STRATUS CONSULTING

Associating Soil Lead with Adverse Effects on Songbirds in the Southeast Missouri Mining District

Prepared for:

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Contents

Figures

Tables

Acronyms and Abbreviations

ALAD	δ-aminolevulinic acid dehydratase
dw	dry weight
EcoSSL	Ecological Soil Screening Level
HEA	habitat equivalency analysis
LD50	dose lethal to 50% of the organisms
NRDA	natural resource damage assessment
PRG	preliminary remediation goal
ROD	Record of Decision
SEMO	Southeast Missouri Mining District
USFWS	U.S. Fish and Wildlife Service
ww	wet weight

1. Introduction

The U.S. Fish and Wildlife Service (USFWS) retained Stratus Consulting to help develop a model to relate lead concentrations in soils to natural resource injuries and compensable damages for the Southeast Missouri Mining District (SEMO) natural resource damage assessment (NRDA). Originally, the USFWS estimated natural resource injuries based on impacts to vegetation, using floristic quality indices. Whereas terrestrial injuries at some lead-contaminated mine sites have been quantified using vegetation metrics [e.g., parts of the Coeur d'Alene Basin, Idaho (Stratus Consulting, 2000); Anaconda, Montana (Kapustka, 2002); Arkansas River, Colorado (Industrial Economics, 2006)], soils at those other mine sites were highly contaminated with other metals (cadmium, copper, zinc) to which plants are likely more sensitive than to lead. At the SEMO sites, where lead is the primary metal of concern, vegetation injuries may not be a sensitive indicator of terrestrial effects and may underestimate injuries to other Trustee resources such as songbirds.

In this draft report, we discuss approaches that could be considered as a basis for relating soil lead to songbird injuries. Specifically, we discuss data from laboratory toxicity studies that relate tissue lead concentrations to observed adverse effects. We then discuss how these data were used at another site with mining-related lead contamination, summarizing the relationship between soil lead and songbird tissue lead concentrations measured at that site. We present site-specific data from SEMO and discuss how the data can be used to estimate natural resource injuries at SEMO. Finally, we present a proposed model that the SEMO Trustees could use to quantify natural resource injuries using a restoration-based approach.

The remainder of this document is organized as follows: In Chapter 2, we discuss observed adverse effects of lead in songbirds, summarizing review papers by Franson (1996), Pain (1996), Buekers et al. (2009), and Franson and Pain (2011), as well as a laboratory study by Beyer et al. (1988). Chapter 3 then presents relevant methods and data from the Coeur d'Alene Basin in Idaho and from SEMO, comparing the data and providing a proposed method for injury quantification.

2. Effects of Lead on Birds

Franson (1996), Pain (1996), and Franson and Pain (2011) discuss the adverse effects of lead on birds, summarizing data from numerous laboratory and field toxicity studies across a broad range of bird species, lead types (e.g., lead shot, lead fishing weights, lead paint, lead-contaminated soil), and dosing methods. Despite numerous variables, the data presented in the three Franson and Pain summary papers consistently show lead concentrations in bird tissues increase with increased lead ingestion, and that the degree of adverse effects increases with increasing lead tissue concentrations. Those authors also proposed tissue-based concentration thresholds as a means of evaluating the adverse effects of lead in birds. These published concentration thresholds could be used as the basis for a revised injury scaling model.

To aid in evaluating the applicability of the published concentration thresholds in developing an injury scaling model, we extracted and inspected data on lead in tissues as summarized in the Franson (1996), Pain (1996), and Franson and Pain (2011) publications. Blood lead concentrations in µg/dL were converted to mg/kg wet weight (ww) by first converting to µg/L, and then dividing by the density of avian blood (approximately 1.05 g; Gurkan and Akkus, 2008). Tissue concentrations in mg/kg ww were converted to dry weight (dw) assuming 82% moisture for blood and 66% moisture for liver (Hansen et al., 2011).

Franson and Pain (2011) classified the adverse effects data into clinical effects categories, based on pathological observations (Table 2.1). These categories included background/no exposure/no adverse effect, and three categories of lead poisoning: subclinical poisoning, clinical poisoning, and severe clinical poisoning. Subclinical poisoning was defined as physiological effects insufficient to severely impair normal biological functioning (e.g., suppressed δ-aminolevulinic acid dehydratase, or ALAD). Clinical poisoning was used as a threshold marking pathological manifestations of physiological effects, such as anemia, weight loss, lesions, or anorexia. Clinical poisoning responses would be expected to impair the viability of organisms in field settings. Severe clinical poisoning was an approximate threshold for directly life-threatening pathological effects.

Beyer et al. (2013) subsequently suggested a revised nomenclature for these three categories of adverse effects from lead: “adverse physiological effects” rather than subclinical poisoning; “systematic toxic effects” rather than clinical poisoning; and “directly life-threatening effects” rather than severe clinical poisoning. This revised nomenclature is used hereafter.

For the orders of Anseriformes, Falconiformes, and Columbiformes, Franson and Pain (2011) present concentration thresholds/ranges corresponding to adverse physiological, systematic toxic, and directly life-threatening effects. The ranges/thresholds for lead levels in blood and liver in Anseriformes and Falconiformes are identical; the blood and liver lead thresholds for Columbiformes are somewhat higher (Table 2.1).

Table 2.1. Tissue-based adverse effect levels for lead in blood and liver for three orders of birds, as presented in Franson and Pain (2011)[a]

	Blood Pb (mg/kg dw)	Liver Pb (mg/kg dw)
Anseriformes and Falconiformes		
Background	< 1.1	< 5.9
Adverse physiological effects	1.1–2.6	5.9–17.6
Systematic toxic effects	> 2.6–5.3	> 17.6–29.4
Directly life-threatening effects	> 5.3	> 29.4
Columbiformes		
Background	< 1.1	< 5.9
Adverse physiological effects	1.1–10.6	5.9–17.6
Systematic toxic effects	> 10.6–15.9	> 17.6–44.1
Directly life-threatening effects	> 15.9	> 44.1

a. Blood data converted from µg/dL; liver data converted from mg/kg ww.

Buekers et al. (2009) also examined the relationship between adverse effects and lead tissue concentrations. They compiled blood lead and adverse effects data for a wide variety of studies on both birds and mammals, proposing critical blood concentrations for the onset of adverse effects. They concluded that (1) biochemical adverse effects such as ALAD inhibition occur at considerably lower blood lead concentrations than adverse effects to other endpoints such as growth or reproduction (Figure 2.1), and (2) mammals are more sensitive to lead than birds (Figure 2.2). Based on the cumulative data for blood lead concentrations in birds exhibiting toxic endpoints other than ALAD inhibition (e.g., growth, reproduction, other physiological effects), they proposed a blood lead concentration of 3.8 mg/kg dw as a threshold below which 95% of birds in their dataset showed no adverse effects. This value is generally consistent with the Franson and Pain (2011) proposed range for adverse physiological effects (Table 2.1). It is worth noting, however, that the proposed value protective of 95% of the mammals in the Buekers et al. (2009) dataset is < 1 mg/kg dw. This suggests that mammals would exhibit adverse effects from lead at lower tissue doses than those that cause adverse effects in birds.

Franson and Pain (2011) and Buekers et al. (2009) include relatively few data on Passeriformes (songbirds). Data from studies of passerines exposed to lead (e.g., Beyer et al., 1988, 2004) suggest that songbirds may incorporate lead into their tissues at a faster rate than other bird species, which in turn could suggest that the Franson and Pain (2011) tissue lead thresholds (Table 2.1) could underestimate adverse effects of lead in songbirds.

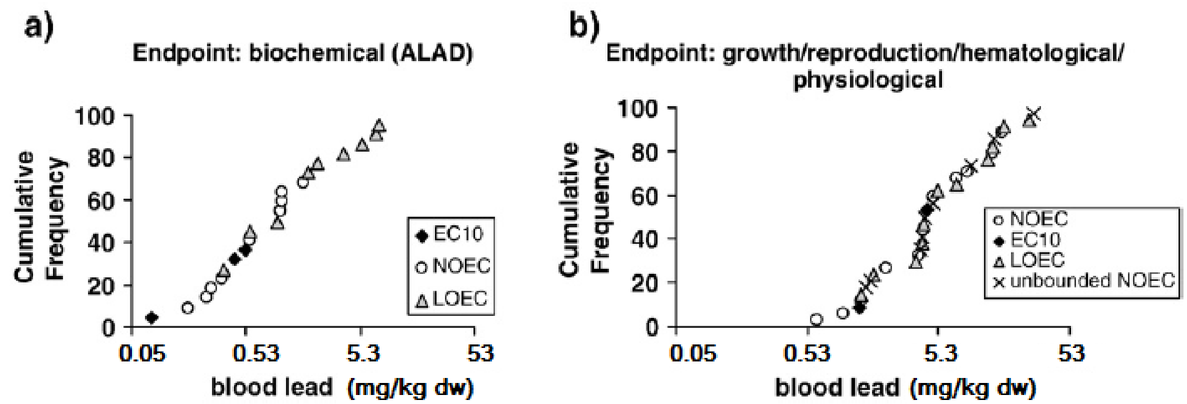


Figure 2.1. Cumulative frequency of adverse effects thresholds for (a) ALAD inhibition and (b) other toxic endpoints for birds and mammals from multiple studies.

Source: Buekers et al., 2009, Figure 1 (with modified units on x axis).

