{soil}) + B$	0.6873	-2.283	Appendix B-1 of USACHPPM (2004)	0.345	developed from raw data
Mercury	BAF	$C_{tissue} = A * C_{soil}$	0.5556	NA	Appendix B-1 of USACHPPM (2004)	NA	median BAF; developed from raw data
Molybdenum	BAF	$C_{tissue} = A * C_{soil}$	0.98	NA	Hargreaves et al. (2011)	NA	mean BAF (median BAF not reported)
Selenium	BAF	$C_{tissue} = A * C_{soil}$	1.3871	NA	Appendix B-1 of USACHPPM (2004)	NA	median BAF; developed from raw data
Thallium	BAF	$C_{tissue} = A * C_{soil}$	0.054	NA	Appendix B-1 of USACHPPM (2004)	NA	median BAF; developed from raw data
Vanadium	BAF	$C_{tissue} = A * C_{soil}$	0.0081	NA	Appendix B-1 of USACHPPM (2004)	NA	median BAF; developed from raw data
Zinc	regression	$\ln(C_{tissue}) = A * \ln(C_{soil}) + B$	0.2344	3.978	Appendix B-1 of USACHPPM (2004)	0.412	developed from raw data
Earthworms							
Aluminum	BAF	$C_{tissue} = A * C_{soil}$	0.043	NA	Sample et al. (1998a)	NA	median BAF from validation data set
Barium	BAF	$C_{tissue} = A * C_{soil}$	0.091	NA	Sample et al. (1998a), as reported in USEPA (2007b)	NA	median BAF
Cadmium	regression	$\ln(C_{tissue}) = A * \ln(C_{soil}) + B$	0.795	2.114	Sample et al. (1998a), as reported in USEPA (2007b)	0.67	NA
Chromium	BAF	$C_{tissue} = A * C_{soil}$	0.306	NA	Sample et al. (1998a), as reported in USEPA (2007b)	NA	median BAF
Copper	BAF	$C_{tissue} = A * C_{soil}$	0.515	NA	Sample et al. (1998a), as reported in USEPA (2007b)	NA	median BAF
Iron	BAF	$C_{tissue} = A * C_{soil}$	0.036	NA	Sample et al. (1998a)	NA	median BAF from validation data set
Lead	regression	$\ln(C_{tissue}) = A * \ln(C_{soil}) + B$	0.807	-0.218	Sample et al. (1998a), as reported in USEPA (2007b)	0.58	NA
Mercury	BAF	$C_{tissue} = A * C_{soil}$	1.693	NA	Sample et al. (1998a)	NA	median BAF
Molybdenum	BAF	$C_{tissue} = A * C_{soil}$	0.953	NA	Sample et al. (1998a)	NA	median BAF from validation data set
Selenium	regression	$\ln(C_{tissue}) = A * \ln(C_{soil}) + B$	0.733	-0.075	Sample et al. (1998a), as reported in USEPA (2007b)	0.43	NA
Thallium	BAF	$C_{tissue} = A * C_{soil}$	1	NA	Default BAF = 1	NA	NA
Vanadium	BAF	$C_{tissue} = A * C_{soil}$	0.042	NA	Sample et al. (1998a), as reported in USEPA (2007b)	NA	median BAF from validation data set
Zinc	regression	$\ln(C_{tissue}) = A * \ln(C_{soil}) + B$	0.328	4.449	Sample et al. (1998a), as reported in USEPA (2007b)	0.45	NA

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Small Mammals and Ungulates							
Aluminum	BAF	$C_{tissue} = A * C_{soil}$	0.0263	NA	Sample et al. (1998b)	NA	median BAF
Barium	BAF	$C_{tissue} = A * C_{soil}$	0.0566	NA	Sample et al. (1998b)	NA	median BAF
Cadmium	regression	$\ln(C_{tissue}) = A * \ln(C_{soil}) + B$	0.4723	-1.2571	Sample et al. (1998b), as reported in USEPA (2007b)	0.64	NA
Chromium	regression	$\ln(C_{tissue}) = A * \ln(C_{soil}) + B$	0.7338	-1.4599	Sample et al. (1998b), as reported in USEPA (2007b)	0.42	NA
Copper	regression	$\ln(C_{tissue}) = A * \ln(C_{soil}) + B$	0.1444	2.0420	Sample et al. (1998b), as reported in USEPA (2007b)	0.26	NA
Iron	regression	$\ln(C_{tissue}) = A * \ln(C_{soil}) + B$	0.5969	-0.2879	Sample et al. (1998b)	0.68	NA
Lead	regression	$\ln(C_{tissue}) = A * \ln(C_{soil}) + B$	0.4422	0.0761	Sample et al. (1998b), as reported in USEPA (2007b)	0.37	NA
Mercury	BAF	$C_{tissue} = A * C_{soil}$	0.0543	NA	Sample et al. (1998b)	NA	median BAF
Molybdenum	BAF	$C_{tissue} = A * C_{soil}$	1	NA	Default BAF = 1	NA	NA
Selenium	regression	$\ln(C_{tissue}) = A * \ln(C_{soil}) + B$	0.3764	-0.4158	Sample et al. (1998b), as reported in USEPA (2007b)	0.31	NA
Thallium	BAF	$C_{tissue} = A * C_{soil}$	0.1124	NA	Sample et al. (1998b)	NA	median BAF
Vanadium	BAF	$C_{tissue} = A * C_{soil}$	0.0123	NA	Sample et al. (1998b), as reported in USEPA (2007b)	NA	NA
Zinc	regression	$\ln(C_{tissue}) = A * \ln(C_{soil}) + B$	0.0706	4.3632	Sample et al. (1998b), as reported in USEPA (2007b)	0.31	NA

Notes:

[a] All calculations were performed as dry weight.

[b] Lipid content for aquatic plants were assumed to be 14 percent based on the KABAM 1.0 (USEPA 2009) average of mean percent lipid (dry weight) based on available data in the literature (Table C1 in Appendix C of USEPA [2009]). The selected value is the mean of the reported mean percent lipid on a dry weight basis for freshwater phytoplankton. Value is assumed to be conservative for macrophytes.

[c] Aquatic invertebrate bioaccumulation models used in the COPC Refinement (TAI 2020) were based on 90th percentile biota-sediment accumulation factors (BSAFs). Bioaccumulation models for this BERA are based on regressions, where possible (the following acceptance criteria are met: 1. a statistically significant slope [$p < 0.05$], 2. $R^2 \geq 0.2$, 3. a positive slope, and 4. number of data points > 10), or median BSAFs.

[d] Lipid content for small aquatic invertebrates was assumed to be 12.5 percent based on the KABAM 1.0 (USEPA 2009) default value for benthic invertebrates based on available data in the literature (see discussion in Section C.3 in Appendix C of USEPA [2009]), converted from wet weight (3 percent, the 75th percentile for freshwater benthic invertebrates in Table C10 in Appendix C of USEPA [2009]) to dry weight using the KABAM default percent moisture for benthic invertebrates (76 percent, the mean from Table C3 in Appendix C of USEPA [2009]). Value was selected to represent a high-end estimate, which is conservative.

[e] Models for adult flying insects of aquatic origin were based on regression models from Bechtel Jacobs (1998b) in the COPC Refinement (TAI 2020).

Model parameters:

C_{adult} - concentration in tissue of adult flying insects from aquatic origin

C_{larval} - concentration in tissue of larval aquatic invertebrates

C_{orgsed} - OC-normalized concentration in sediment (C_{sed}/f_{OC})

C_{sed} - concentration in sediment

C_{soil} - concentration in soil

C_{tissue} - concentration in dietary item tissue

f_{lipid} - fraction of lipids

f_{OC} - fraction of organic carbon

BAF - bioaccumulation factor

COPC - chemical of potential concern

ln - natural logarithm

log10 - base 10 logarithm

NA - not applicable

OC - organic carbon

PCB - polychlorinated biphenyl

TEQ - toxic equivalent

ERM

FIGURES

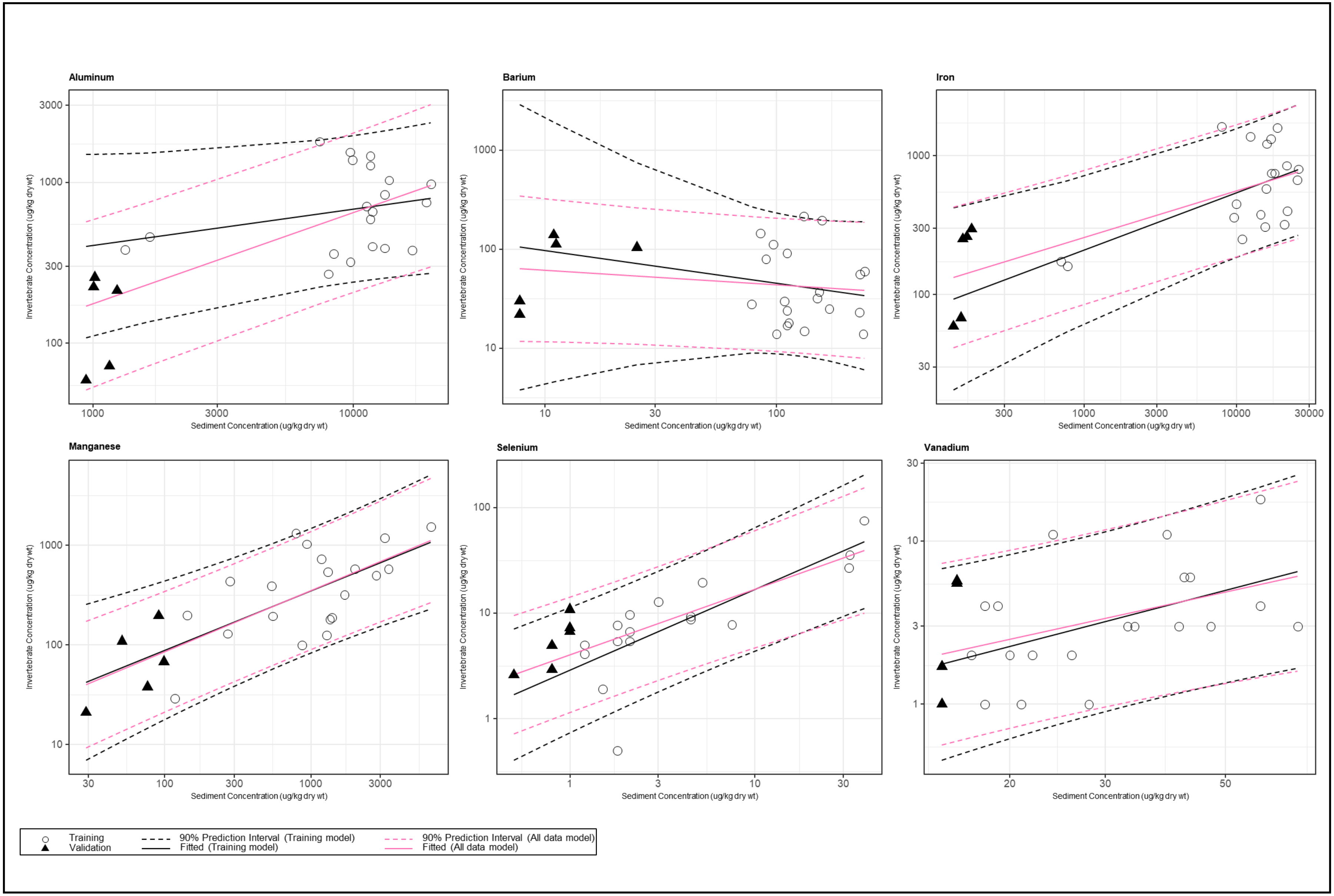

Figure E-1. Truncated (Low) Validation for Aquatic Invertebrates

ERM

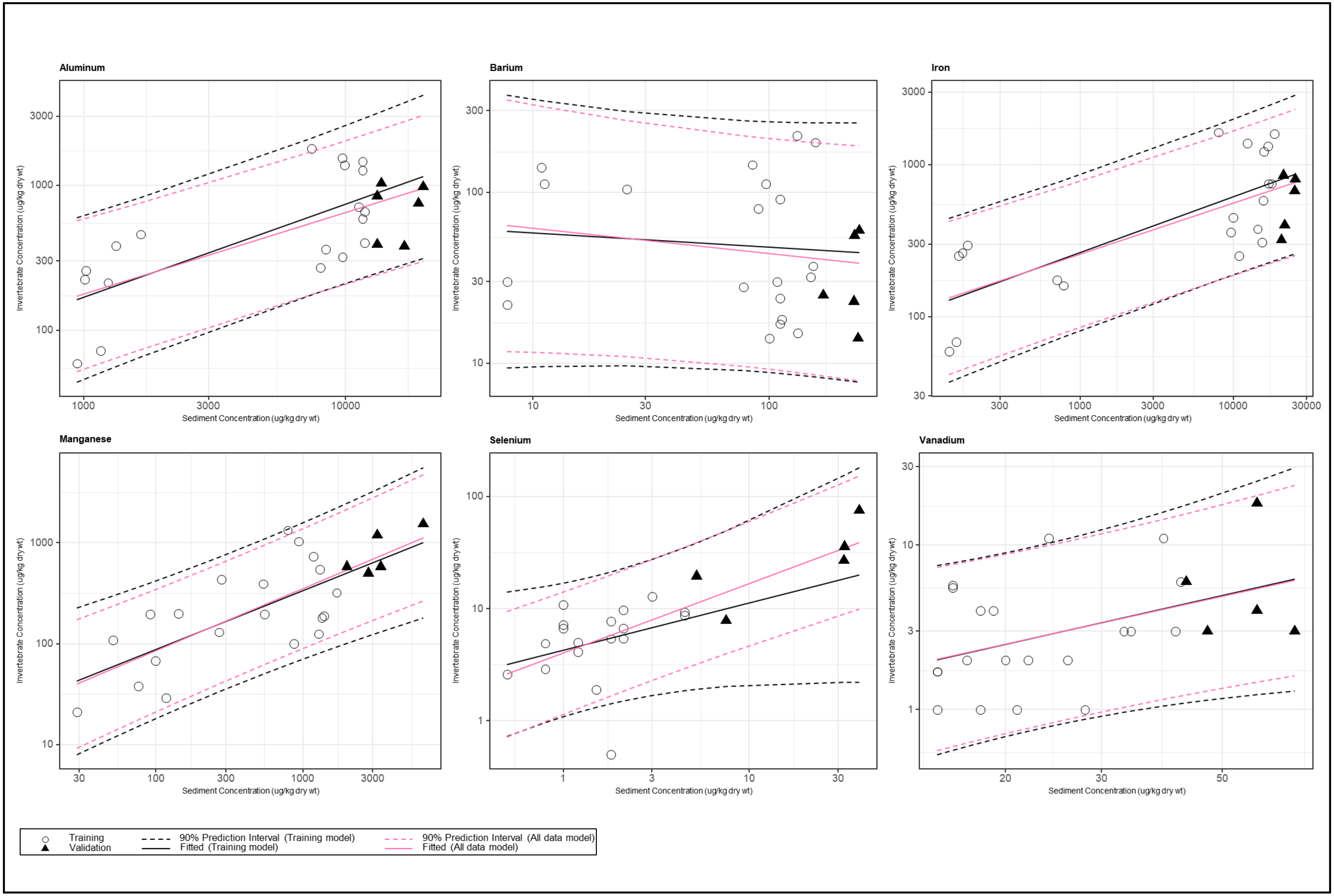

Figure E-2. Truncated (High) Validation for Aquatic Invertebrates

ERM

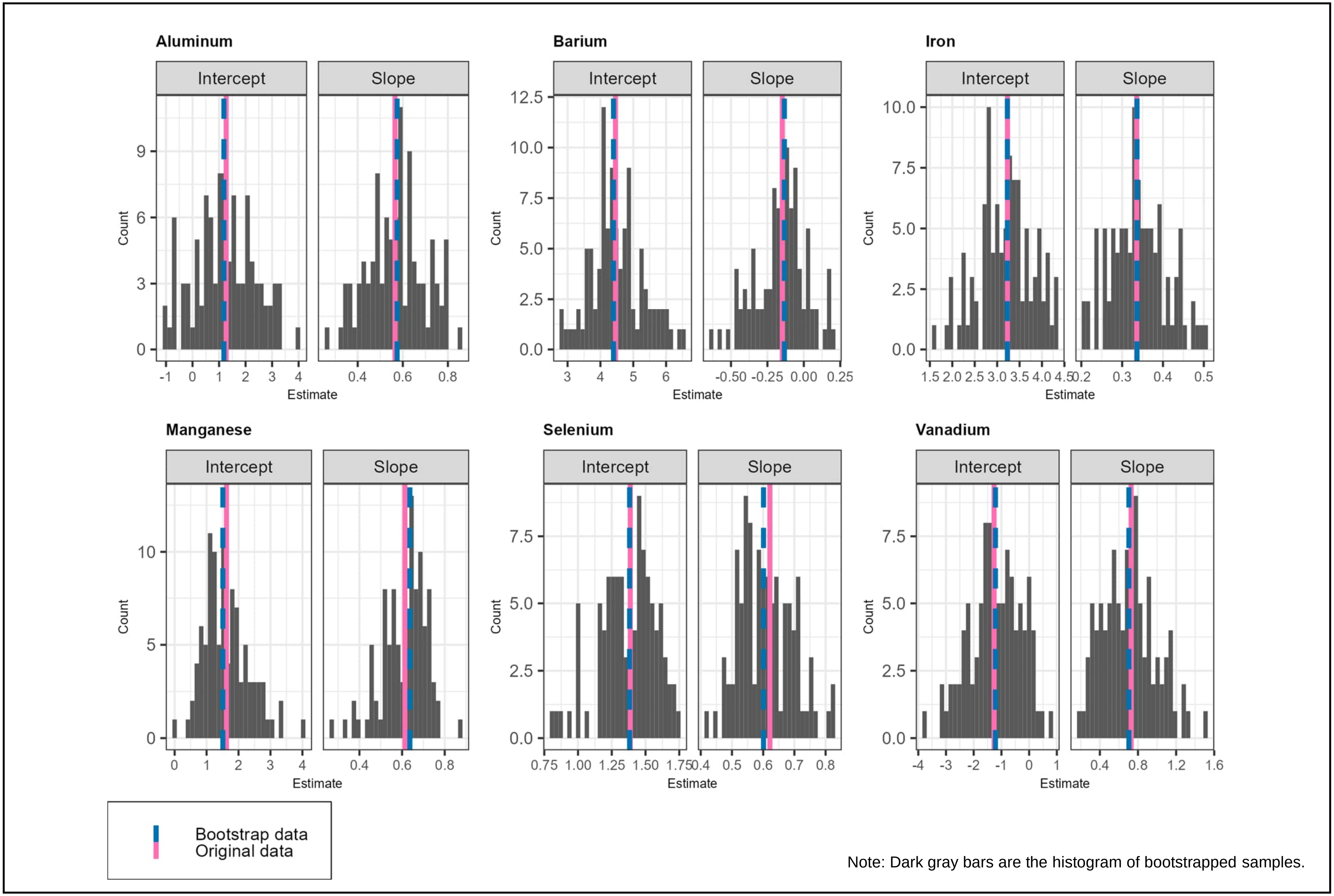

Figure E-3. Bootstrap Regression Model Parameter Estimates for Aquatic Invertebrates

ERM

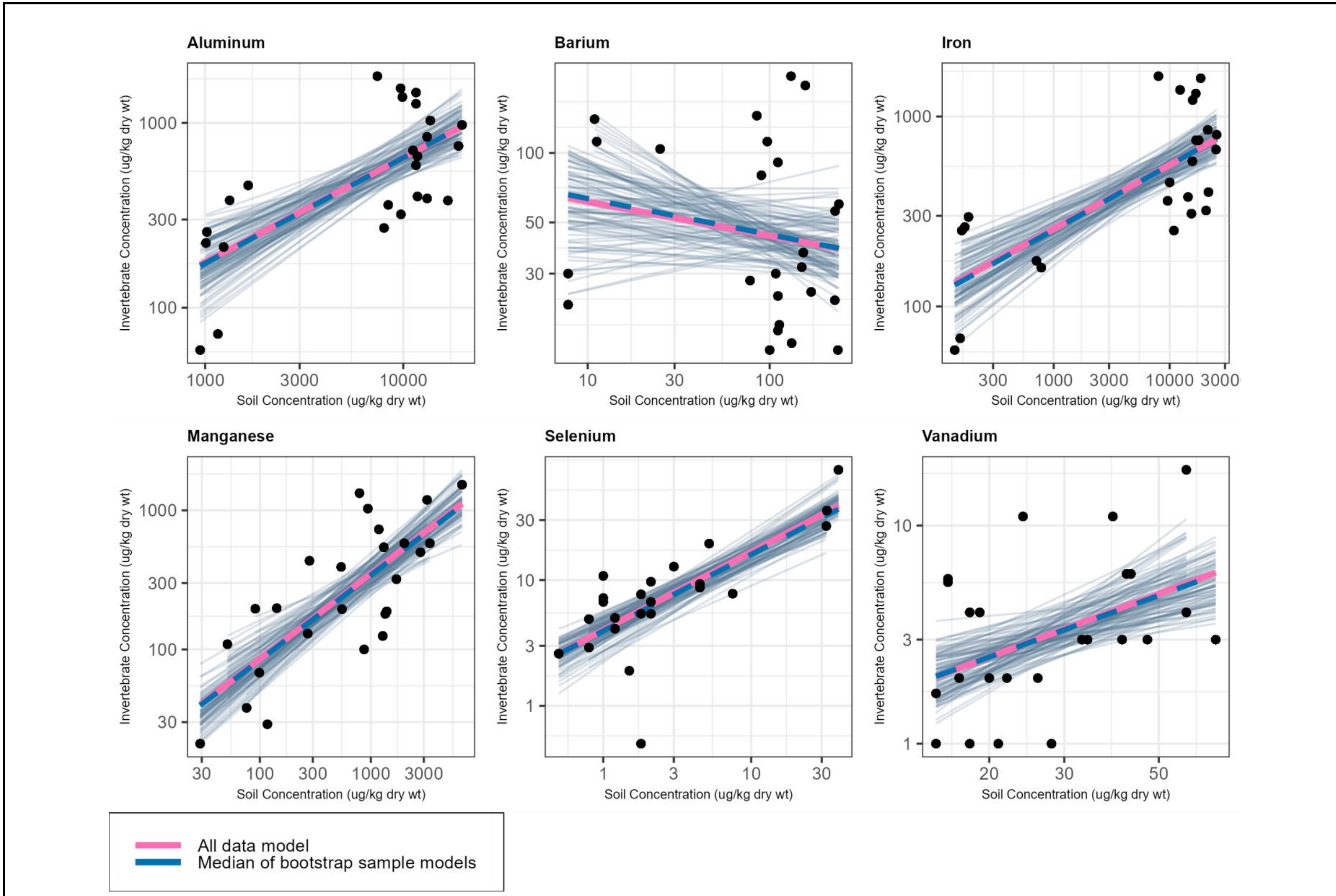

Figure E-4. Bootstrap Regression Model Fits for Aquatic Invertebrates

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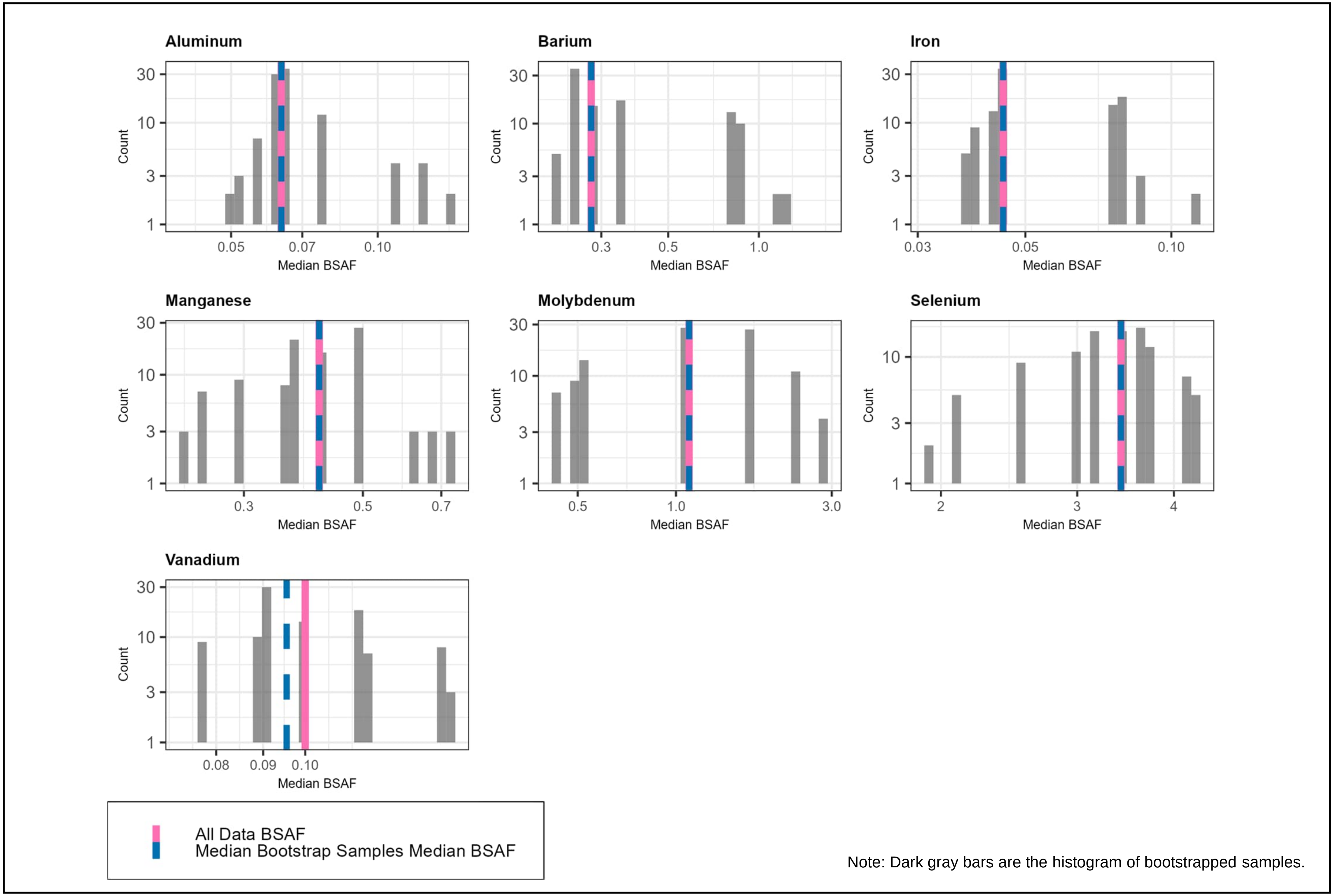