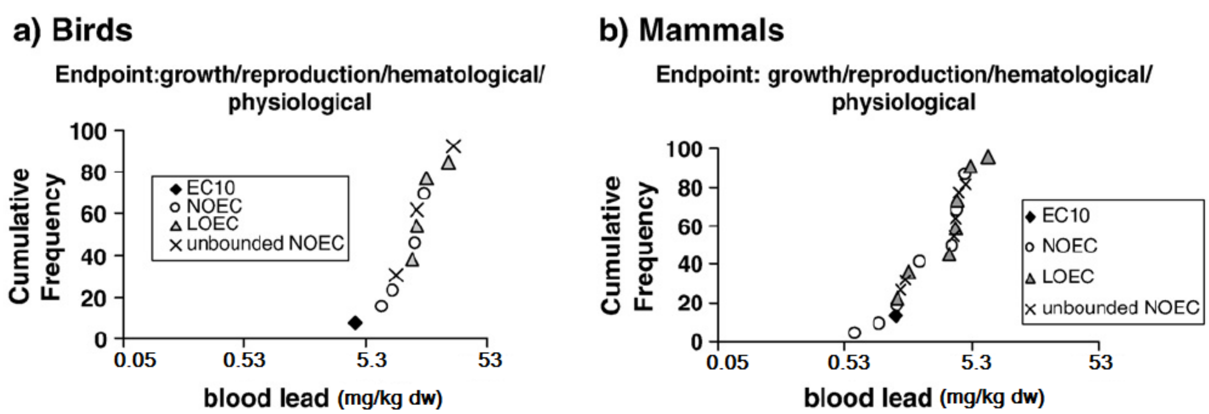


Figure 2.2. Cumulative frequency of adverse effects thresholds (not including biochemical endpoints such as ALAD inhibition) for (a) birds and (b) mammals from multiple studies.

Source: Buekers et al., 2009, Figure 2 (with modified units on x axis).

At SEMO, Beyer et al. (2013) captured primarily northern cardinals and American robins. These two species are good representatives of the range of dietary preferences for ground-foraging passerine species, with the robins' breeding season diet consisting primarily of ground-dwelling invertebrates, while the northern cardinal's diet is dominated by plant materials (Table 2.2). Exposure to lead in soils for many of the Beyer et al. (2013) species may be influenced by diet, foraging strategies, and in some instances nesting sites (Table 2.2). Hansen et al. (2011) and Beyer et al. (2004) suggested that higher-than-expected lead concentrations in song sparrows and a brown thrasher, respectively, may be the result of foraging techniques such as digging and scratching that disturbs soils and potentially leads to additional exposure.

Table 2.2. Factors potentially affecting soil ingestion in passerine species collected by Beyer et al. (2013) and additional passerine species likely to be present in SEMO

Species	Body weight (g)	Diet (during breeding season)	Foraging technique	Foraging habitat
Species that Beyer et al. (2013) collected				
American robin	77–85	Omnivorous (90% animal in spring, up to 90% fruit in fall)	Probing with beak	Ground
Eastern towhee	32–52	Omnivorous (invertebrates and fruit/seeds)	Two-footed scratching at ground	Ground and arboreal
Blue jay	70–100	Omnivorous (invertebrates, eggs, vertebrates, seeds, acorns)	Digging with beak	Ground and arboreal
Brown-headed cowbird	38–50	Omnivorous (75% seeds, 25% animal)	Probing with beak	Prefers recently disturbed habitat
Carolina wren	18–22	Omnivorous (62% animal, 38% plant)	Lifting and probing with beak	On or near ground level, with forage in leaf litter
Northern cardinal	43–45	Omnivorous (29% animal, 71% plant)	Beak adapted for breaking seeds	Ground for seeds, canopy for buds
Additional species potentially in SEMO				
Acadian flycatcher	11–14	Primarily insectivorous	Generally at 2–4 m height; underside of leaves and in air	Alongside streams
Song sparrow	12–53	Omnivorous (> 50% animal)	Scratching ground with both feet	Ground, foliage, and in air
Summer tanager	30	Primarily insectivorous, with berries in later summer	Gleaning from leaves and in air	Above-ground level
Swainson's thrush	23–45	Omnivorous (up to 90% animal in spring, 60–80% fruit in fall)	Pecking and gleaning from ground and litter	Near ground
Worm-eating warbler	12–14	Primarily insectivorous	Primarily gleans	Leaf litter and foliage; nests on ground

Source: BNA Online, 2013.

Beyer et al. (2013) collected data during nesting season, potentially during egg laying or egg production. Home range estimates for the American robin during the breeding season, particularly when on nest, are approximately 2,000 to 8,000 m^2 (Howell, 1942; Young, 1955; Knupp et al., 1977; Pitts, 1984), and the home range of the northern cardinal is on the order of 12,000 m^2 (Dow, 1969). Given the limited home range during breeding season, it is reasonable to assume that captured birds were primarily exposed to lead in soils in the vicinity of the nest. However, songbirds may still exhibit a wide range of tissue lead concentrations even when exposed to similar soil lead concentrations. For example, in laying females, there is a requirement for additional calcium uptake for egg shell production. Uptake of calcium from the gastrointestinal tract is increased, leading to additional lead uptake (Scheuhammer, 1991). This increase in lead uptake could result in higher-than-expected tissue lead concentrations, and/or shorter exposure times to induce toxic effects from lead exposure. Thus, breeding female birds may be exposed to relatively low levels of lead, but the preferential uptake from the gastrointestinal tract could result in high tissue lead levels.

Songbirds also produce altricial young (i.e., young that need parents to provide their nutrition), which require nutrient-rich food sources during development. Custer et al. (2003) sampled nestling tree swallows near an impacted stream that had sufficient lead exposure to result in decreased ALAD. Nestling tree swallows would be expected to have little lead exposure as they are fed insects captured on the wing; however, any lead exposure in a species with such high metabolic rates and nutritional requirements for developing nestlings could lead to rapid accumulation of lead in tissues.

Beyer et al. (1988) conducted a lead dose-response study on passerines (red-winged blackbirds, brown-headed cowbirds, and common grackles) in which lead acetate was added to the diet of the test birds, and the exposures were continued until half of the exposed birds in each experiment died (suggesting a dose lethal to 50% of the organisms, or LD50). The remainder were sacrificed and necropsied. Exposed birds had substantially increased protoporphyrin and decreased ALAD. Most of necropsied birds had inclusion bodies (lesions) in kidneys that are often indicative of toxic effects from lead exposure (Beyer et al., 1988). The median liver lead concentrations [converted from mg/kg ww by Sample et al. (2011)] ranged from 53 mg/kg dw for male red-winged blackbirds to 152 mg/kg dw for female common grackles.[1] These surviving birds suffered from life-threatening adverse effects. The weights of the sacrificed birds had decreased by 20–29% over the course of the study (and the other 50% of the birds in the study had already perished from lead poisoning when these birds were sacrificed). The range of 53–

1. Sample et al. (2011) used slightly different conversion factors. Using the conversion factors described previously in this document, the range is 59 to 147 mg/kg dw. We have reproduced the Sample et al. (2011) numbers here; while the numbers are slightly different, the conclusions are the same using either conversion factor.

152 mg/kg liver lead concentrations in these birds with life-threatening adverse effects is consistent with the Franson and Pain (2011) proposed thresholds (Table 2.1).

While tissue lead concentrations and ALAD suppression resemble those of other avian groups, the songbirds treated with lead acetate (Beyer et al., 1988) did not show the same declines in packed cell volume as mallard and bobwhite quail, which is likely because songbirds have higher metabolic rates and therefore require shorter exposure durations to induce toxic effects. In the Beyer et al. (1988) study, the exposure duration (i.e., the time until 50% of the test birds died) was 26–50 days shorter in songbirds compared to the other birds tested. Passerine basal metabolic rates are 2–3 fold higher than in other avian species (see Rezende et al., 2002; Nagy, 2005). A higher basal metabolic rate means higher clearance rates, which may result in more damage to organs (such as liver and kidney) associated with these processes. So while the levels of damage observed by Beyer et al. (1988) were similar to those expected according to the Franson and Pain (2011) thresholds, it is important to note that these adverse effects occurred in a shorter timeframe than they occurred in other species tested. As noted above, this information suggests that lead poisoning may occur more quickly in songbirds that are exposed to dietary lead. While clinical pathologies such as lesions may be present in songbirds, it is also possible that systematic or life-threatening adverse effects may occur before the bird has been exposed to lead long enough to form lesions on critical organs. Thus, tissue lead concentrations may be a better indicator of toxic effects than the demonstrable presence of lesions.

Overall, application of the Franson and Pain (2011) effects thresholds appears to be a reasonable basis for development of an injury model for birds in SEMO. However, as described previously, these thresholds may underestimate adverse effects to songbirds and to mammals, and thus the use of the Franson and Pain (2011) thresholds to estimate the degree of injury to songbirds and mammals may underestimate natural resource injuries to these more sensitive organisms.

3. Relating Soil Lead to Avian Toxicity

Natural resource trustees have quantified potential injuries to songbirds resulting from mining-related lead releases at other locations. In this chapter, we first present data from the Coeur d'Alene Basin in Idaho, which is one of the more well-studied lead mining areas (Section 3.1). We then present site-specific data from SEMO (Section 3.2), comparing those data to the Coeur d'Alene information. Finally, we propose a method for quantifying natural resource injuries at SEMO in a restoration-based model based on the tissue-based adverse effects thresholds presented in Chapter 2.