Figure E-5. Bootstrap Median BSAF Estimates for Aquatic Invertebrates

ERM

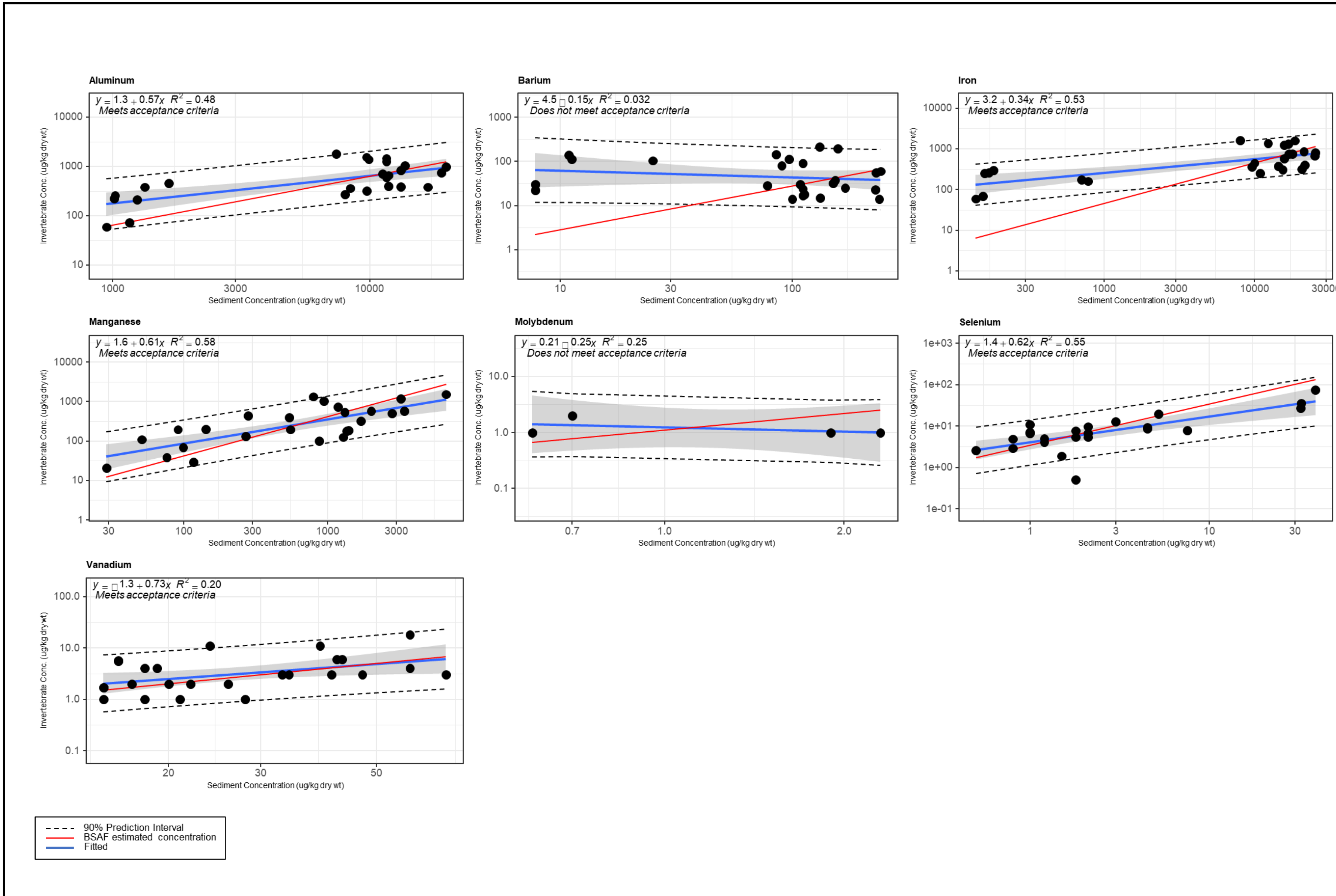

Figure E-6. Regression Models Using All Data for Aquatic Invertebrates

ERM

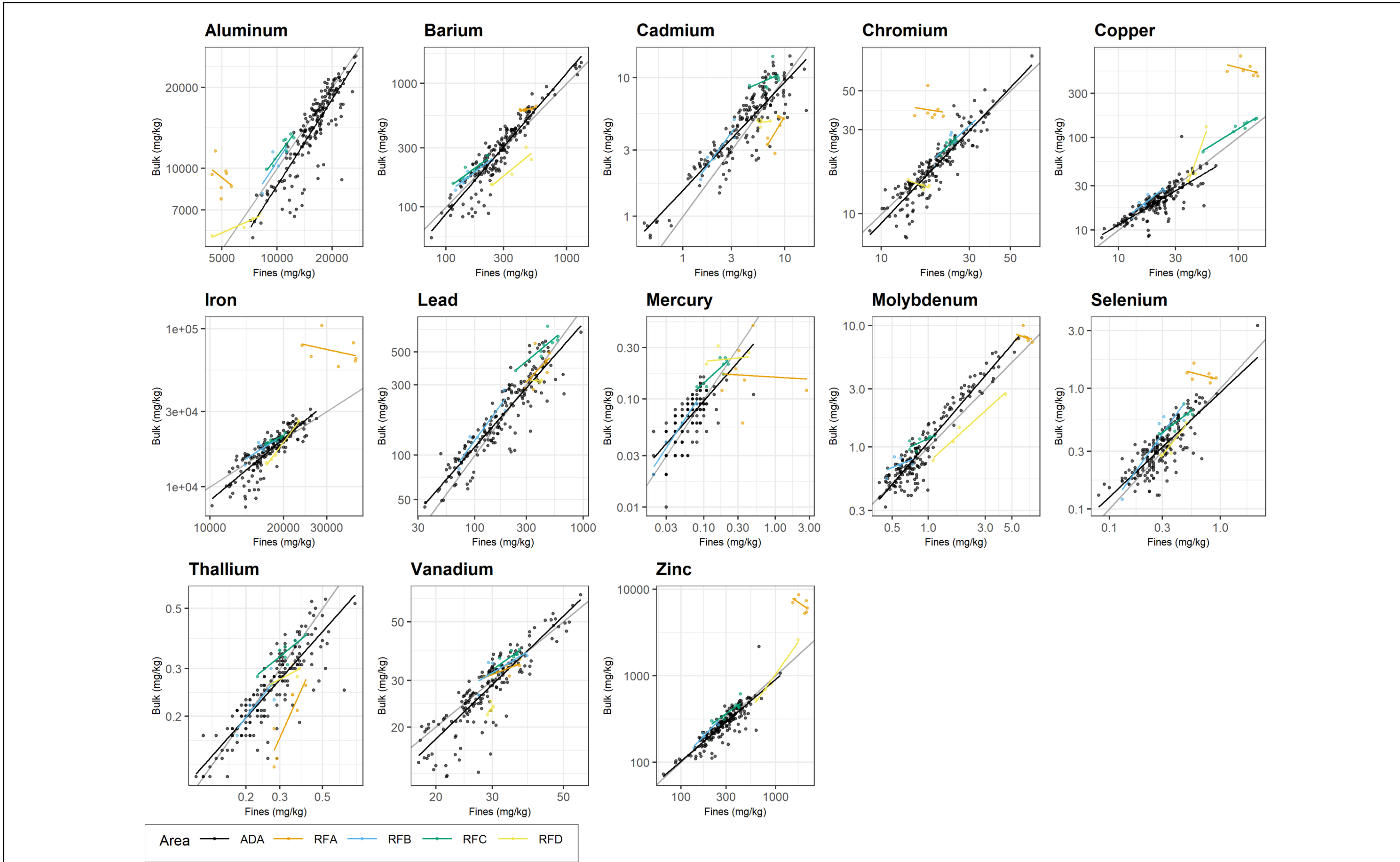

Figure E-7. ANCOVA Results

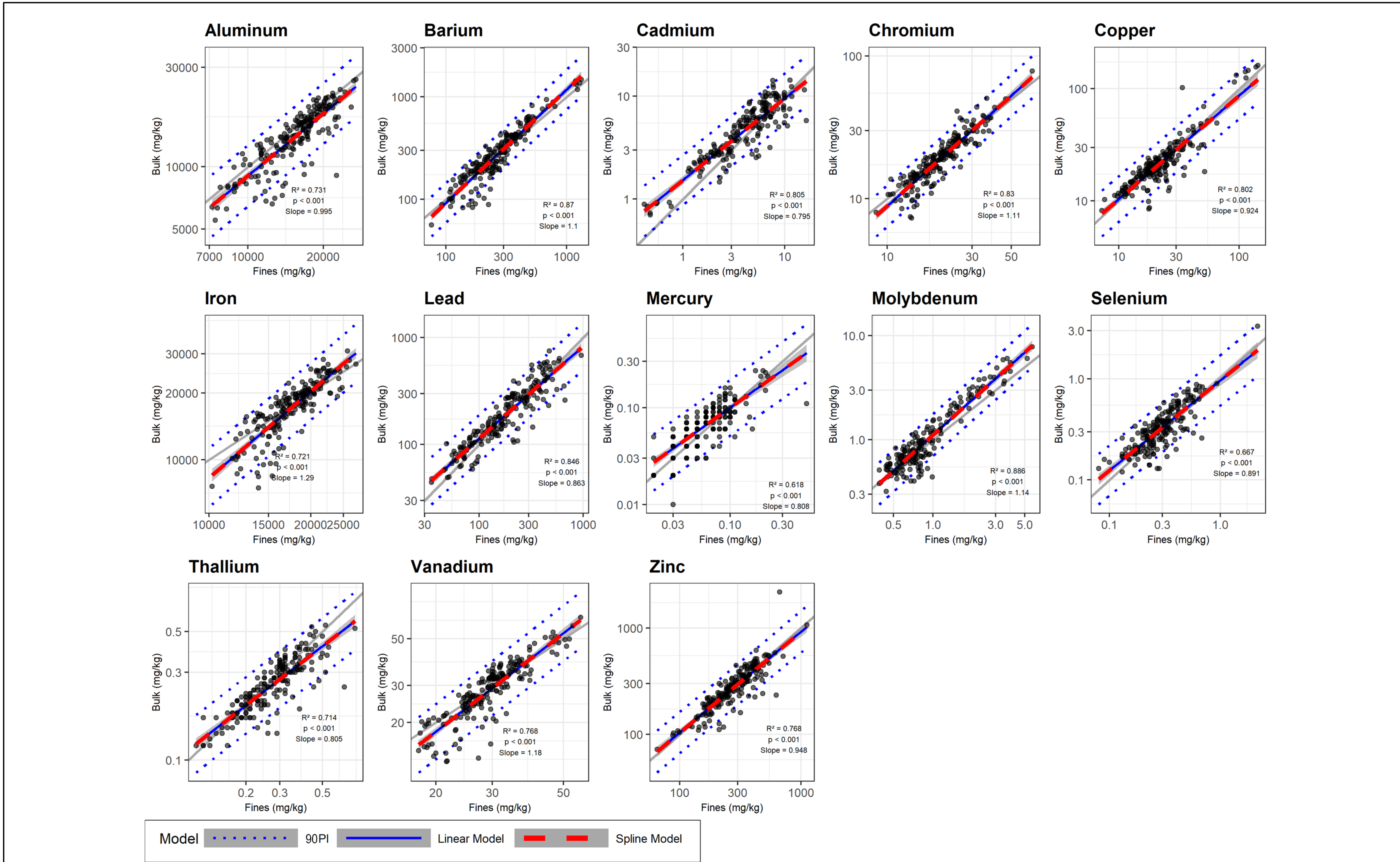

Figure E-8. Fines-Bulk Model Derived from 2018 Plant Tissue Study Soil Data

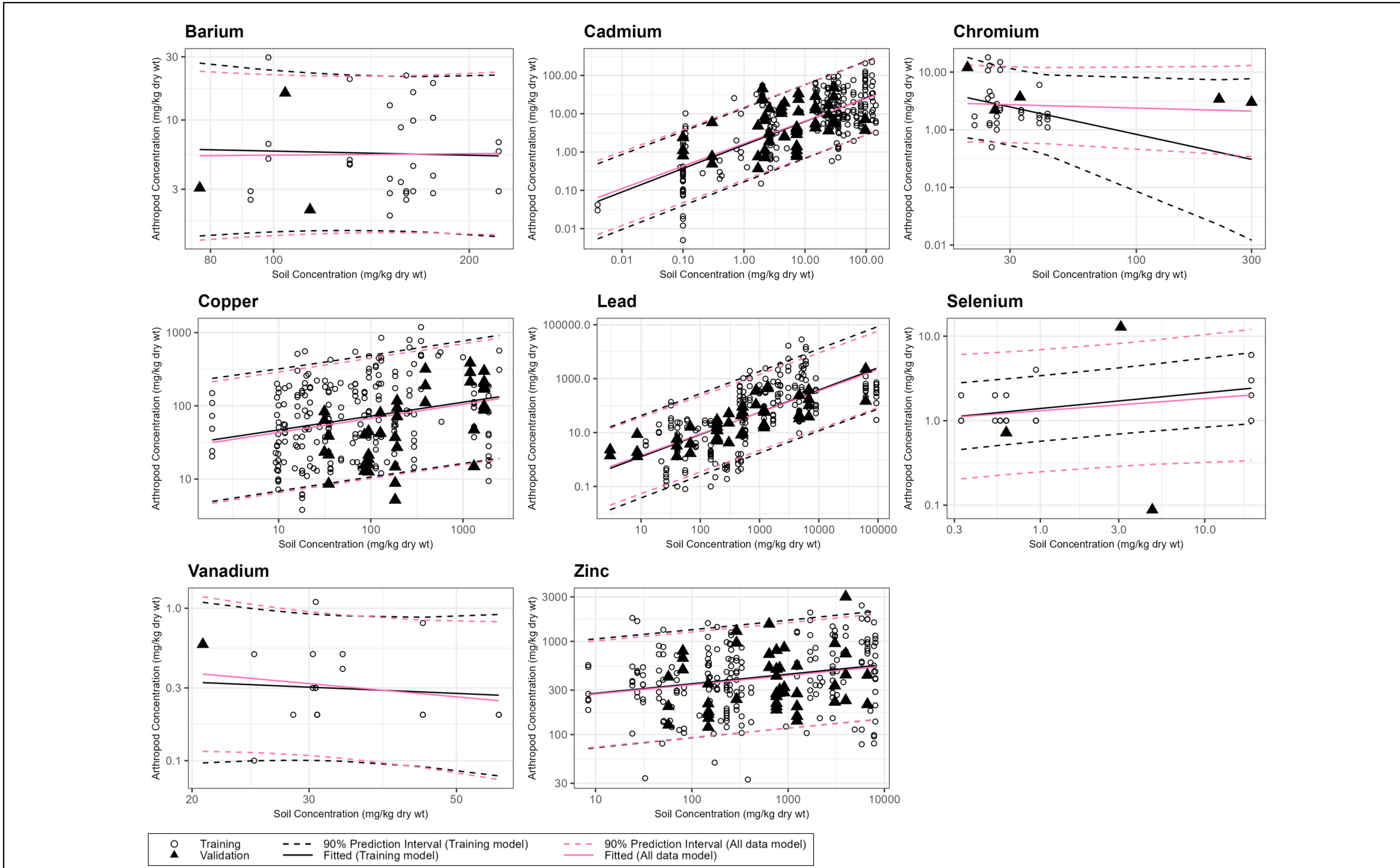

Figure E-9. Study Split Validation for Terrestrial Arthropods

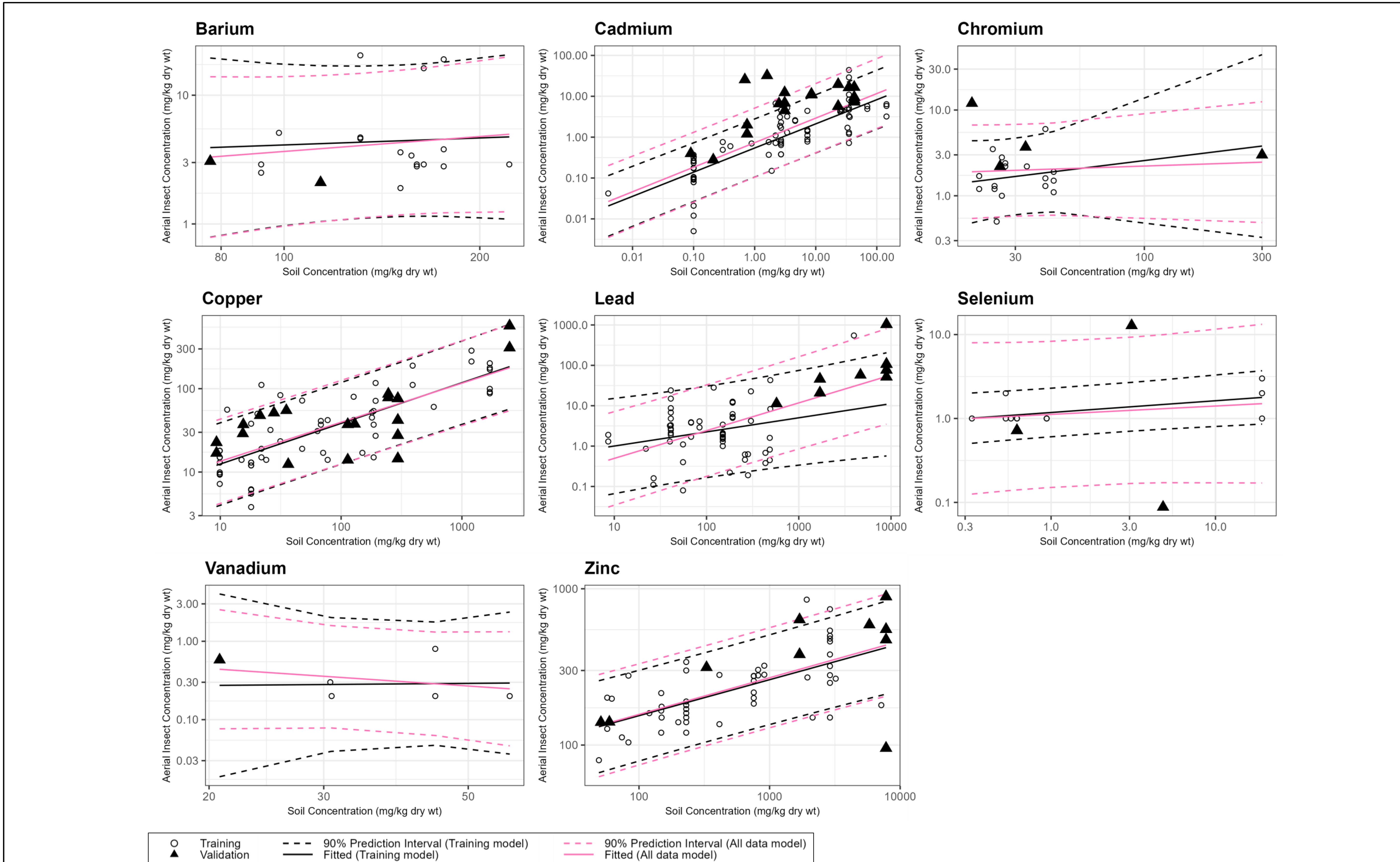

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Figure E-10. Study Split Validation for Aerial Insects

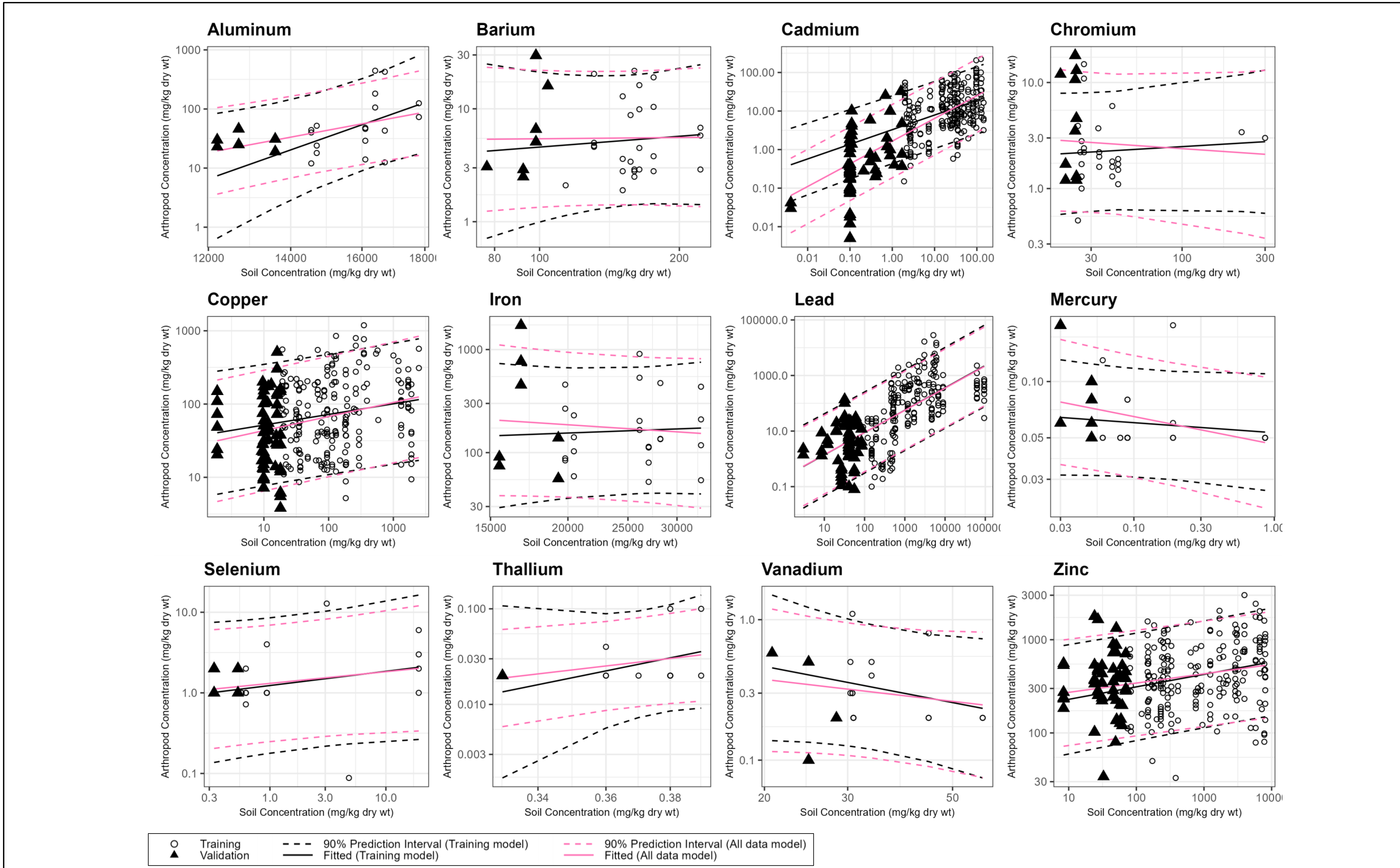

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Figure E-11. Truncated (Low) Validation for Terrestrial Arthropods

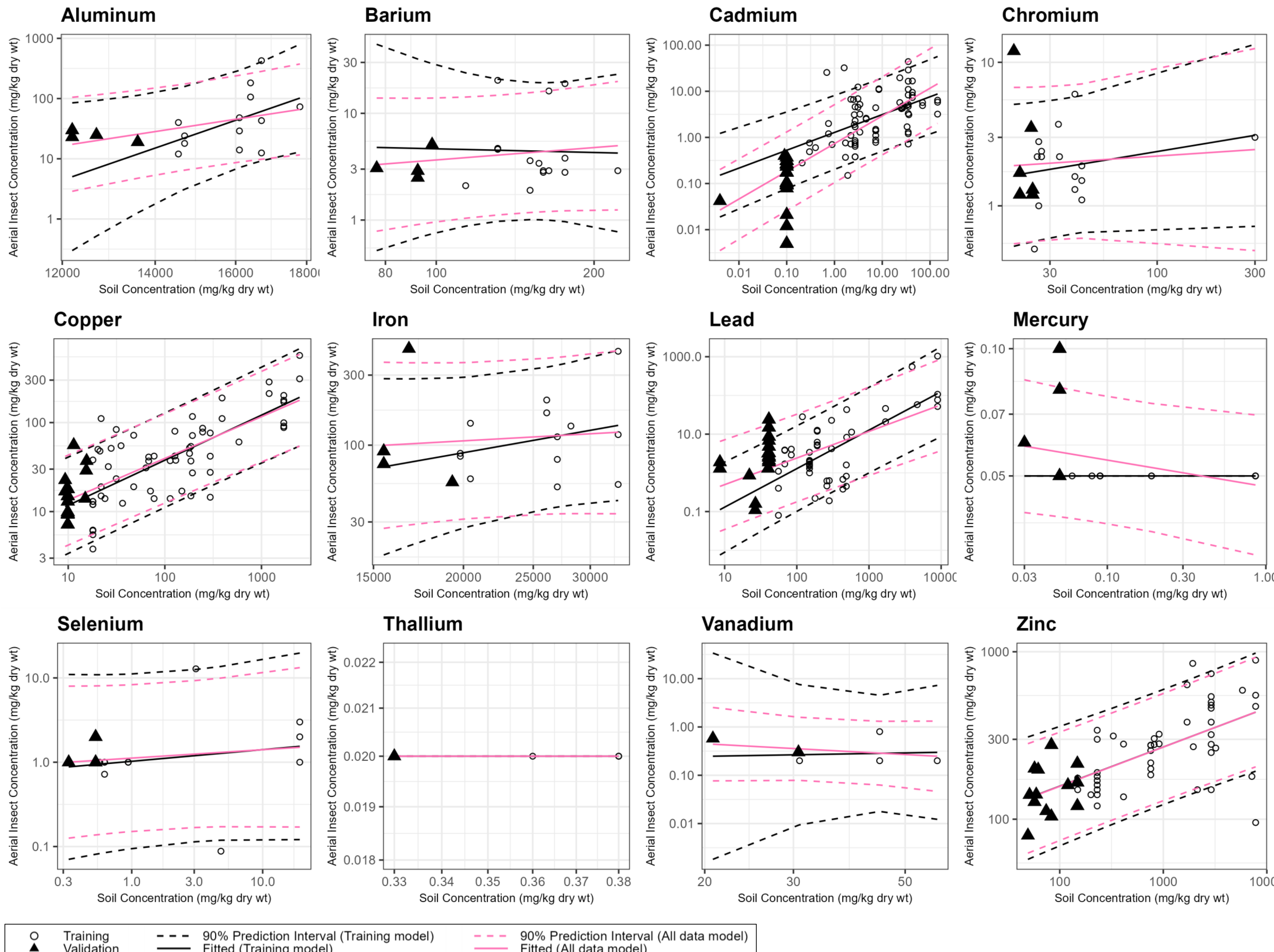

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Figure E-12. Truncated (Low) Validation for Aerial Insects