3.1 Coeur d'Alene Basin, Idaho

One of the more intensely studied mining areas where lead is a primary contaminant of concern to birds is the Coeur d'Alene Basin in Idaho. The damage assessment at Coeur d'Alene included numerous field and laboratory studies assessing the adverse effects of lead on birds. A large body of peer-reviewed literature has been published summarizing the results of the injury assessment phase in the 1990s (e.g., Henny et al., 1991, 1994; Blus et al., 1993, 1995, 1999; Beyer et al., 1997, 1998; Heinz et al., 1999; Hoffman et al., 2000a, 2000b; Sileo et al., 2001). Stratus Consulting (2000) summarized much of the data in the natural resource injury report for the Coeur d'Alene Basin.

Much of the focus in the Coeur d'Alene assessment was on waterfowl that ingested lead-contaminated sediment in lateral lakes downstream of the mining area. Dozens of dead tundra swans, ducks, coots, and geese had been collected in the Coeur d'Alene area, providing a clear indication of natural resource injuries. Lead poisoning in songbirds, however, is less likely to result in observable mortalities in field settings. Most songbirds are considerably smaller than waterfowl, their carcasses are hard to find even if one is systematically looking for them, and in most habitats, carcasses are rapidly scavenged (Mineau, 2005; Prosser et al., 2007; Sample et al., 2011).[1]

Some limited studies were performed on songbirds and raptors in the Coeur d'Alene Basin in the 1990s. Blus et al. (1995) found elevated blood lead and liver lead concentrations in American robins in the Coeur d'Alene Basin, and Henny et al. (1991, 1994) found ALAD activity suppressed by greater than 50% in ospreys and kestrels. More recently, the USFWS conducted focused studies of songbirds in lead-contaminated floodplains. Hansen et al. (2011) assessed tissue lead concentrations in Coeur d'Alene songbirds, and Sample et al. (2011) estimated the

1. These issues notwithstanding, a number of smaller birds, including passerines, were observed dead or sick in the Coeur d'Alene Basin, albeit in smaller numbers than large waterfowl (Stratus Consulting, 2000, Table 6-5).

soil lead concentrations that resulted in lead poisoning in songbirds. These data are reasonably applicable to lead-contaminated upland forest and floodplains in SEMO and can be used to support a model for estimating natural resource injuries from lead releases.

Hansen et al. (2011) summarized the results of bird studies performed in 2003, 2004, and 2007. They collected American robins, song sparrows, and Swainson's thrushes in lead-contaminated floodplains. Robins and sparrows were observed eating ground insects (primarily ants), while the thrushes appeared to inhabit adjacent upland areas and ate insects off of leaf litter rather than foraging in floodplain soils. Hansen et al. (2011) compared the blood lead concentrations in Coeur d'Alene birds to the Franson and Pain (2011) toxicity categories discussed in the previous chapter. They also summarized the percentage of exposed birds that exhibited at least a 50% inhibition in ALAD compared to reference birds. These data are reproduced in Table 3.1.

The songbirds in Coeur d'Alene floodplains showed a clear pattern of increased blood lead concentrations and ALAD inhibition with increased exposure to elevated soil lead concentrations (Table 3.1). The degree of pathology-based threshold exceedences in the Swainson's thrush was less than in robins or sparrows, a response that is reasonable given their preference for upland habitat and for eating invertebrates that are on leaf litter rather than buried in lead-contaminated soil.

Hansen et al. (2011) estimated that soil ingestion rates at the time of year when these studies were conducted (late spring/early summer) were approximately 20% for robins, 17% for song sparrows, and less than 1% for Swainson's thrushes. Soil ingestion rates for robins and song sparrows were similar, even though robins would normally consume a diet comprising a substantially higher percentage of ground-dwelling invertebrates. The song sparrow's foraging strategy includes kicking up leaf litter, potentially increasing soil lead exposure through inhalation. Song sparrows may also use a foraging technique similar to the brown thrasher, which sweeps through soil with side-to-side head movements (Cavitt and Haas, 2000), which would also expose the bird to lead via both ingestion and inhalation pathways. In the Tri-State Mining District, Beyer et al. (2004) found the highest liver and kidney lead levels in the single brown thrasher that they captured.

Few of the captured birds in Coeur d'Alene had blood lead or liver lead concentrations indicative of direct life-threatening effects, but by definition, birds with directly life-threatening adverse effects from lead exposure would be unlikely to live very long and thus would be difficult to capture in the field. Many birds from the Coeur d'Alene floodplain had blood lead and liver lead concentrations consistent with adverse physiological or systematic toxic effects (Table 3.1).

ALAD inhibition was greater than 50% on average for all birds in highly contaminated areas, and all robins and sparrows in moderately contaminated areas (Table 3.1). ALAD decreased greatly with increased tissue lead concentrations, including blood (Figure 3.1).

Table 3.1. Percentage of songbirds from the Coeur d'Alene Basin showing signs of lead toxicity from elevated blood lead concentrations, elevated liver lead concentrations, and ALAD inhibition, as well as the percentage of songbirds with no apparent lead toxicity, consistent with background values (adapted from Hansen et al., 2011, Tables 3 and 4)[a]

Species, exposure, # samples (blood, liver)	Background		Adverse physiological		Systematic toxic		Directly life-threatening		> 50% ALAD inhibition
	Blood	Liver	Blood	Liver	Blood	Liver	Blood	Liver	
American robin									
Reference (n = 6, n = 4)	100%	100%	0%	0%	0%	0%	0%	0%	0%
Moderate[b] (n = 12, n = 2)	42%	100%	33%	0%	0%	0%	25%	0%	55%
High[c] (n = 33, n = 6)	6%	0%	24%	67%	52%	33%	18%	0%	85%
Song sparrow									
Reference (n = 23, n = 9)	100%	100%	0%	0%	0%	0%	0%	0%	0%
Moderate[b] (n = 9, n = 6)	89%	33%	11%	33%	0%	17%	0%	17%	57%
High[c] (n = 57, n = 15)	19%	20%	72%	27%	9%	27%	0%	27%	64%
Swainson's thrush									
Reference (n = 12, n = 6)	100%	100%	0%	0%	0%	0%	0%	0%	0%
Moderate[b] (n = 21, n = 9)	95%	100%	5%	0%	0%	0%	0%	0%	12%
High[c] (n = 20, n = 6)	65%	50%	30%	50%	5%	0%	0%	0%	57%

a. See Table 2.1 for blood lead and liver lead concentrations associated with each category of lead poisoning.
b. Moderately contaminated soils had lead concentrations ranging from 170 to 1,300 mg/kg dw.
c. Highly contaminated soils had lead concentrations ranging from 2,000 to 5,000 mg/kg dw.

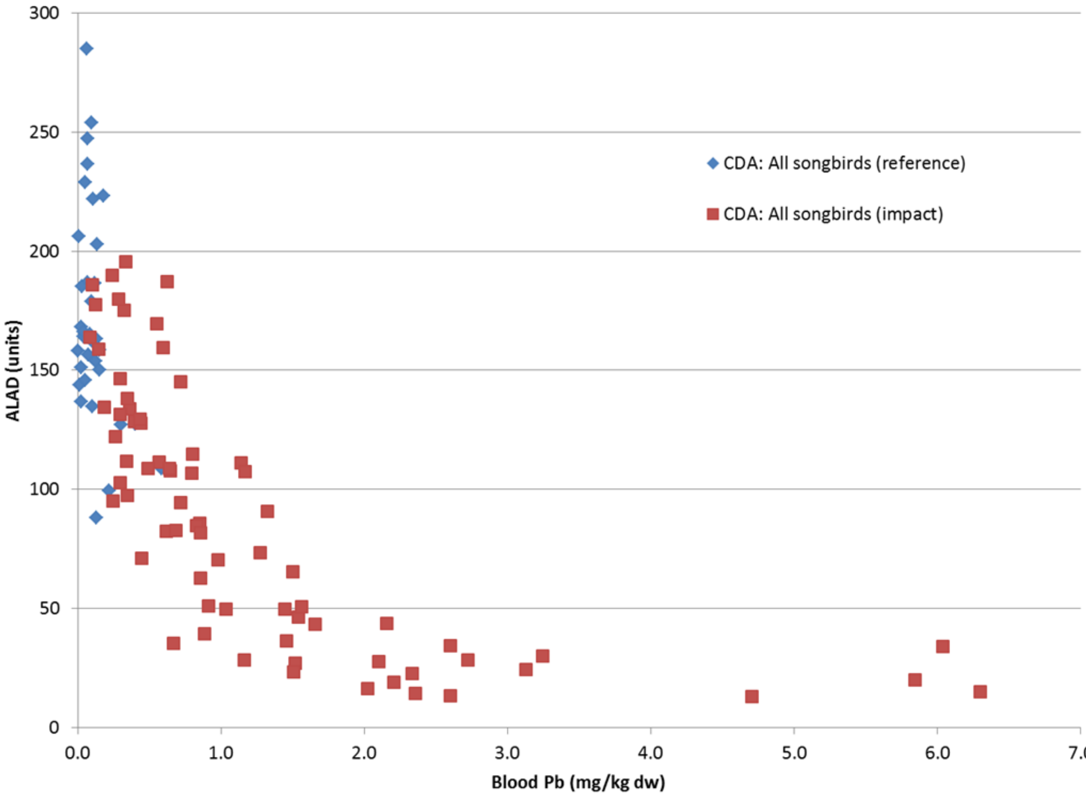


Figure 3.1. ALAD and blood lead concentrations in Coeur d'Alene songbirds.
CDA = Coeur d'Alene.