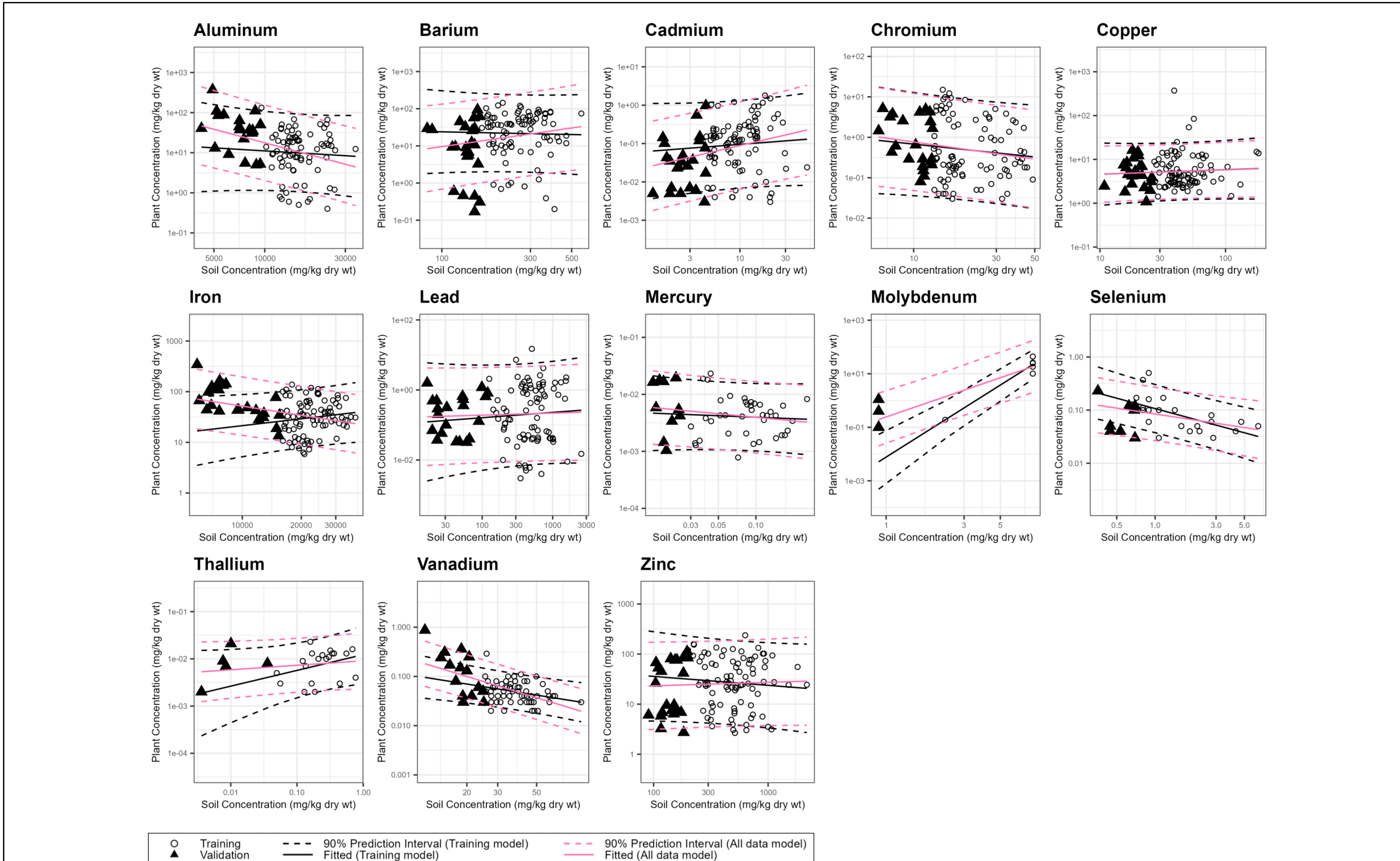

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Figure E-13. Truncated (Low) Validation for Aboveground Terrestrial Plant Parts

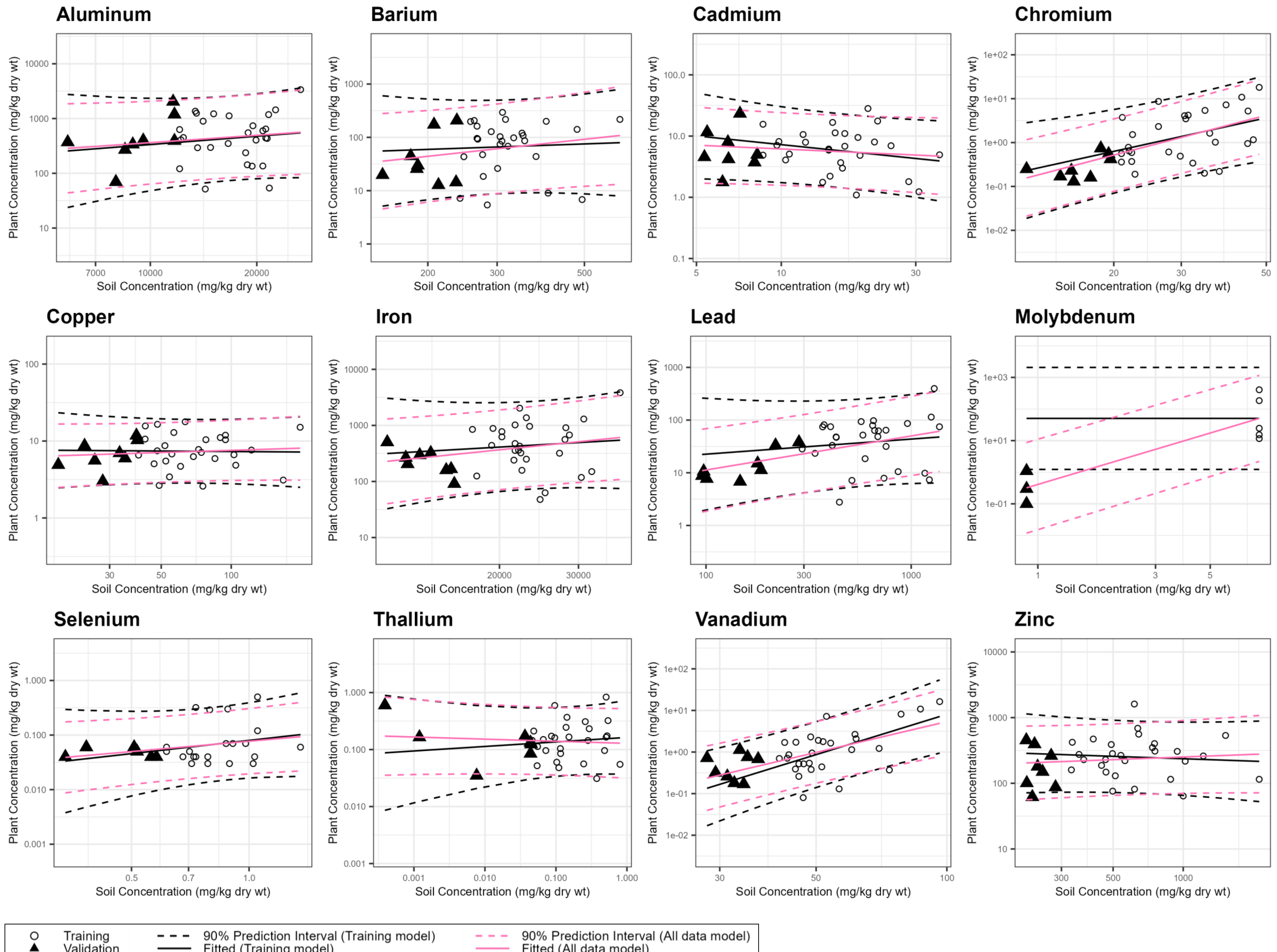

Figure E-14. Truncated (Low) Validation for Belowground Terrestrial Plant Parts

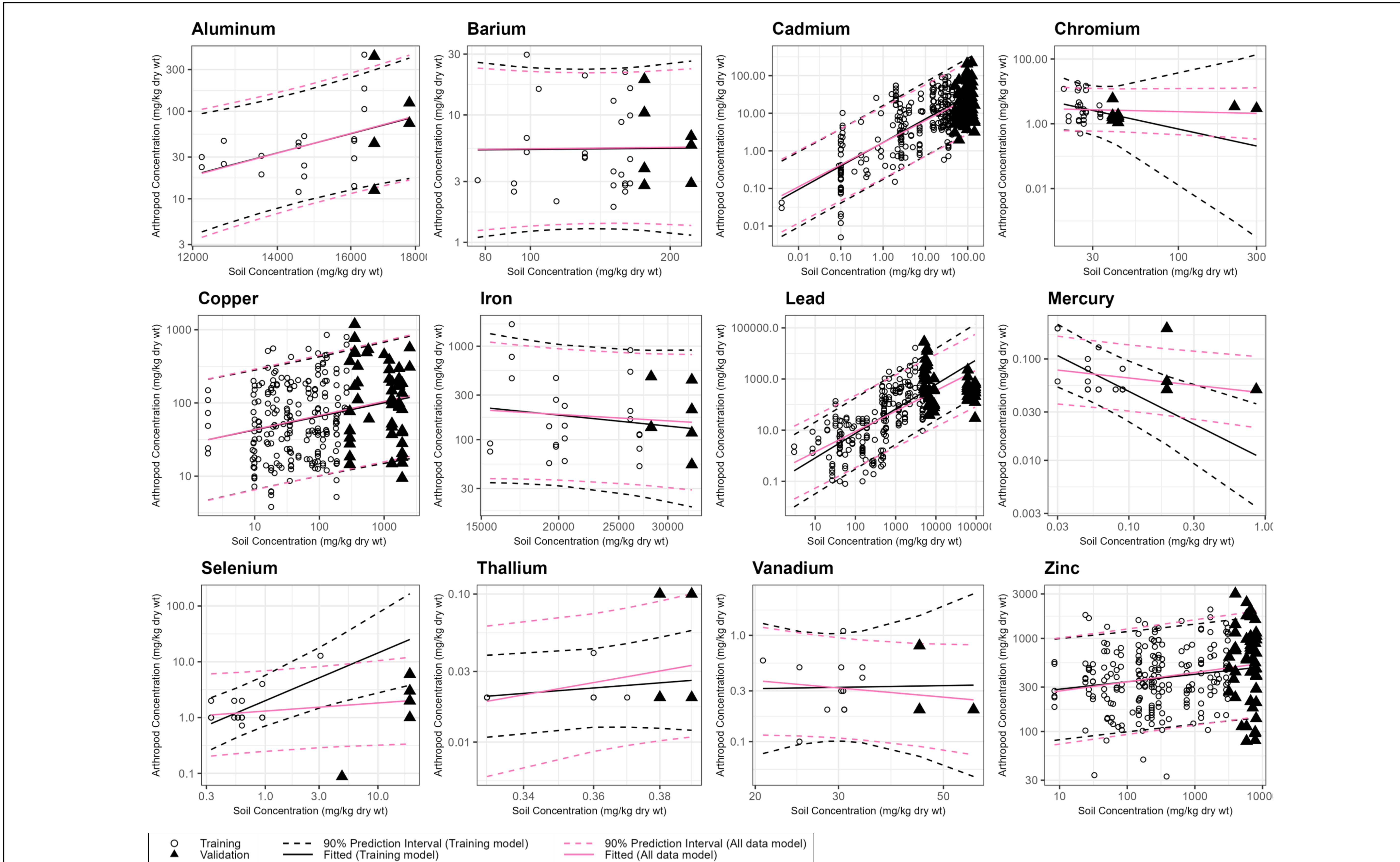

Figure E-15. Truncated (High) Validation for Terrestrial Arthropods

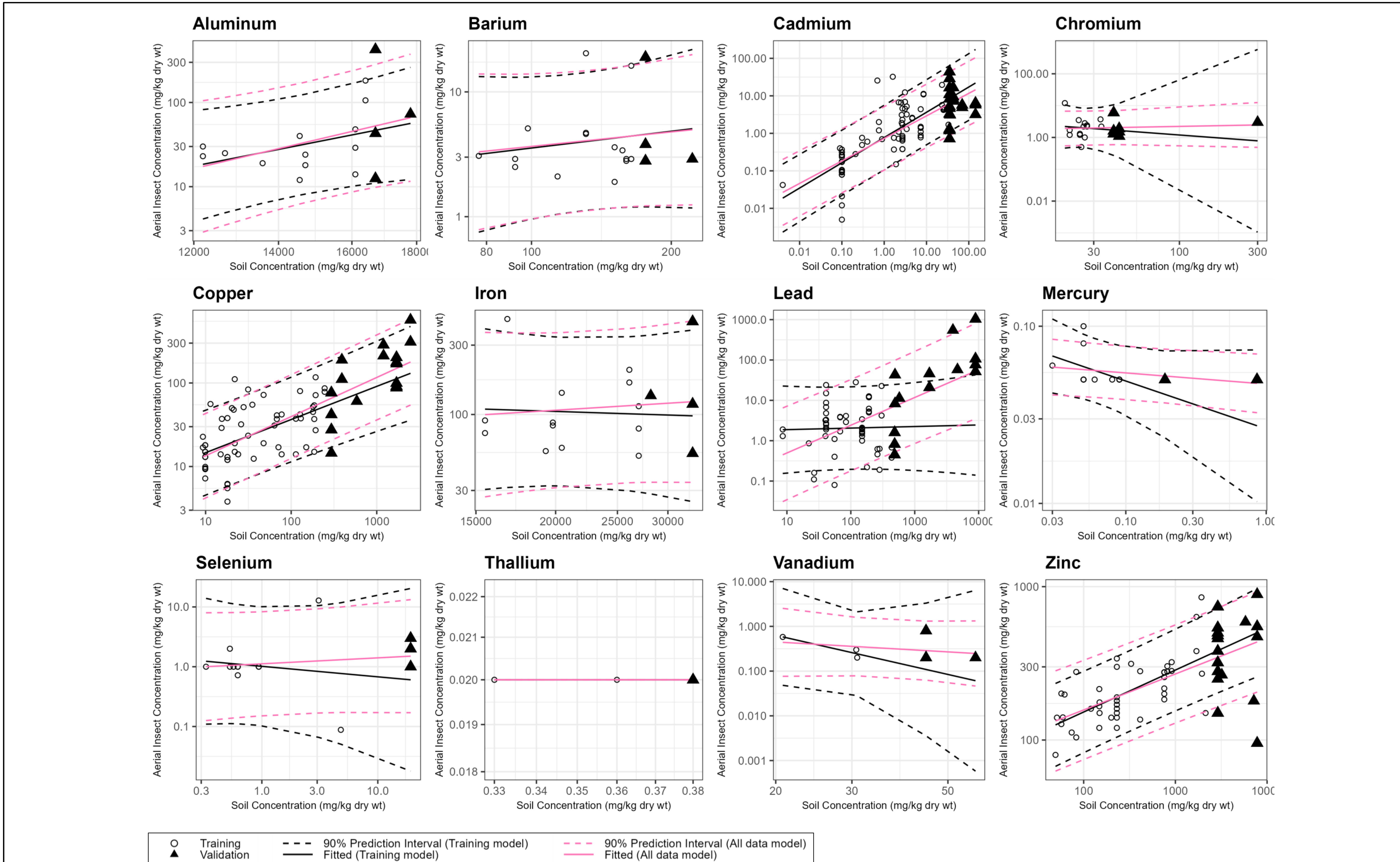

Figure E-16. Truncated (High) Validation for Aerial Insects

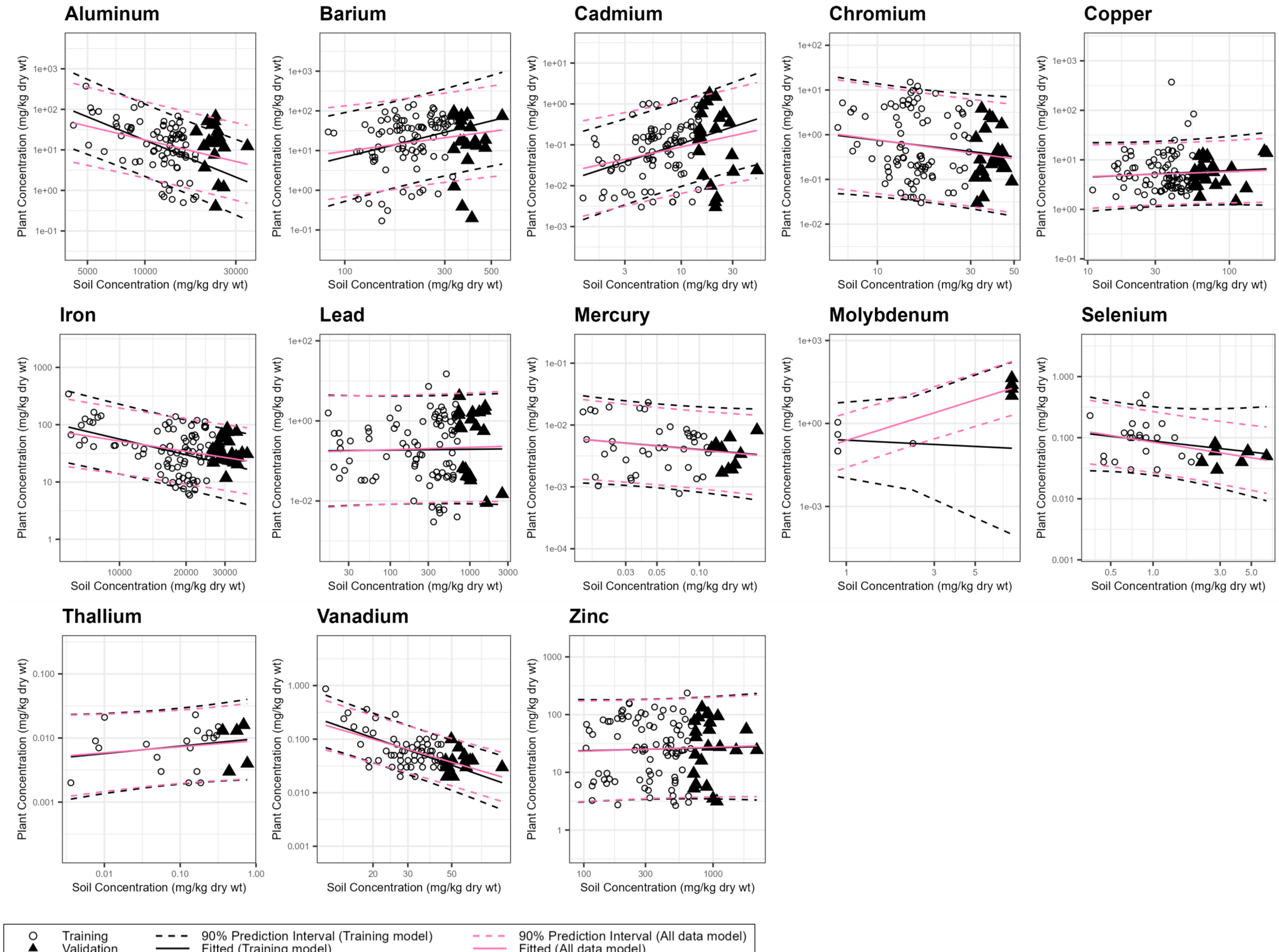

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Figure E-17. Truncated (High) Validation for Aboveground Terrestrial Plant Parts

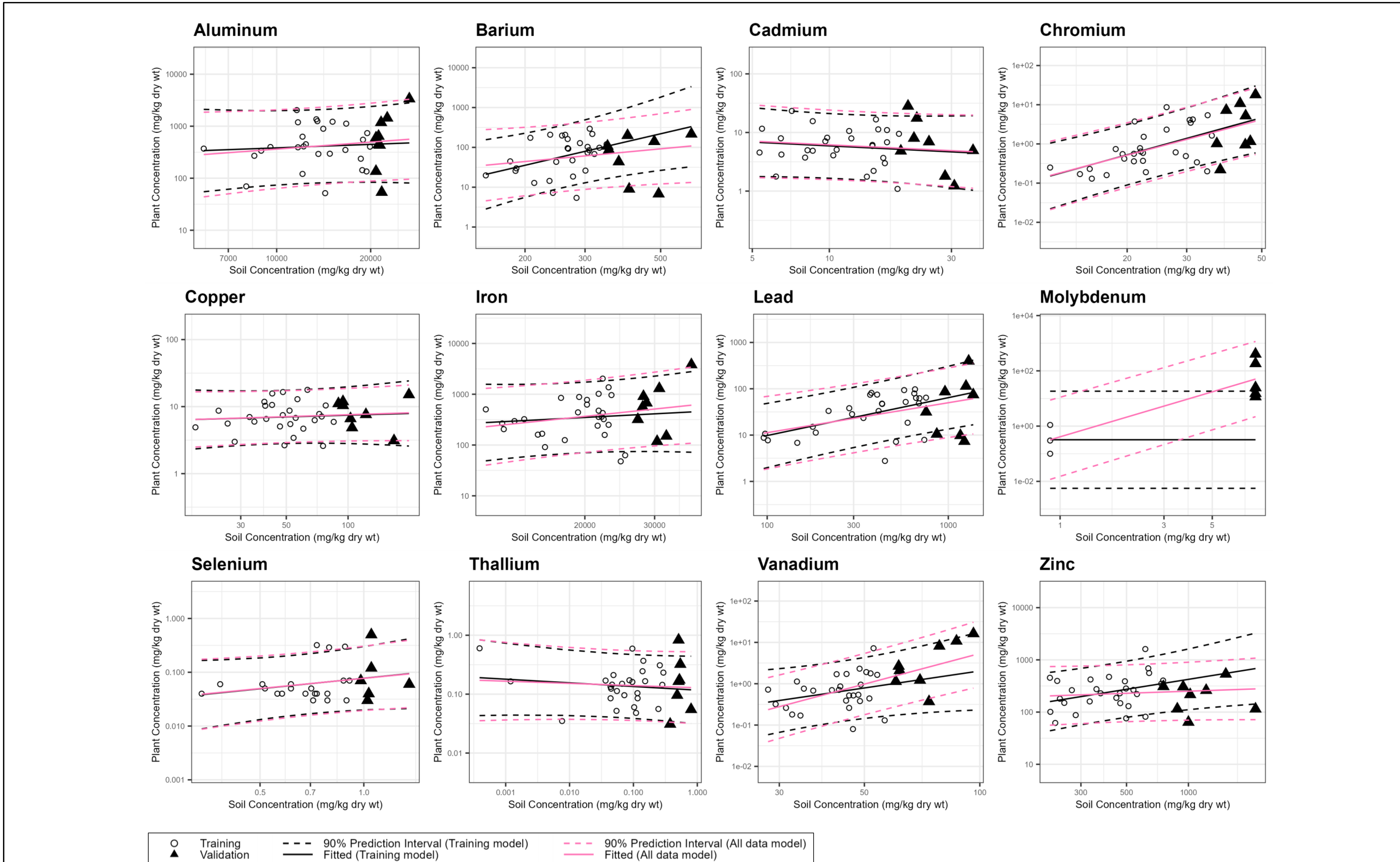

Figure E-18. Truncated (High) Validation for Belowground Terrestrial Plant Parts

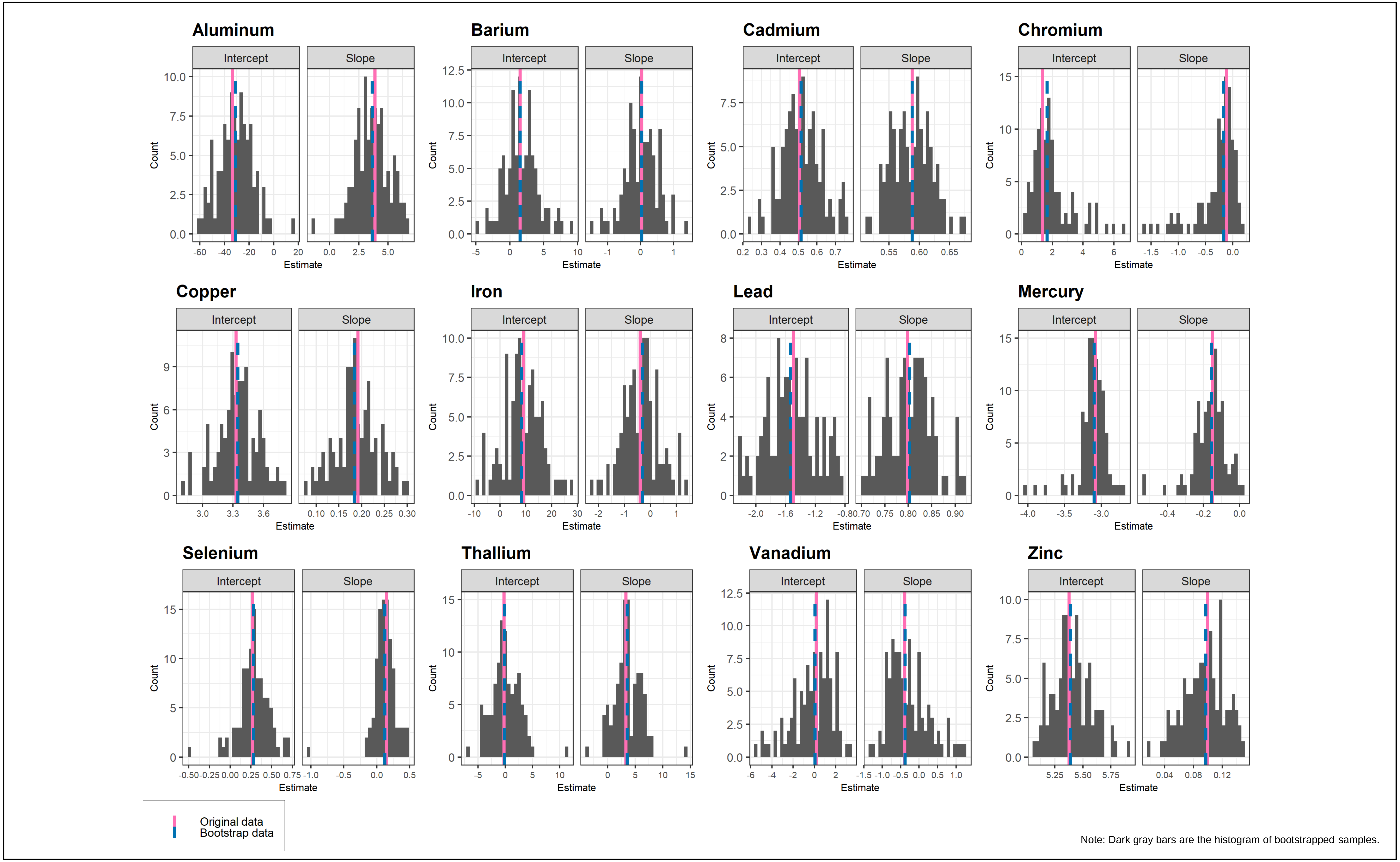

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Figure E-19. Bootstrap Regression Model Parameter Estimates for Terrestrial Arthropods

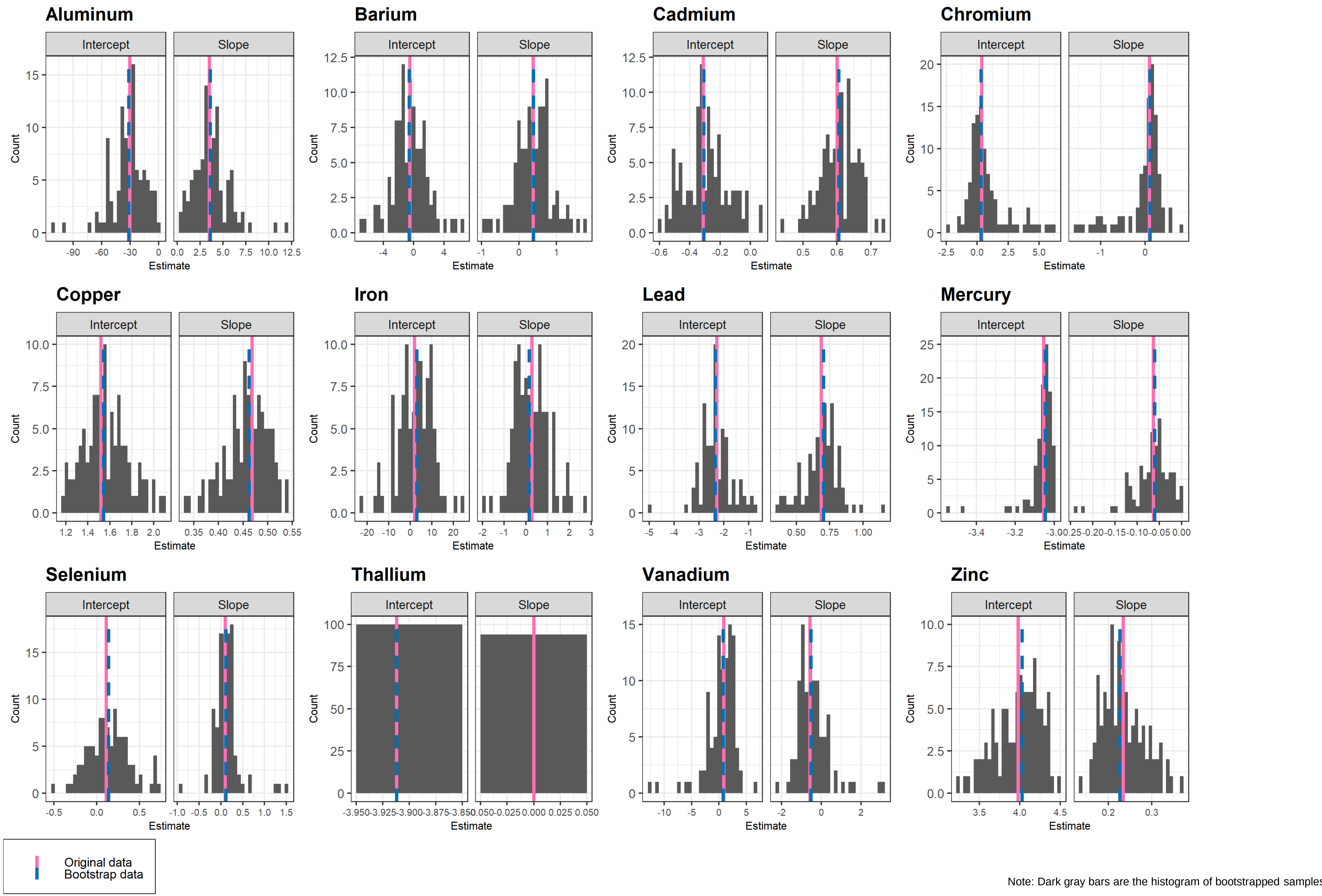

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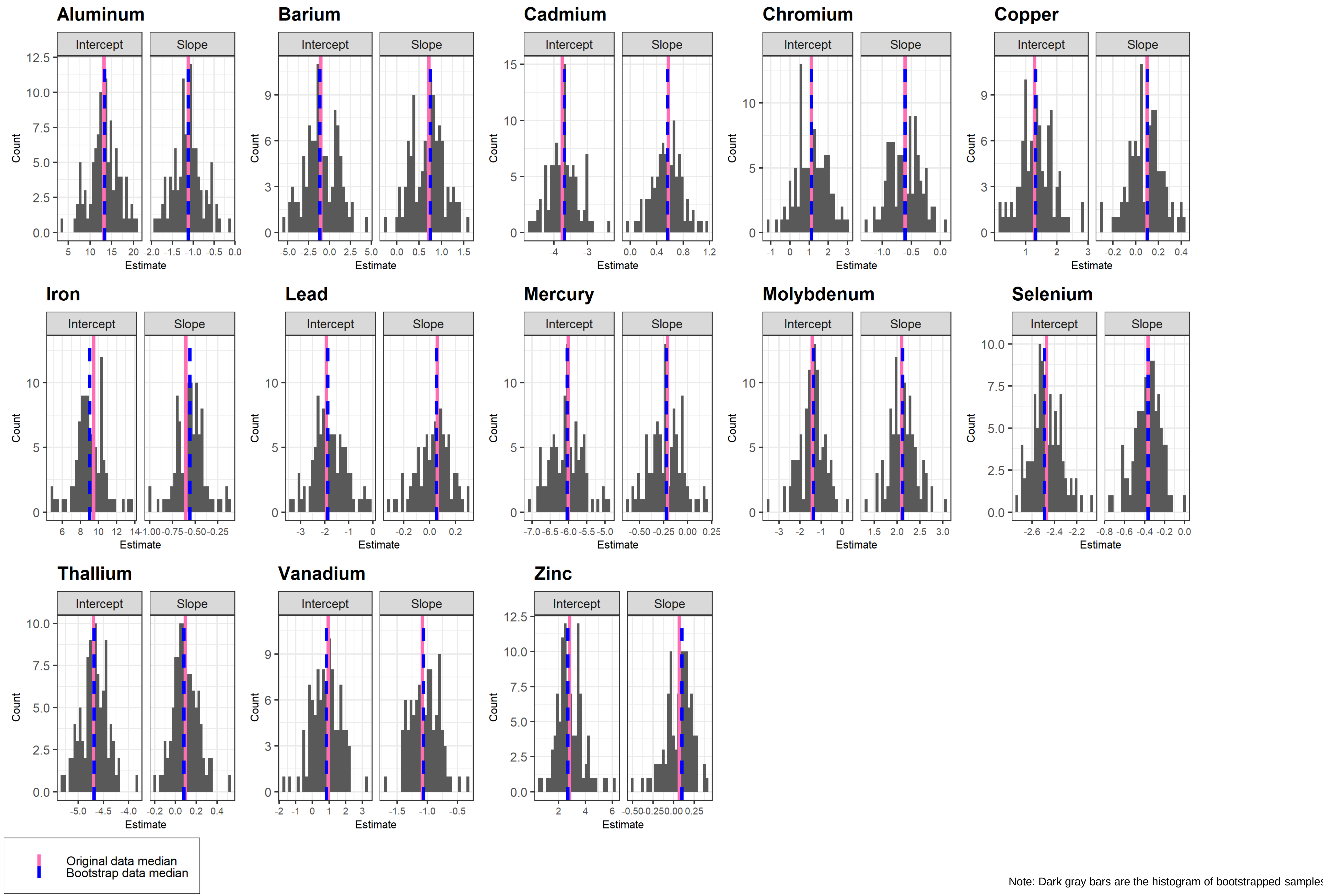
Figure E-20. Bootstrap Regression Model Parameter Estimates for Aerial Insects



Note: Dark gray bars are the histogram of bootstrapped samples.