Source: Brad Sample (unpublished data).

Sample et al. (2011) estimated the concentrations of lead in floodplain soils that resulted in the adverse effects summarized in Hansen et al. (2011). They plotted both blood lead concentrations vs. co-located soil lead concentrations and liver lead concentrations vs. co-located soil lead concentrations. The results showed a log-linear relationship between tissue lead and soil lead concentrations. The r^2 value when regressing blood lead against soil lead was 0.42 for all songbirds, ranging from 0.32 for robins to 0.53 for Swainson's thrush (Figure 3.2). The r^2 value when regressing liver lead against soil lead was 0.52 for all songbirds, ranging from 0.78 for robins to 0.45 for song sparrows (Figure 3.3). The correlation of blood lead and liver lead to soil lead was approximately the same for sparrows and thrushes; liver lead was more highly correlated to soil lead than was blood lead in robins.

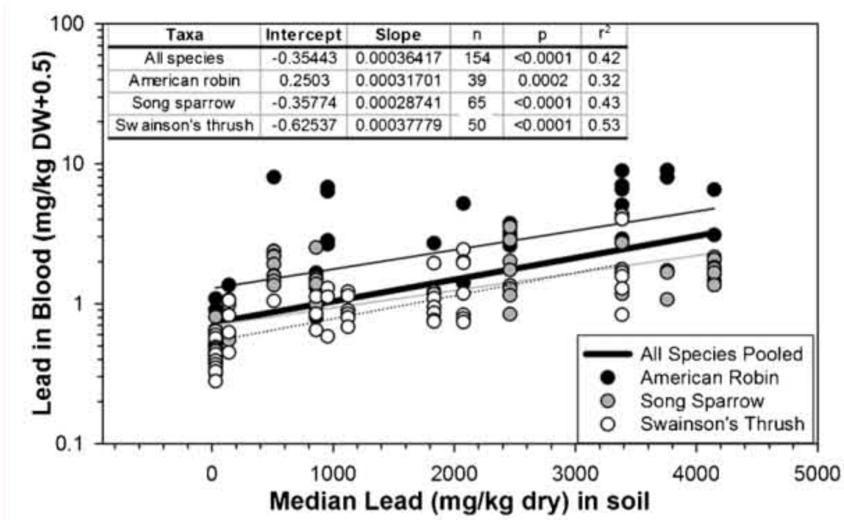


Figure 3.2. Relationship between blood lead and soil lead concentrations in songbirds collected in the Coeur d'Alene Basin.

Source: Sample et al., 2011, Figure 4.

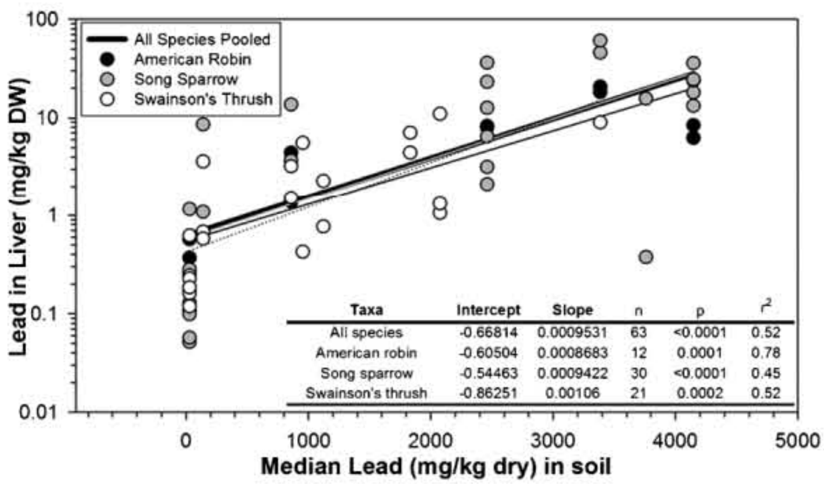


Figure 3.3. Relationship between liver lead and soil lead concentrations in songbirds collected in the Coeur d'Alene Basin.

Source: Sample et al., 2011, Figure 5.

Sample et al. (2011) used the equations generated in Figures 3.2 and 3.3 to estimate the soil lead concentrations that would result in adverse effects in songbirds. Specifically, they estimated the threshold soil lead concentrations that would result in adverse physiological, systematic toxic, and directly life-threatening effects in songbirds, using the thresholds that Franson and Pain (2011) developed for Columbiformes, Anseriformes, and Falconiformes (see Table 2.1). In addition, they interpreted the Beyer et al. (1988) data as LD50 concentrations (the tests were stopped and the remaining birds sacrificed after 50% had died), and they estimated the threshold soil lead concentrations that resulted in the minimum measured liver lead concentration, the median measured liver lead concentration, and the maximum measured liver lead concentration in surviving songbirds. These soil lead threshold estimates are shown in Figure 3.4.

The species most sensitive to lead in soil in the Sample et al. (2011) dataset was the American robin, which ingests more soil because of the greater quantity of earthworms and other ground-dwelling prey in its diet. Sample et al. (2011) calculated a threshold soil lead concentration of 490 mg/kg that corresponded with the 1.0 mg/kg blood lead concentration for adverse physiological effects on robins. They proposed 490 mg/kg as a preliminary remediation goal (PRG) for soil lead in the Coeur d'Alene Basin.

In addition to the Sample et al. (2011) study relating soil lead to adverse effects in songbirds in the Coeur d'Alene Basin, Beyer et al. (2000) related sediment lead concentrations to adverse effects in Coeur d'Alene waterfowl. The estimated soil lead thresholds for songbirds in Sample et al. (2011) are consistent with the Beyer et al. (2000) estimates, assuming 22% sediment in waterfowl diet in the Coeur d'Alene Basin (Figure 3.5). Beyer et al. (2000) show ALAD suppression of greater than 50% at 530 mg/kg sediment lead concentration. Adverse effects increased with increasing sediment lead concentrations. A sediment lead concentration of about 3,000 mg/kg corresponded to protoporphyrin increasing by a factor of 10, a liver lead concentration of 10 mg/kg, and a blood lead concentration of about 3 mg/kg. A sediment lead concentration of 5,000 mg/kg corresponded to protoporphyrin increasing by a factor of more than 15, liver lead concentrations in excess of 15 mg/kg, and blood lead concentrations of about 5 mg/kg (Figure 3.5). The Beyer et al. (2000) data are presented as a linear increase in adverse effects with increasing sediment lead (Figure 3.5).

As noted previously, Sample et al. (2011) estimated that the threshold soil lead concentration resulting in adverse effects in robins in the Coeur d'Alene Basin is 490 mg/kg. Beyer et al. (2000) estimated a similar threshold concentration of 530 mg/kg of lead in sediment that results in 50% ALAD inhibition in waterfowl. In the following section, we examine site-specific songbird data from SEMO, compare the SEMO data to these data from Coeur d'Alene, and discuss threshold concentrations in soils that may be associated with adverse effects in SEMO songbirds.