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Figure E-21. Bootstrap Regression Model Parameter Estimates for Aboveground Terrestrial Plant Parts

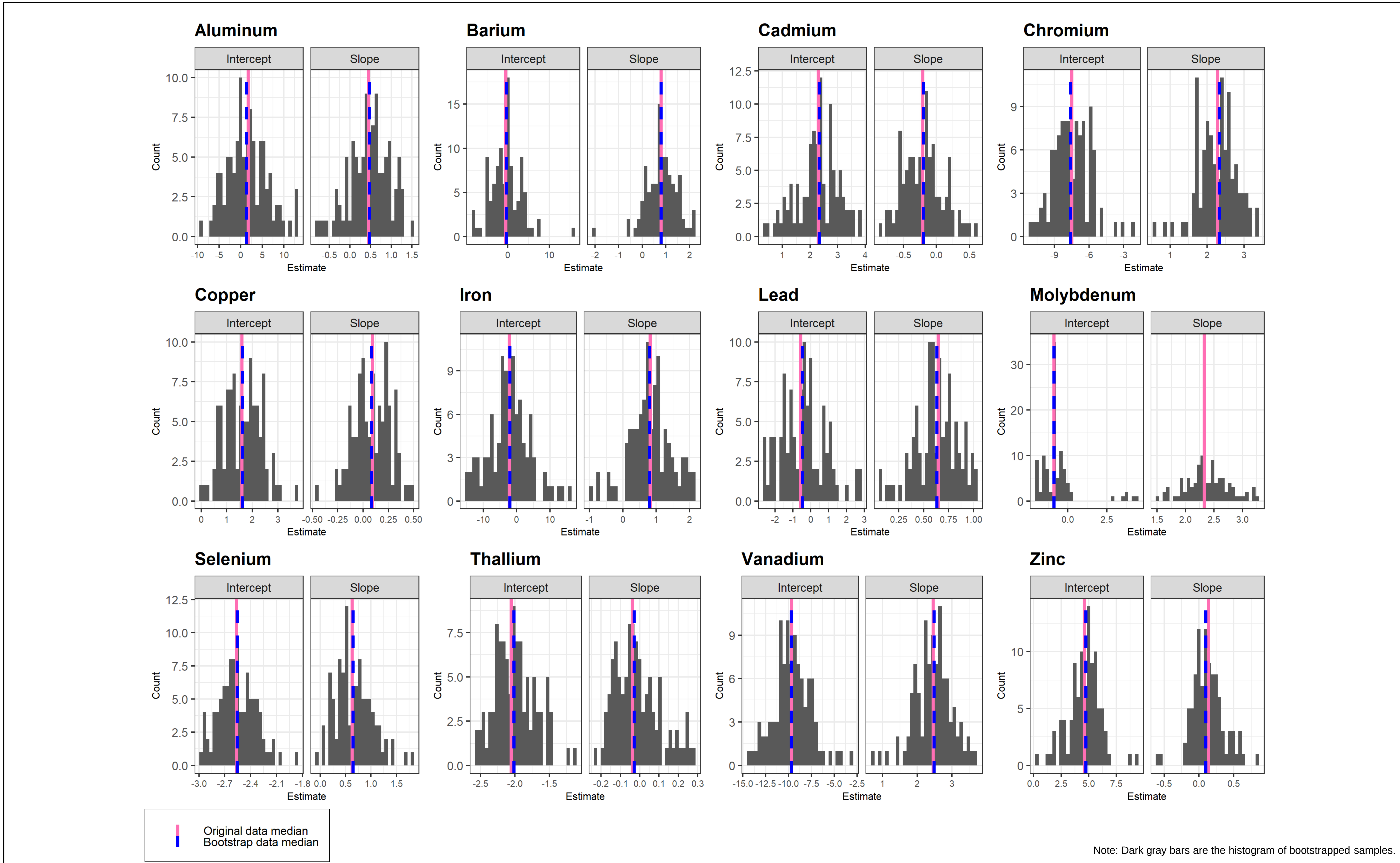

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Figure E-22. Bootstrap Regression Model Parameter Estimates for Belowground Terrestrial Plant Parts

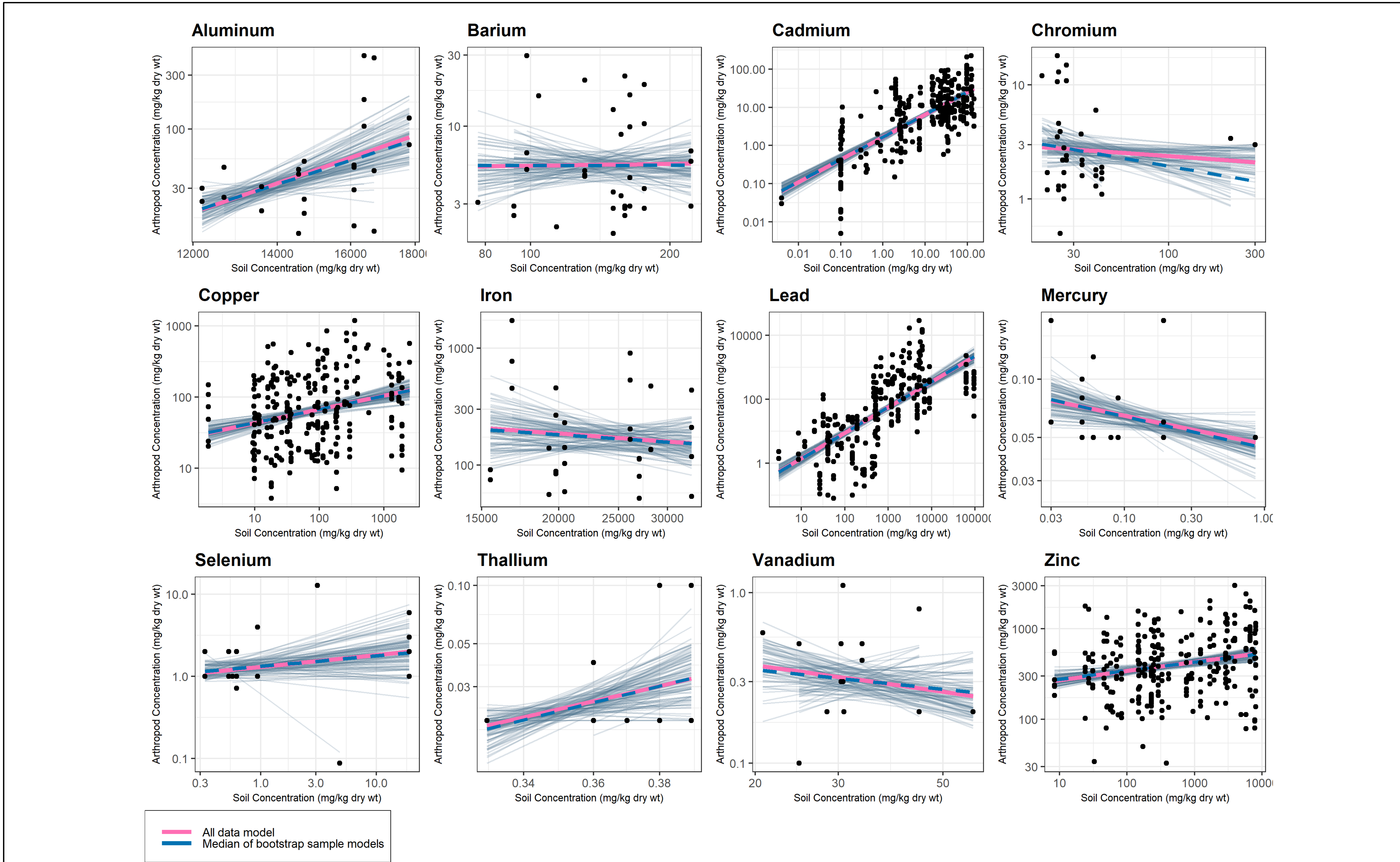

Figure E-23. Bootstrap Regression Model Fits for Terrestrial Arthropods

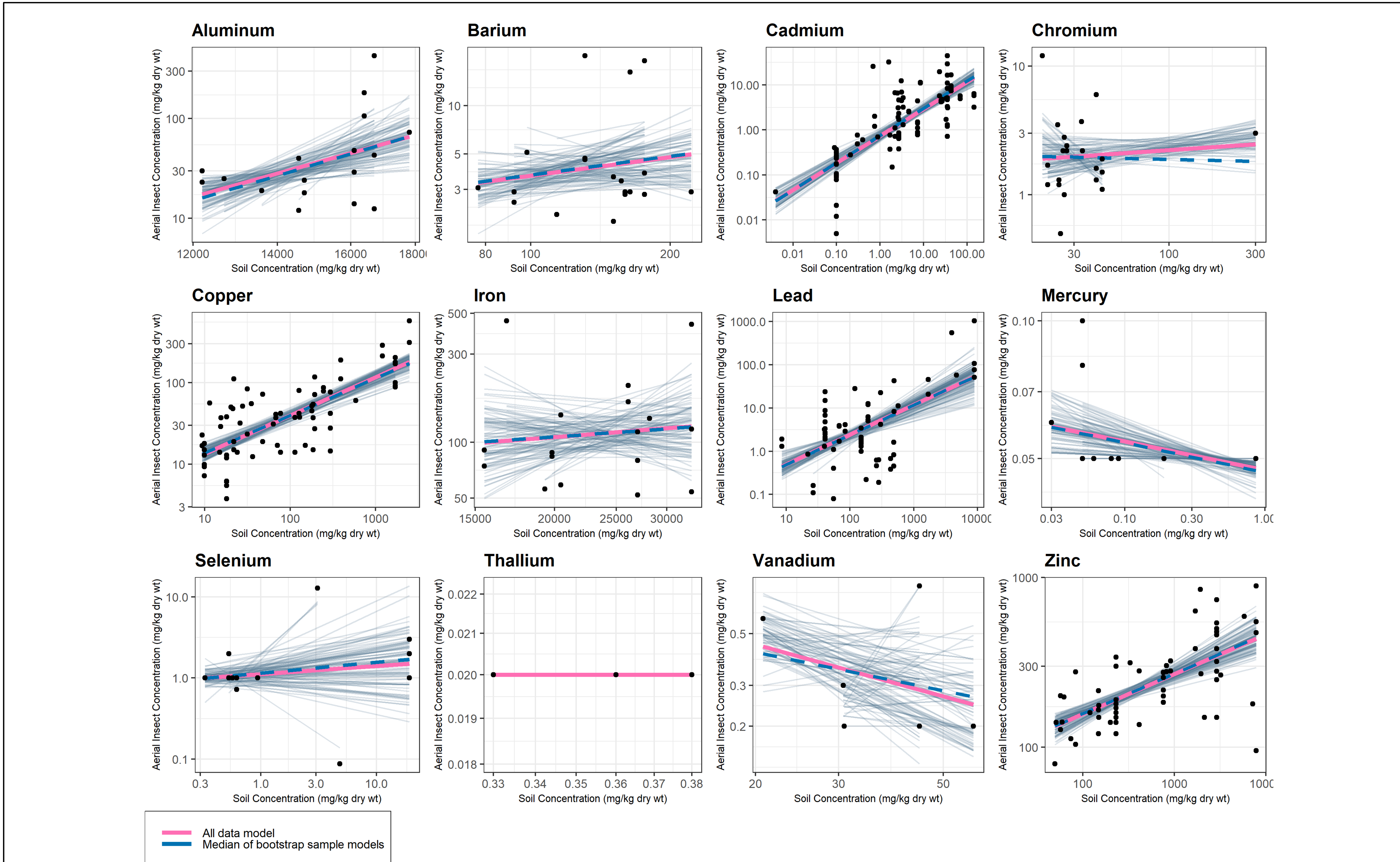

Figure E-24. Bootstrap Regression Model Fits for Aerial Insects

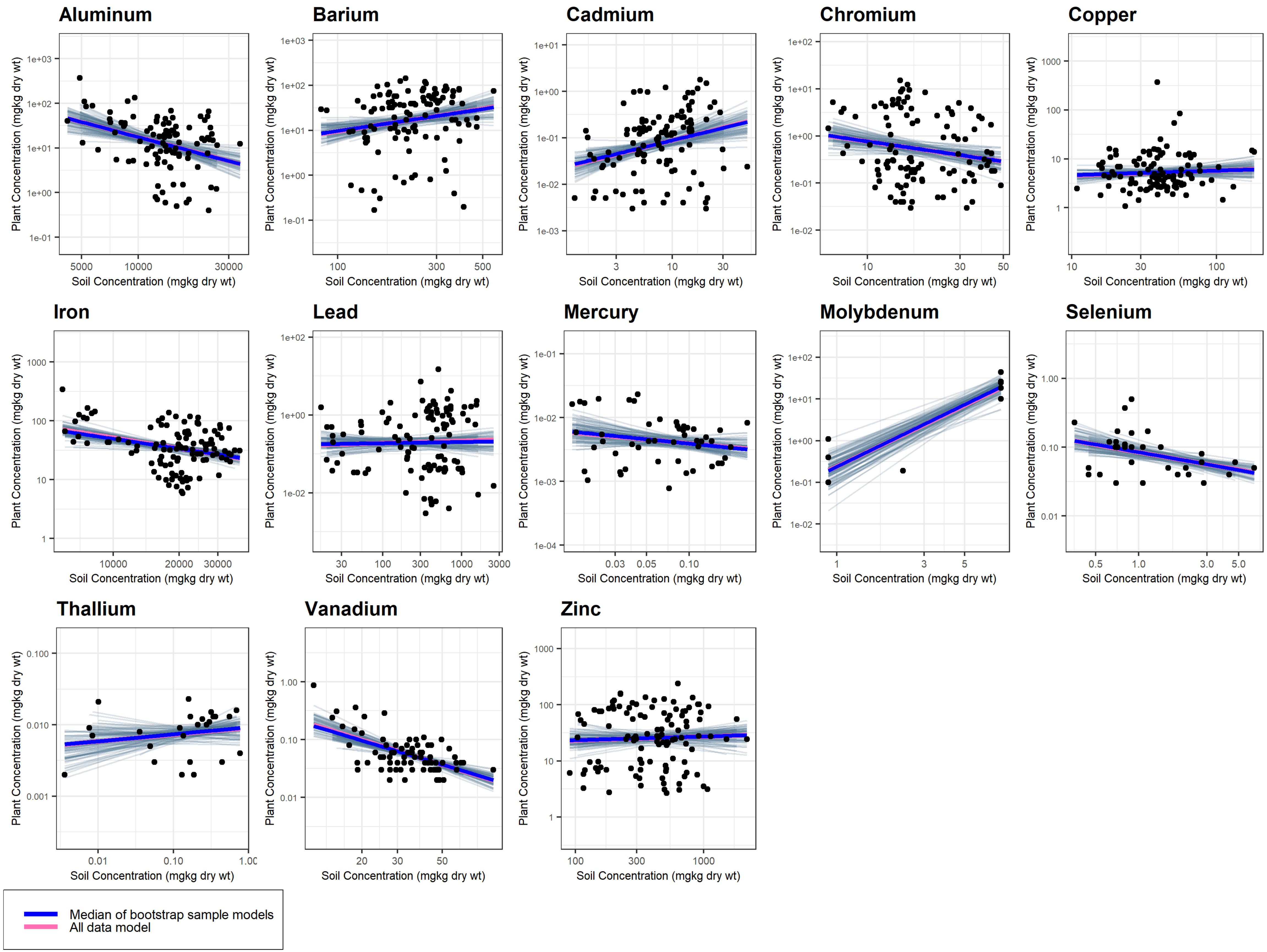

Figure E-25. Bootstrap Regression Model Fits for Aboveground Terrestrial Plant Parts

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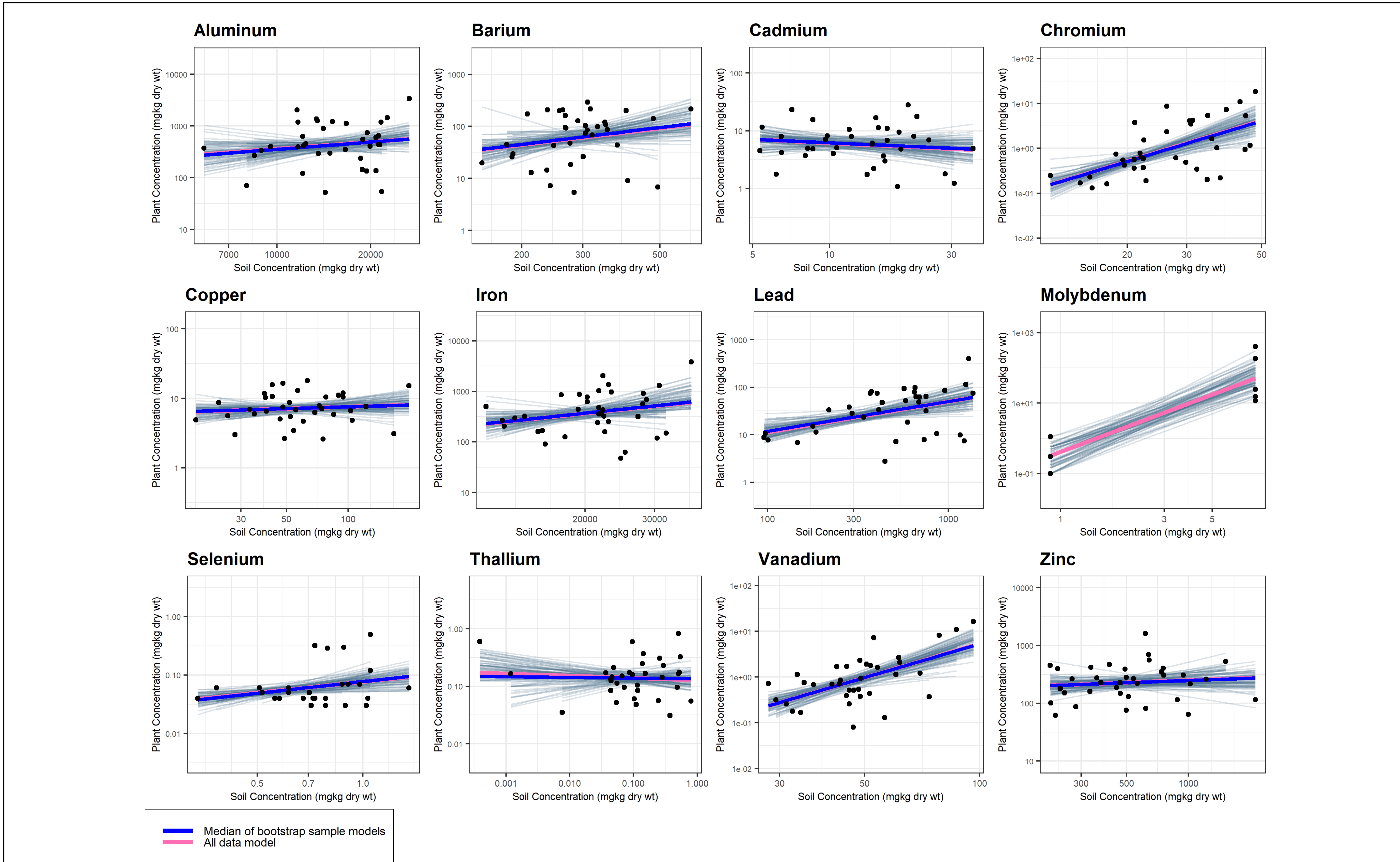

Figure E-26. Bootstrap Regression Model Fits for Belowground Terrestrial Plant Parts

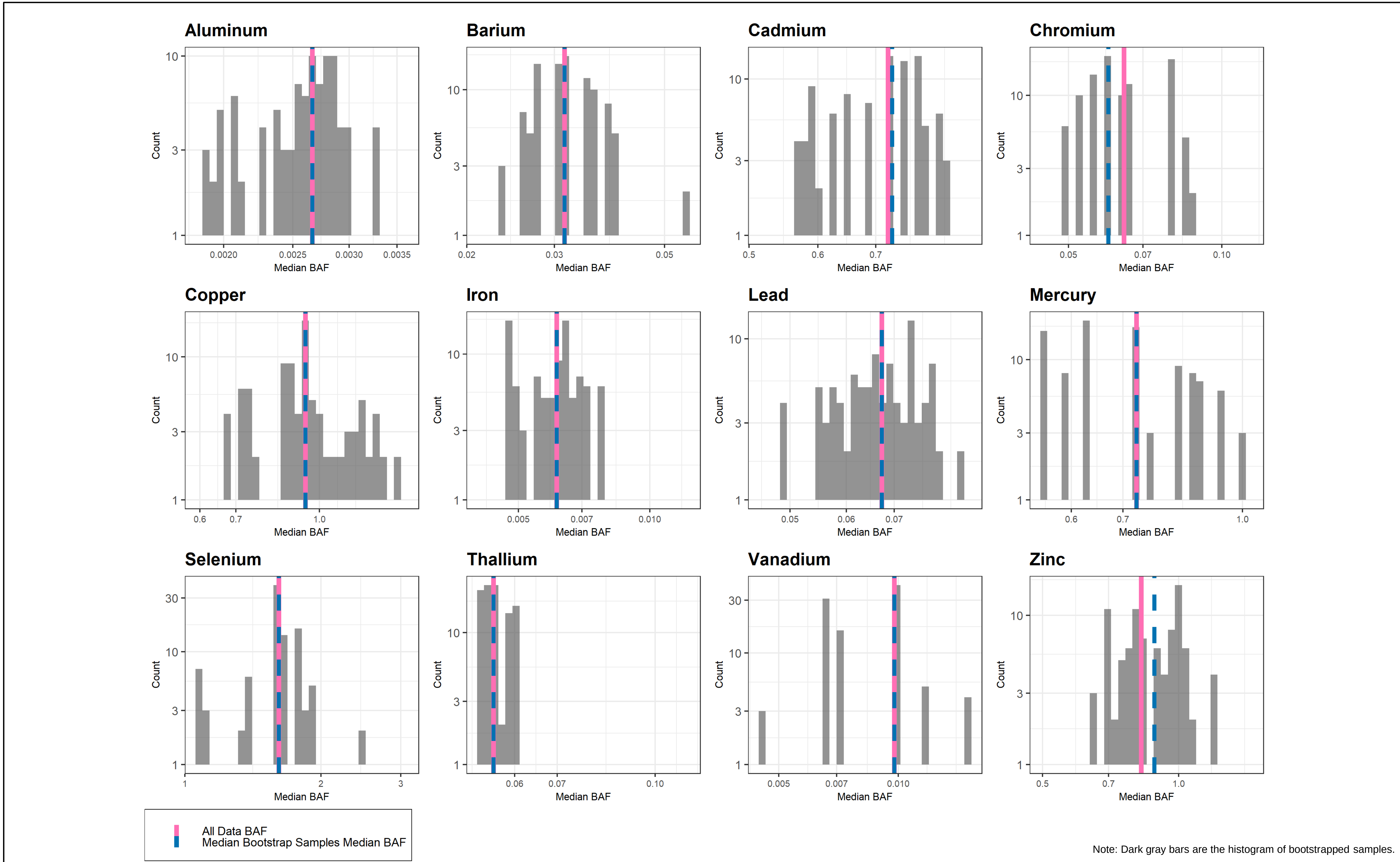

Figure E-27. Bootstrap Median BAF Estimates for Terrestrial Arthropods

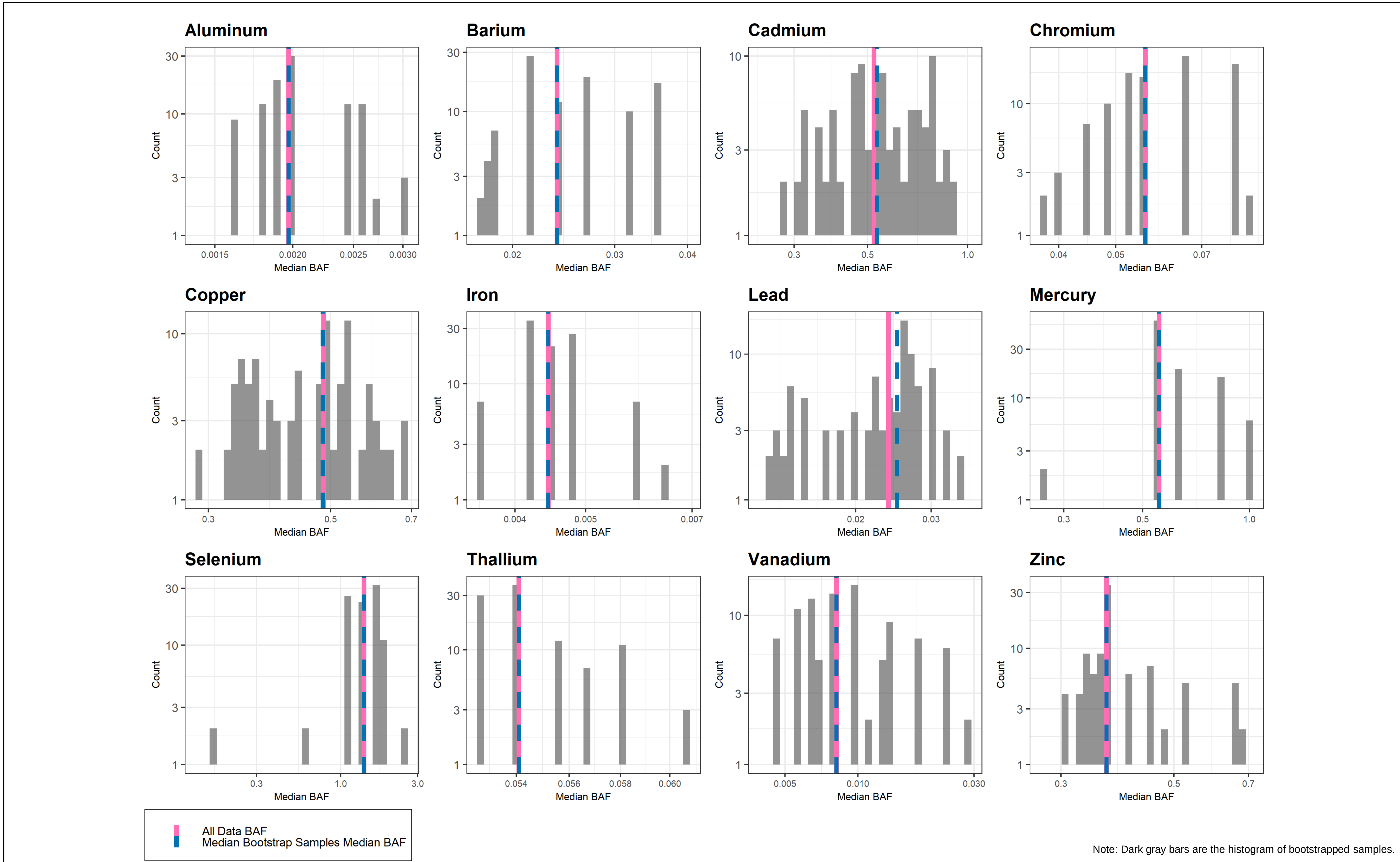

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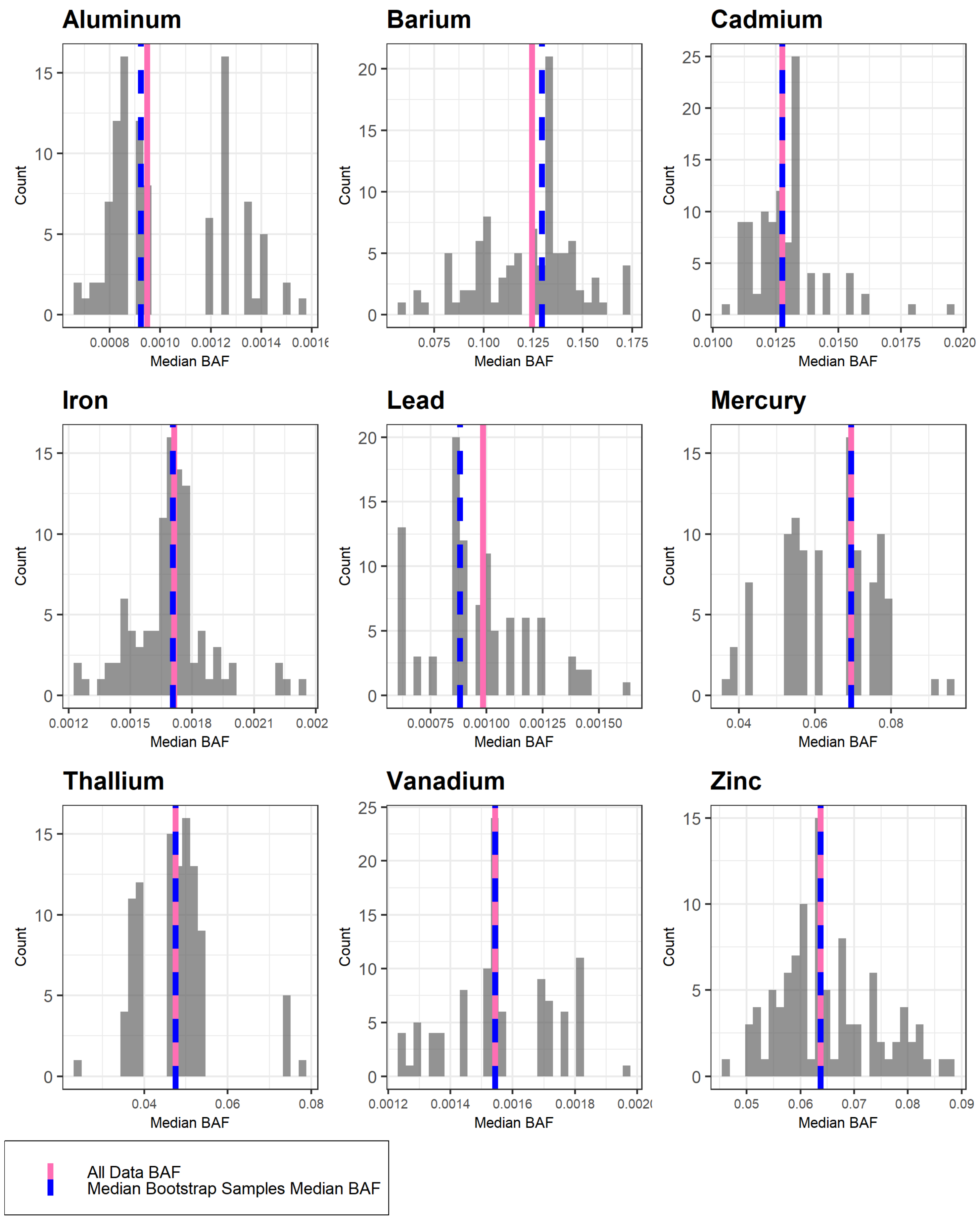
Figure E-28. Bootstrap Median BAF Estimates for Aerial Insects



Note: Dark gray bars are the histogram of bootstrapped samples.