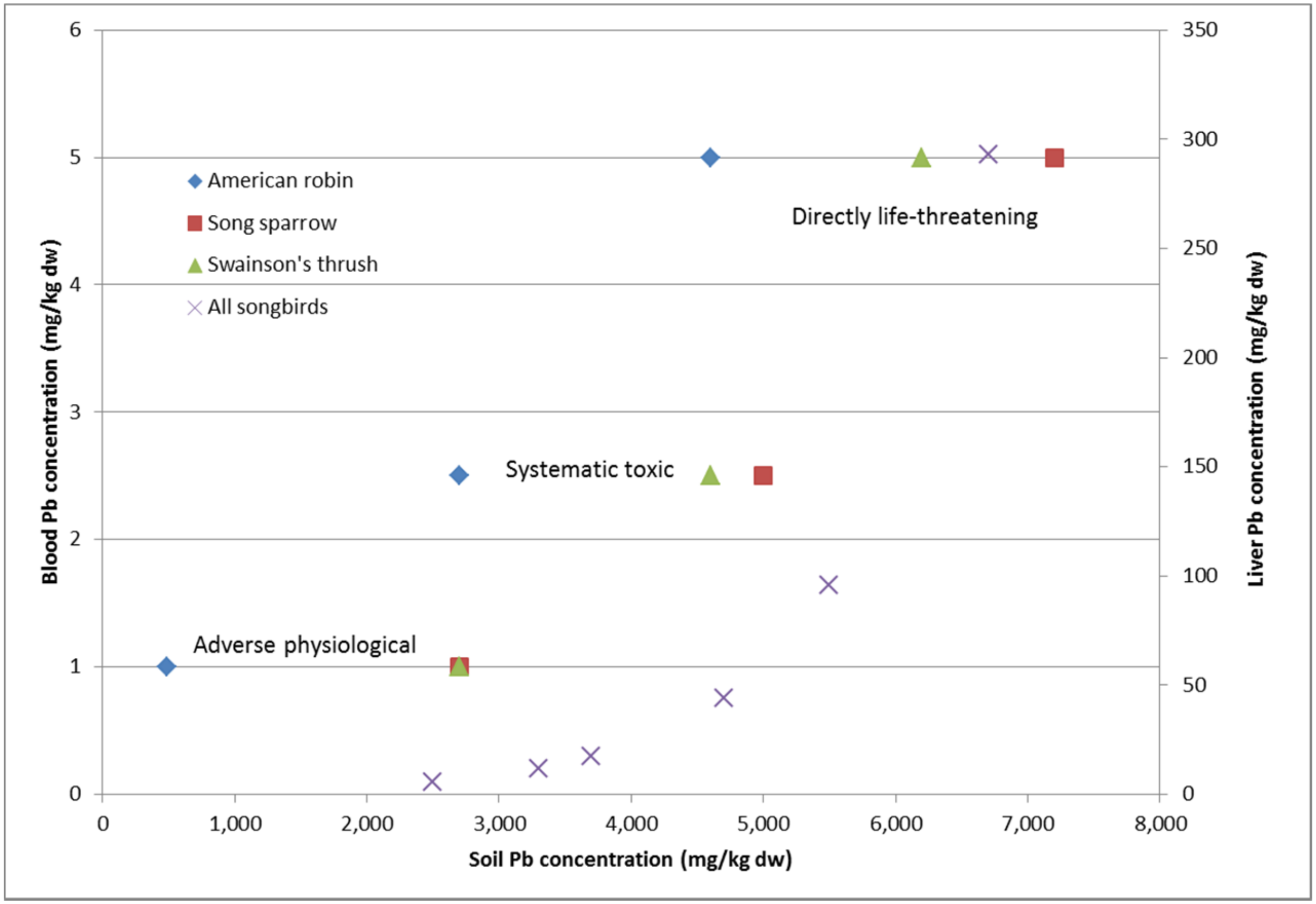


Figure 3.4. Estimated soil lead concentrations associated with adverse physiological, systematic toxic, and directly life-threatening effects in songbirds in the Coeur d'Alene Basin. The labels suggest an approximate grouping.

Source: Sample et al., 2011, Table 5.

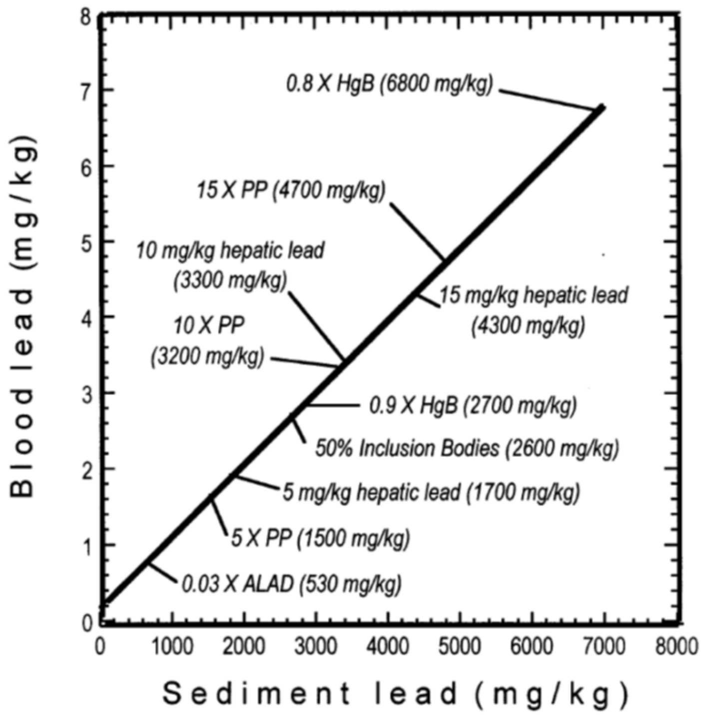


Figure 3.5. Sediment lead concentrations associated with multiple adverse effects in waterfowl consuming a diet with 22% sediment in the Coeur d'Alene Basin.
HgB = hemoglobin; PP = protoporphyrin.

Source: Beyer et al., 2000, Figure 4.

3.2 SEMO

Beyer et al. (2013) collected songbirds in lead-contaminated habitats and nearby reference sites at SEMO (Figure 3.6). This study was similar to the studies from the Coeur d'Alene Basin but was less extensive. The results were generally consistent with results from Coeur d'Alene and the adverse effects discussed in Chapter 2. The species with the most data in the SEMO dataset was the northern cardinal, with 18 cardinals captured at reference sites and 15 cardinals at impacted sites (although not all specimens were analyzed for ALAD or lead in tissues). The second-most captured species was the American robin, with seven robins from reference sites and six robins from impacted sites, although robins were only captured in two of three impacted sample locations. Of the remaining species captured, three (catbird, cowbird, phoebe) were only captured in reference sites, two (blue jay, Carolina wren) were only captured at impacted sites, and two (towhee, wood thrush) had two or fewer specimens to compare between reference and impacted sites.

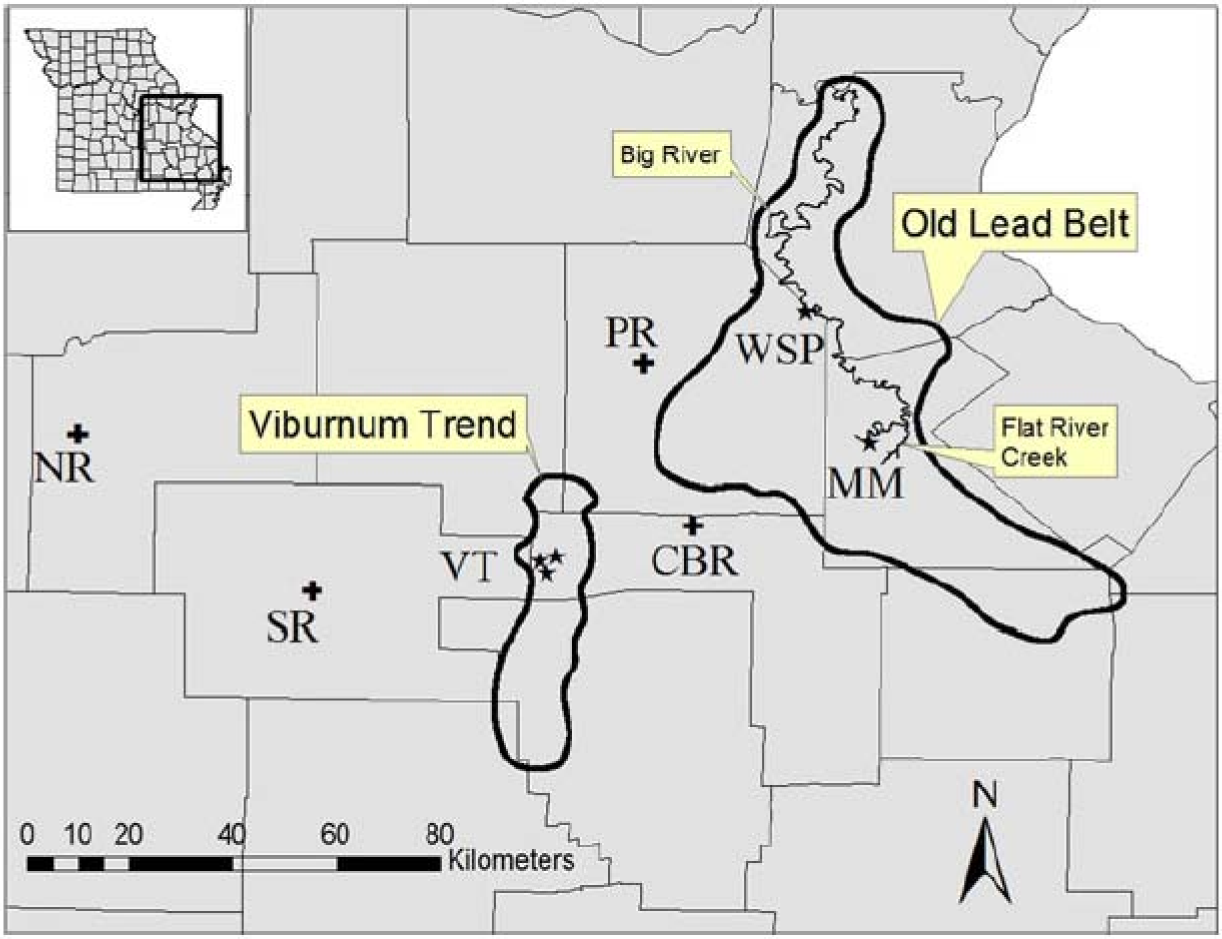


Figure 3.6. Sites in SEMO where Beyer et al. (2013) collected songbirds. The Buick Mine/Mill at Viburnum Trend (VT) and the Federal Mine/Mill at Missouri Mines (MM) contain lead from mining, milling, and smelting operations. The Washington State Park (WSP) site contains lead-contaminated floodplain deposits from the Big River. Salem (SR), Potosi (PR), Newburg (NR), and Council Bluff Lake Recreation Area (CBR) were reference sites.

Source: Beyer et al., 2013, Figure 1.