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Figure E-29. Bootstrap Median BAF Estimates for Aboveground Terrestrial Plant Parts

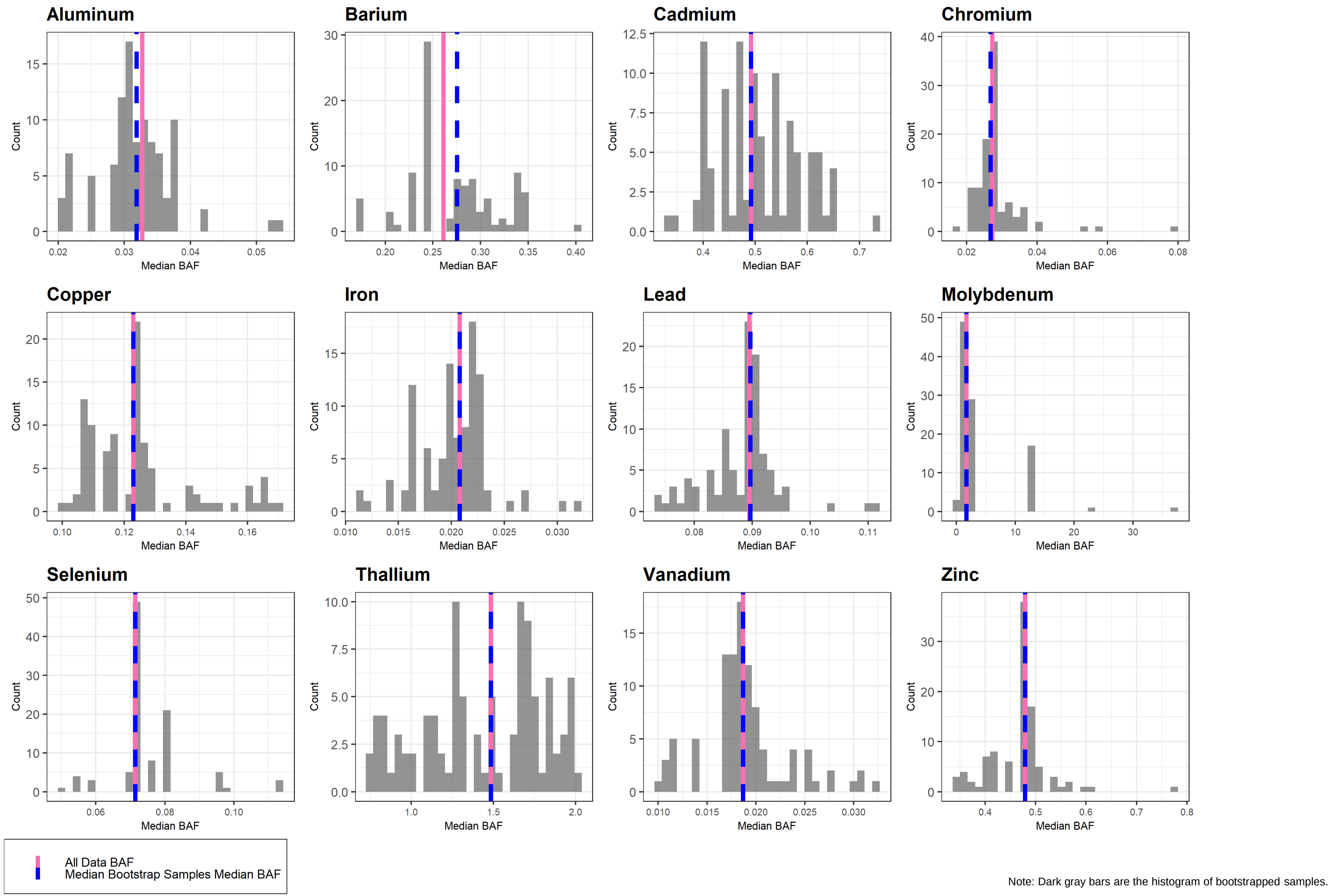

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Figure E-30. Bootstrap Median BAF Estimates for Belowground Terrestrial Plant Parts

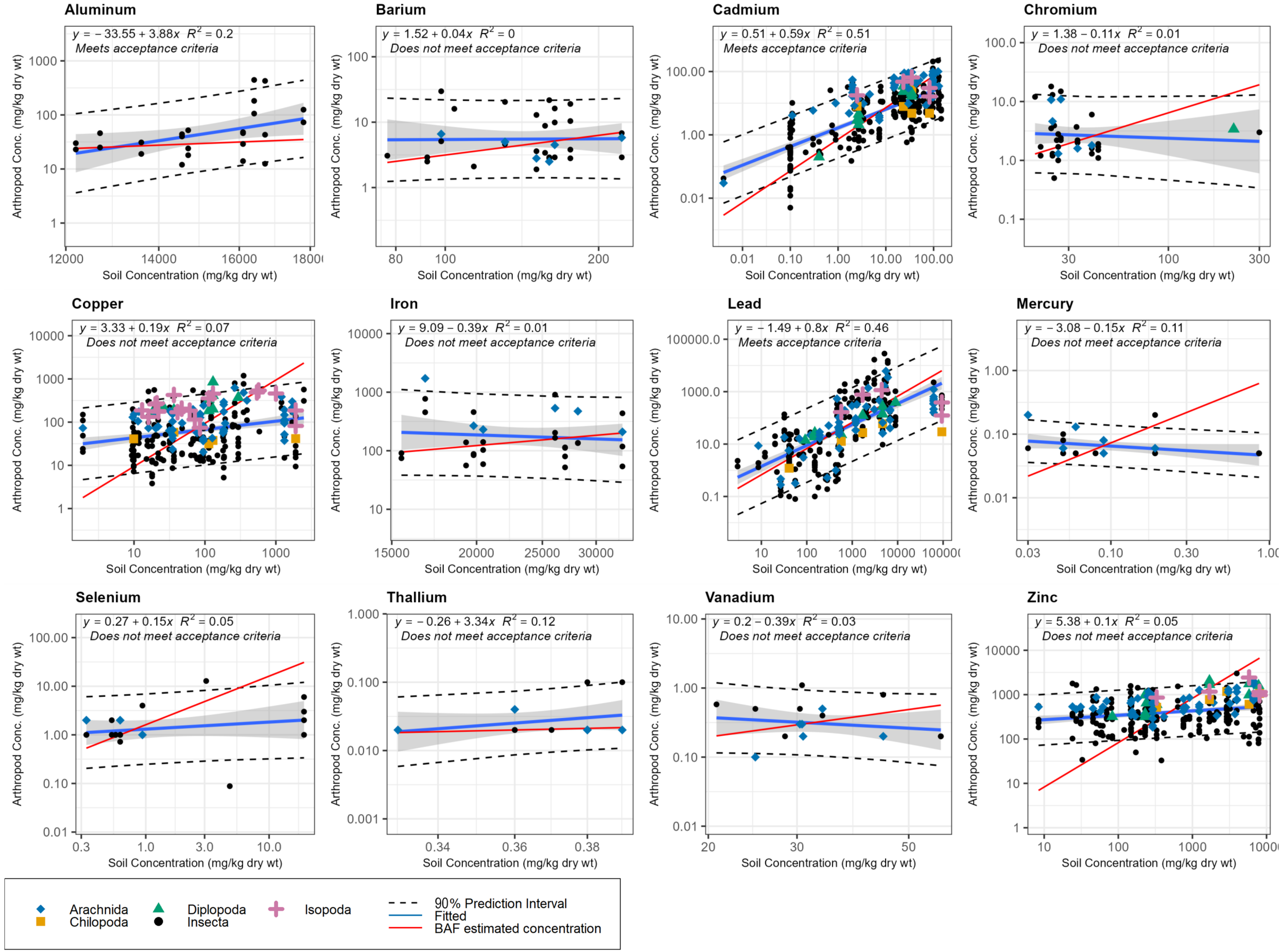

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Figure E-31. Regression Models using All Data for Terrestrial Arthropods

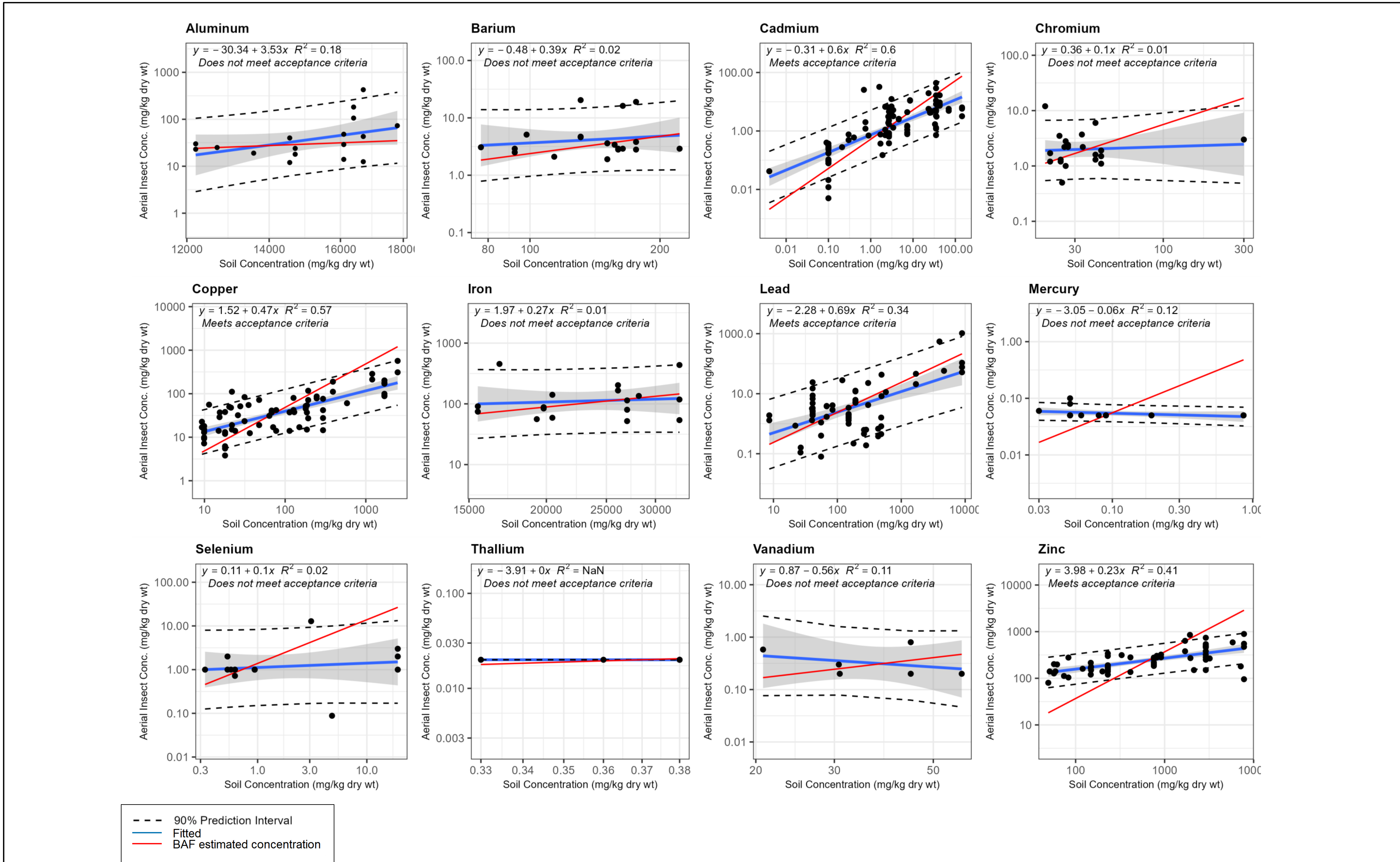

Figure E-32. Regression Models Using All Data for Aerial Insects

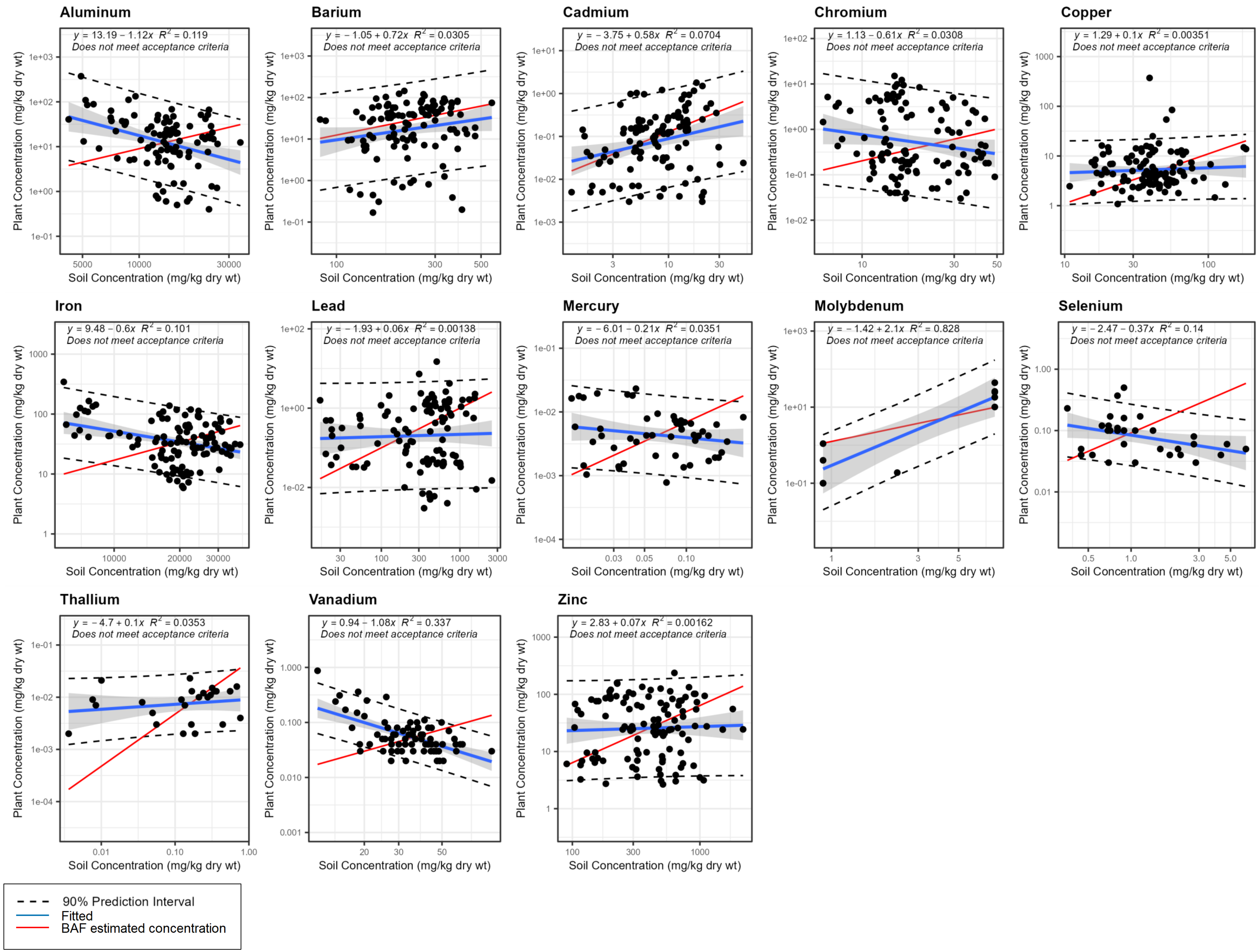

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Figure E-33. Regression Models Using All Data for Aboveground Terrestrial Plant Parts

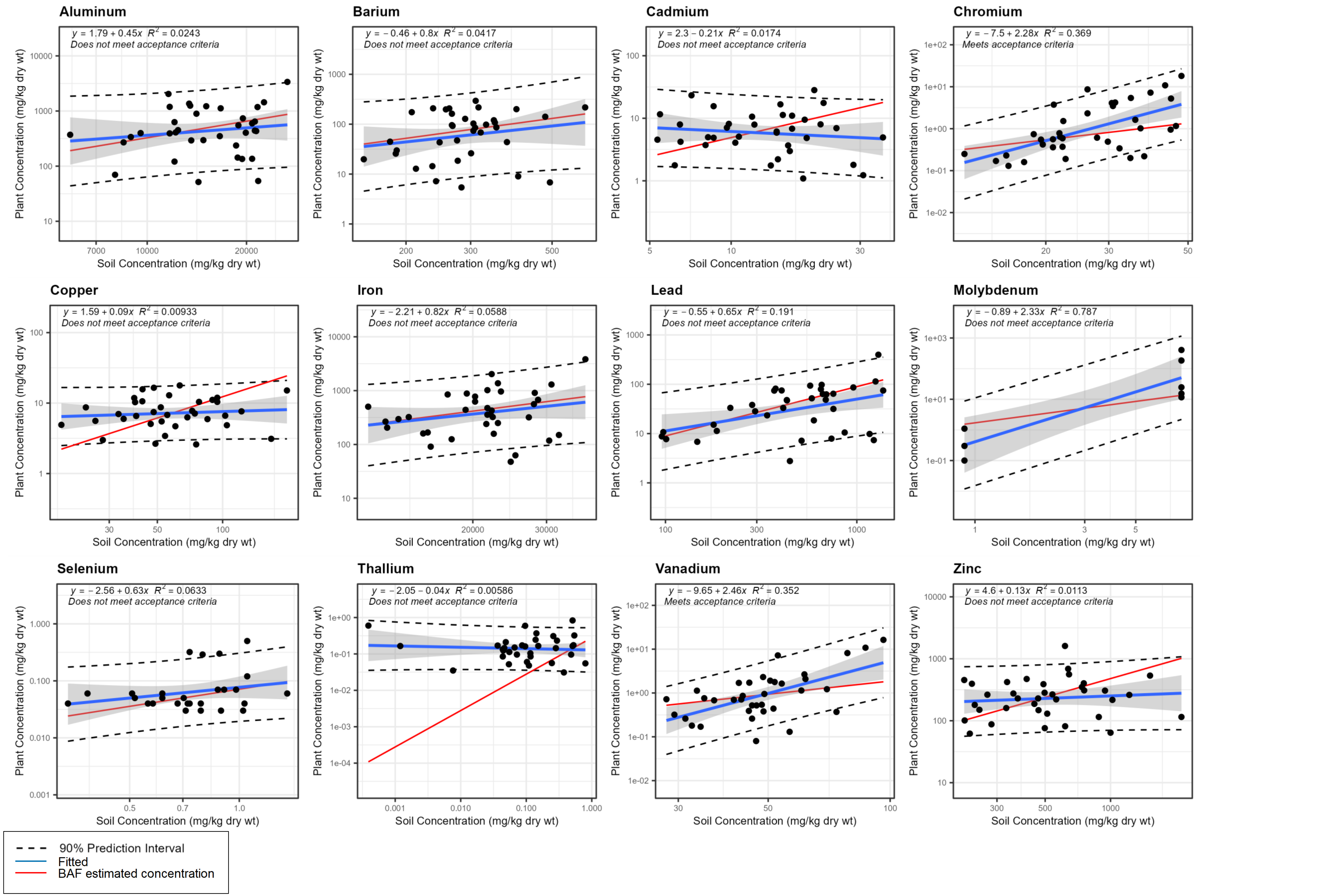

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Figure E-34. Regression Models Using All Data for Belowground Terrestrial Plant Parts

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