3.2.1 Summary of robin and cardinal data

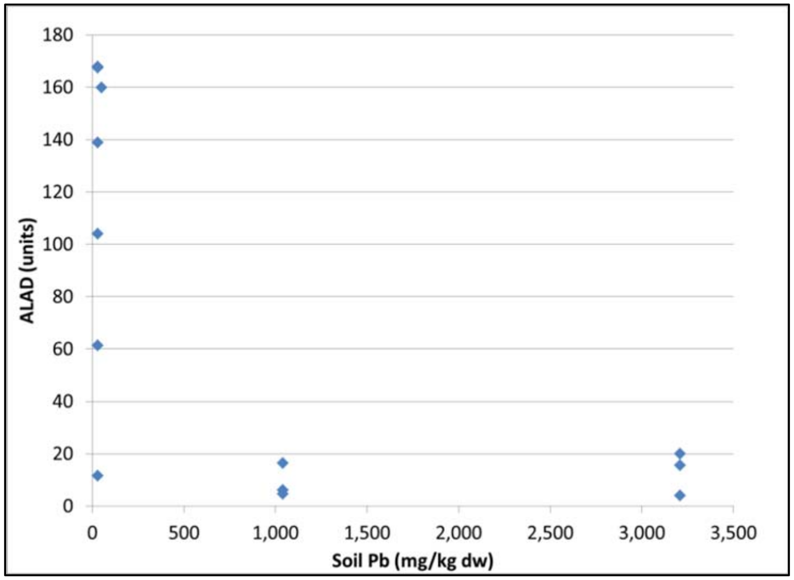
Scatterplots of SEMO data for robins and cardinals show generally consistent patterns of increasing tissue lead concentrations and decreasing ALAD with exposure to lead. ALAD measurements in robins were considerably lower than in cardinals (Figure 3.7). Scatterplots of robin and cardinal blood lead concentrations (Figure 3.8) and liver lead concentrations (Figure 3.9) as a function of soil lead concentrations show a consistent trend of increasing lead in tissues with increasing lead in soils. Notably, robins had higher tissue lead concentrations in both reference and impacted sites. Tissue lead concentrations in robins from near the Buick Mill in Viburnum were particularly elevated. The kidney lead levels in some robins from this area exceeded the Franson and Pain (2011) threshold for directly life-threatening effects. Two of these birds were noted as having acid-fast renal intranuclear inclusion bodies, providing additional indication of severe effects of lead exposure in those animals (Beyer et al., 2013).

While robins had highly elevated lead tissue concentrations at Viburnum Trend (Figures 3.8 and 3.9), suggesting greater adverse effects in robins compared to other songbirds exposed to similar soils, the sample size of robins is limited (no robins were captured at Washington State Park) and the data suggest that some robins captured at reference sites may also have been exposed to lead. As a result, we relied solely upon northern cardinal data to estimate site-specific soil lead concentrations associated with adverse effects to songbirds. This may underestimate potential injuries to robins, which ingest a greater quantity of soil because of the greater quantity of earthworms in their diet. In addition to the evidence from Viburnum Trend, robins were the most sensitive species that Sample et al. (2011) examined (northern cardinals are not found in Idaho), and Beyer et al. (2013) found robins with directly life-threatening effects at sites with relatively modest soil lead concentrations. Thus, a model that estimates natural resource injuries to songbirds based solely on northern cardinal data may underestimate injuries to species such as robins that have greater exposure to lead in soil.

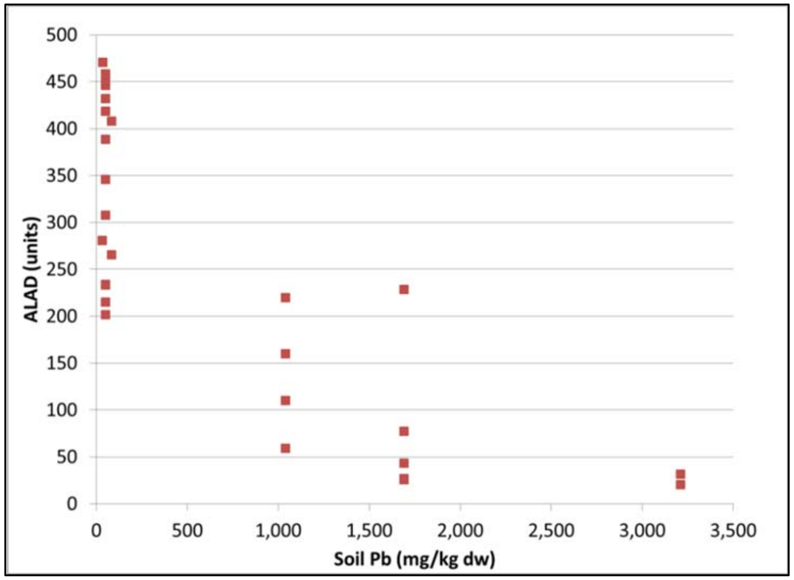
3.2.2 Site-specific thresholds

As mentioned previously, Beyer et al. (2013) captured 18 northern cardinals from reference sites and 15 from impacted sites, including 4 each from Missouri Mines and Viburnum Trend, and 7 from Washington State Park. These data cover a range of potential exposures to soil lead.

Similar to the ALAD data from the Coeur d'Alene Basin, ALAD in SEMO cardinals dropped rapidly with increasing lead in tissues, particularly liver tissues (Figure 3.10). Assuming a logarithmic decrease in ALAD with increasing liver lead, the liver lead concentration associated with a 50% reduction in ALAD is approximately 2.1 mg/kg dw. This estimate is less than Franson and Pain's (2011) estimate of 5.9 mg/kg dw as a lower threshold for adverse physiological effects (see Table 2.1) but is supported by the site-specific data (Figure 3.10).



(a)



(b)

Figure 3.7. ALAD measurements in (a) American robins and (b) northern cardinals collected in SEMO. Left to right, the sites are Reference, Viburnum Trend near Buick Smelter, Big River floodplain at Washington State Park (cardinals only), and Missouri Mines near the Federal Mine-Mill complex (see Figure 3.6).

Source: Beyer et al., 2013.

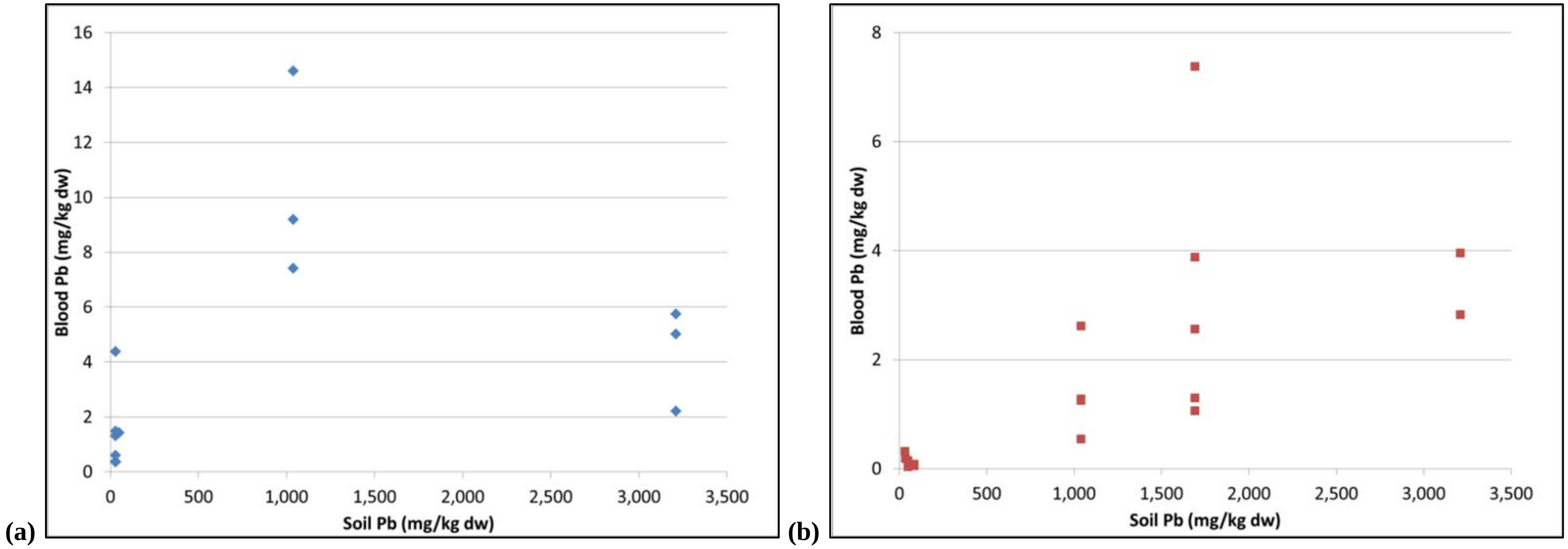


Figure 3.8. Blood lead concentrations in (a) American robins and (b) northern cardinals collected in SEMO. Left to right, the sites are Reference, Viburnum Trend near Buick Smelter, Big River floodplain at Washington State Park (cardinals only), and Missouri Mines near the Federal Mine-Mill complex (see Figure 3.6).

Source: Beyer et al., 2013.

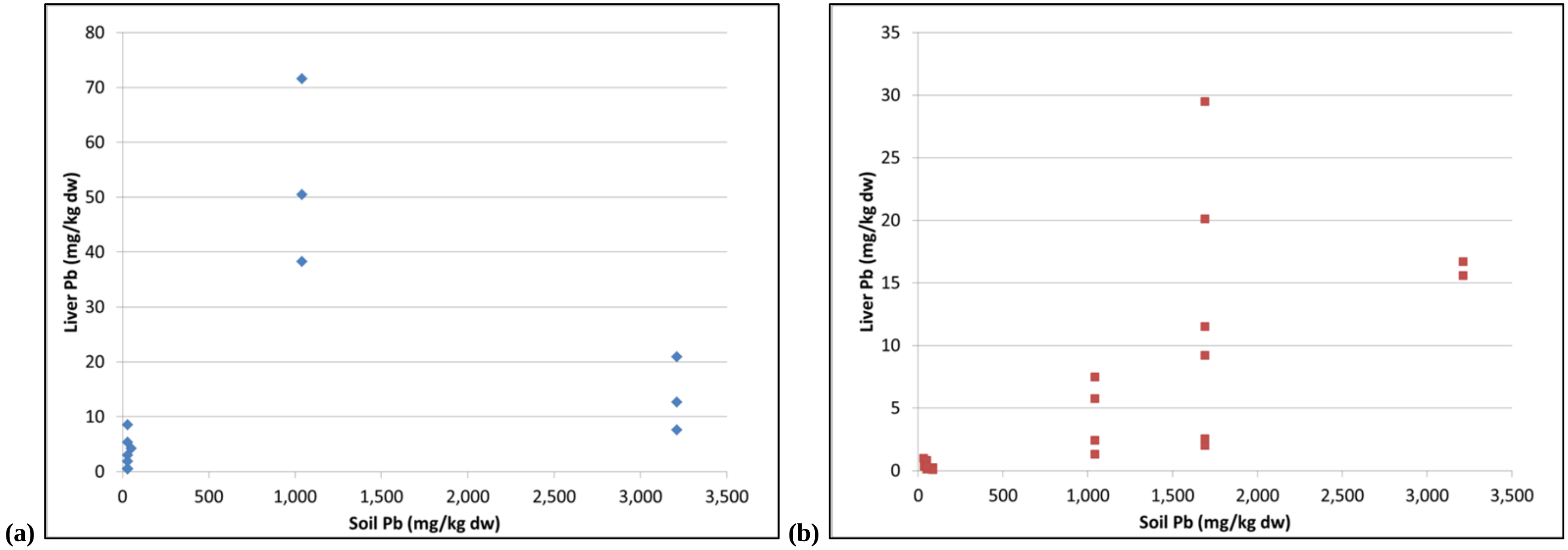


Figure 3.9. Liver lead concentrations in (a) American robins and (b) northern cardinals collected in SEMO. Left to right, the sites are Reference, Viburnum Trend near Buick Smelter, Big River floodplain at Washington State Park (cardinals only), and Missouri Mines near the Federal Mine-Mill complex (see Figure 3.6).

Source: Beyer et al., 2013.

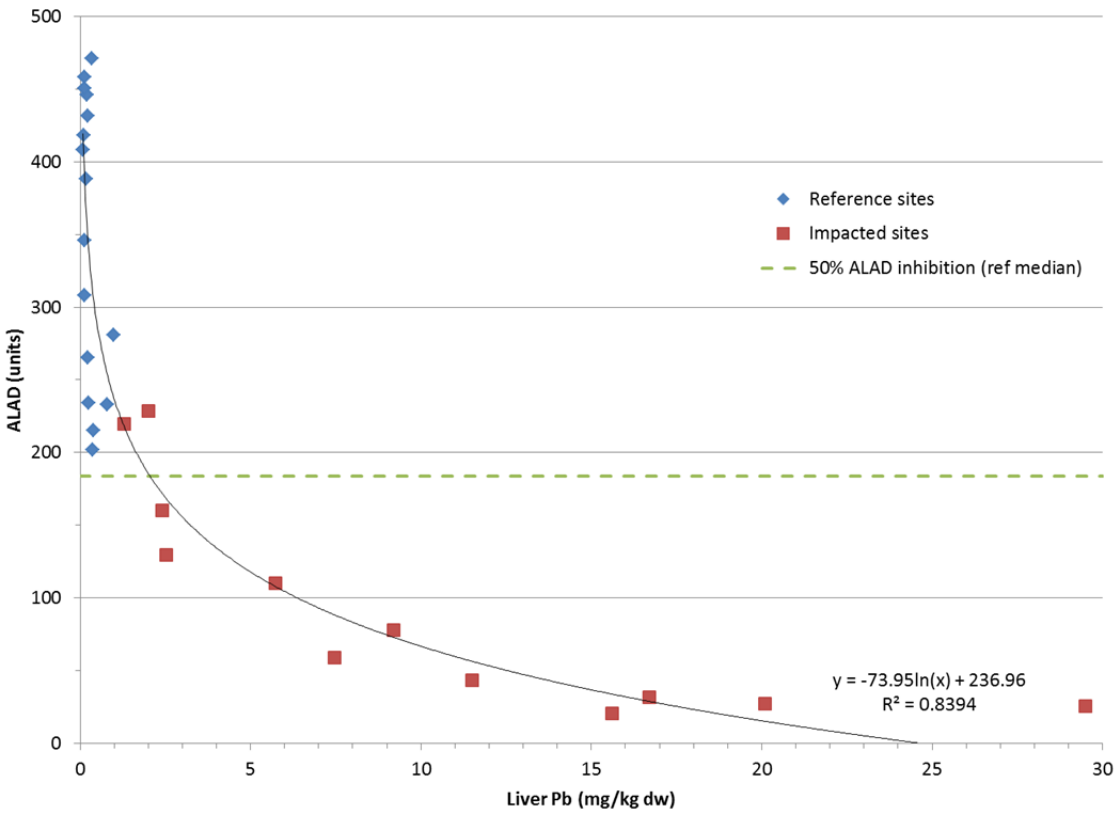


Figure 3.10. Relationship of ALAD and liver lead concentrations in northern cardinals collected in SEMO. The dashed line represents a 50% reduction in ALAD compared to the median ALAD in cardinals from reference sites.

Data source: Beyer et al., 2013, supplemental data.

Beyer et al. (2013) presented a linear relationship between soil lead and liver lead concentrations (Figure 3.11). The relationship of liver lead concentration to estimated soil lead exposure for northern cardinals in SEMO is consistent with the Sample et al. (2011) data from the Coeur d'Alene Basin (Figure 3.12). Using the linear relationship shown in Beyer et al. (2013), the soil lead concentration associated with 2.1 mg/kg liver lead concentration (the concentration at which ALAD inhibition of 50% occurs) is approximately 345 mg/kg dw. The data suggest that ALAD inhibition in SEMO cardinals occurs at a liver lead concentration lower than the adverse physiological effects level predicted in Franson and Pain (2011) and at a lower soil concentration than the threshold value that Sample et al. (2011) estimated for Coeur d'Alene.

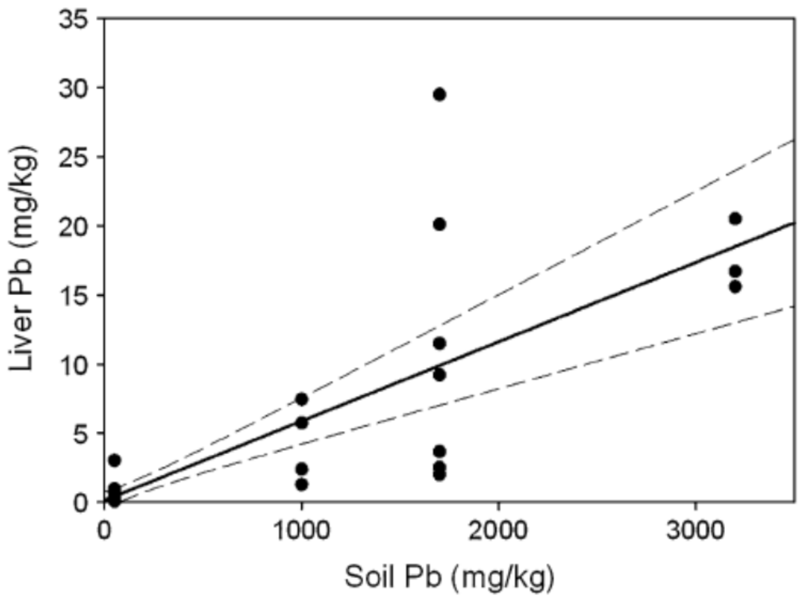


Figure 3.11. Linear regression of liver lead concentrations in northern cardinals and soil lead concentrations at SEMO.

Source: Beyer et al., 2013, Figure 4.

Franson and Pain (2011) estimated that systematic toxic effects occur when liver lead concentrations reach 17.6 mg/kg dw (see Table 2.1). Using the linear relationship between soil lead and liver lead in northern cardinals from SEMO (Beyer et al., 2013), the calculated soil lead concentration at which liver lead concentrations in northern cardinals reach 17.6 mg/kg dw is 3,065 mg/kg dw. For comparison, Sample et al. (2011) calculated a 3,700 mg/kg threshold at Coeur d'Alene, assuming a log-linear relationship between soil and liver lead (see Figure 3.3).

The liver lead concentrations for all three American robins collected at the Viburnum Trend site, where the soil lead concentration was 1,000 mg/kg dw, were more than double the Franson and Pain (2011) systematic toxic effects threshold of 17.6 mg/kg dw (Figure 3.12; Beyer et al., 2013). This suggests that systematic toxic effects may occur in robins where soil lead concentrations are substantially lower than the calculated soil lead thresholds for northern cardinals at SEMO (Beyer et al., 2013) or songbirds at Coeur d'Alene (Sample et al., 2011).

Liver lead thresholds for directly life-threatening effects include 29 mg/kg dw for waterfowl and raptors (Franson and Pain, 2011; see Table 2.1); 44 mg/kg dw for pigeons and doves (Franson and Pain, 2011; see Table 2.1); 53 mg/kg dw for male red-winged blackbirds (Beyer et al., 1988; median liver concentration at LD50 as calculated in Sample et al., 2011); and 152 mg/kg dw for female common grackles (Beyer et al., 1988; median liver concentration at LD50 as calculated in Sample et al., 2011). The calculated soil lead concentration resulting in 29 mg/kg liver lead

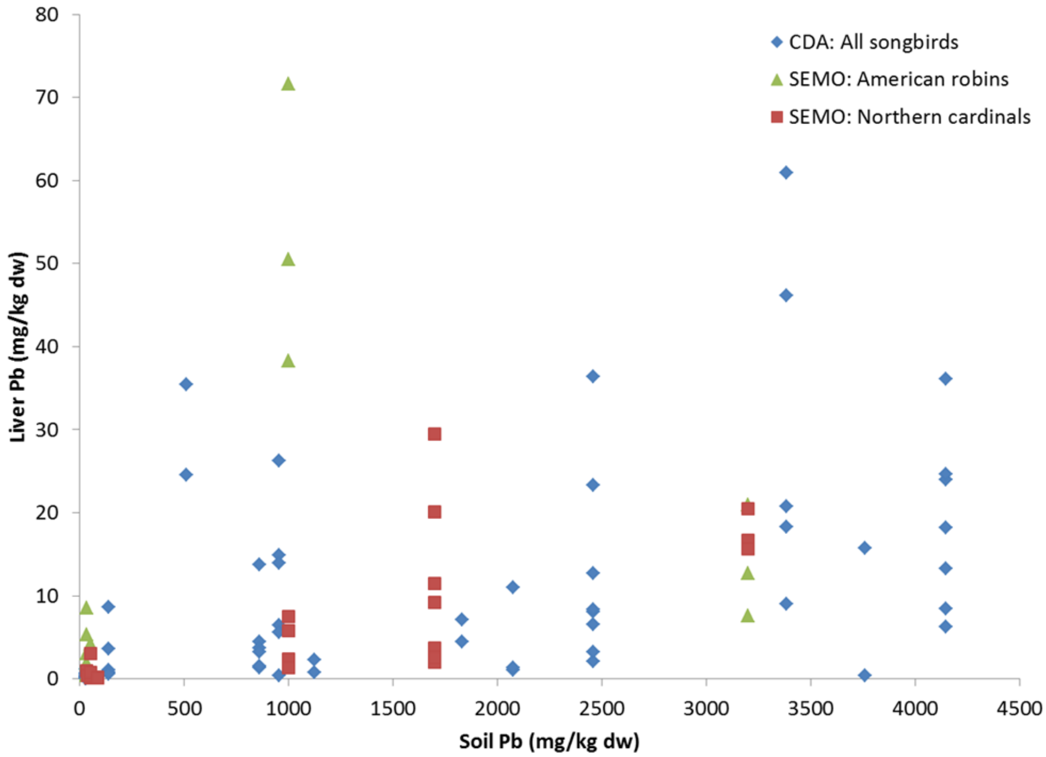


Figure 3.12. Relationship between soil lead and liver lead concentrations in all songbirds from the Coeur d'Alene Basin, and American robins and northern cardinals from SEMO.

Sources: Sample et al., 2011; Beyer et al., 2013.

concentration using the Sample et al. (2011) equation is 4,230 mg/kg, and the calculated soil concentration resulting in 152 mg/kg liver lead concentration is 5,970 mg/kg. Using the linear equation from Beyer et al. (2013), the calculated soil concentration resulting in 29 mg/kg liver lead concentration in cardinals occurs at 5,065 mg/kg lead in soil.

Beyer et al. (2013) captured few cardinals from areas with high lead concentrations. The highest soil lead concentrations were at Missouri Mines, where three cardinals were captured in an area where the soil lead concentration was 3,200 mg/kg (Figure 3.12). The other cardinals were captured in areas where soil lead concentrations were 1,700 mg/kg or less. The Sample et al. (2011) study contains more data from sites with high lead concentrations, including three sites with soil lead concentrations exceeding 3,200 mg/kg, up to a maximum of 4,146 mg/kg. In total, 14 birds were captured and had liver lead concentrations measured at these three highly contaminated sites (Figure 3.12). Thus, the Sample et al. (2011) dataset may be more robust for estimating adverse effects where soil lead concentrations are highly elevated.

3.3 Relating Resource Injuries to Soil Lead

The Trustees have expressed a preference for using a restoration-based model such as habitat equivalency analysis (HEA) to quantify natural resource injuries at SEMO. HEA often incorporates a scaling metric to compare a restored habitat to an injured habitat. Different metrics can be used for this numerical scaling; when such scaling metrics are used, they may be expressed in terms of natural resource "services" or "service loss." Trustees have discretion when selecting metrics for such restoration scaling.

The data presented previously suggest that northern cardinal health may be an appropriate metric for use in a HEA at SEMO, with a relatively lower degree of loss assigned when lead concentrations are associated with the initiation of adverse physiological effects, moderate to high degrees of service loss for lead concentrations associated with systematic toxic effects, and high service loss for lead concentrations associated with directly life-threatening effects. On the other hand, the American robin data from SEMO suggest that robins are more sensitive to soil lead than are cardinals, which would suggest a greater degree of service loss at a given soil lead concentration than would be estimated using cardinal data only. Rather than relying solely on the cardinal data, the Trustees could use a scaling metric based more generally on adverse effects to songbirds, using cardinal and robin data from SEMO as well as songbird data from Coeur d'Alene.

If the Trustees select adverse effects to northern cardinals as a HEA scaling metric, the relationship between soil lead concentrations and service loss could follow a linear model, as suggested in Beyer et al. (2013). Should the Trustees adopt a linear or other continuous loss function, care should be taken to ensure that the model does not suggest a level of precision in the service loss assignments that exceeds that of the underlying data.

An alternative to a continuous service loss function is a stepwise service loss function, where service losses are grouped into bins rather than calculated as a continuous function. Such an approach has been used in many damage assessments and could be implemented at SEMO. The following are suggested injury bins, integrating Beyer et al. (2013) northern cardinal and American robin data, as well as using Sample et al. (2011) data for bins with the highest soil lead concentrations:

- Soil lead concentration < 345 ppm: Low likelihood of injury to songbirds. This soil lead concentration is calculated to be the threshold concentration at which ALAD inhibition exceeds 50% in northern cardinals. Assign songbird service loss factor of 0%.

- Soil lead concentration 345–1,000 ppm: Reasonable likelihood of adverse physiological effects in robins and potential adverse effects to cardinals. Soil lead concentrations in this bin are greater than the calculated concentration at which ALAD inhibition exceeds 50%

in northern cardinals at SEMO. At 1,000 ppm lead in soils, the three American robins captured at Viburnum Trend had liver lead concentrations greatly exceeding adverse physiological effects thresholds. Assign low service loss factor, where the service loss metric is adverse effects on songbirds generally (rather than robins specifically).

- Soil lead concentration > 1,000–3,065 ppm: Reasonable likelihood of adverse physiological effects in both robins and cardinals. Soil lead concentrations in this bin are greater than the concentrations at Viburnum Trend, where three robins had highly elevated liver lead concentrations, and lower than the calculated soil lead concentration resulting in liver lead concentrations associated with systematic toxic effects in waterfowl, raptors, and pigeons/doves (Franson and Pain, 2011). Assign moderate songbird service loss factor.

- Soil lead concentration > 3,065–5,065 ppm: Reasonable likelihood of systematic toxic effects in robins and cardinals. Soil lead concentrations in this bin are greater than the calculated concentration resulting in liver lead concentrations associated with adverse physiological effects in Franson and Pain (2011), and lower than the calculated concentration resulting in a liver lead concentration associated with directly life-threatening effects in waterfowl and raptors (Franson and Pain, 2011). Assign moderate to high songbird service loss factor.

- Soil lead concentration > 5,065–6,700 ppm: Reasonable likelihood of directly life-threatening effects in songbirds. Soil lead concentrations in this bin are greater than the calculated concentration resulting in liver lead concentrations with directly life-threatening effects in waterfowl and raptors (Franson and Pain, 2011) and less than the calculated concentration resulting in liver lead concentrations associated with the maximum LD50 for female common grackles (Beyer et al., 1988) using the data from Coeur d'Alene (Sample et al., 2011). Assign high songbird service loss factor.

- Soil lead concentration > 6,700 ppm: High likelihood of directly life-threatening effects to songbirds. Soil lead concentrations in this bin are associated with liver lead concentrations exceeding all calculated thresholds for directly life-threatening effects in Coeur d'Alene (Sample et al., 2011). Assign highest songbird loss factor.

The bins as described above are shown graphically in Figure 3.13.

As mentioned previously, using the Beyer et al. (2013) northern cardinal data, the soil lead concentration associated with 2.1 mg/kg liver lead concentration (the concentration at which ALAD inhibition of 50% occurs) is approximately 345 mg/kg dw. This injury threshold for soil lead is consistent with thresholds developed elsewhere (generally within the framework of ecological risk assessments and/or soil remediation targets protective of wildlife). In a review of lead soil screening levels for two sites in the State of Washington, the Washington Department of

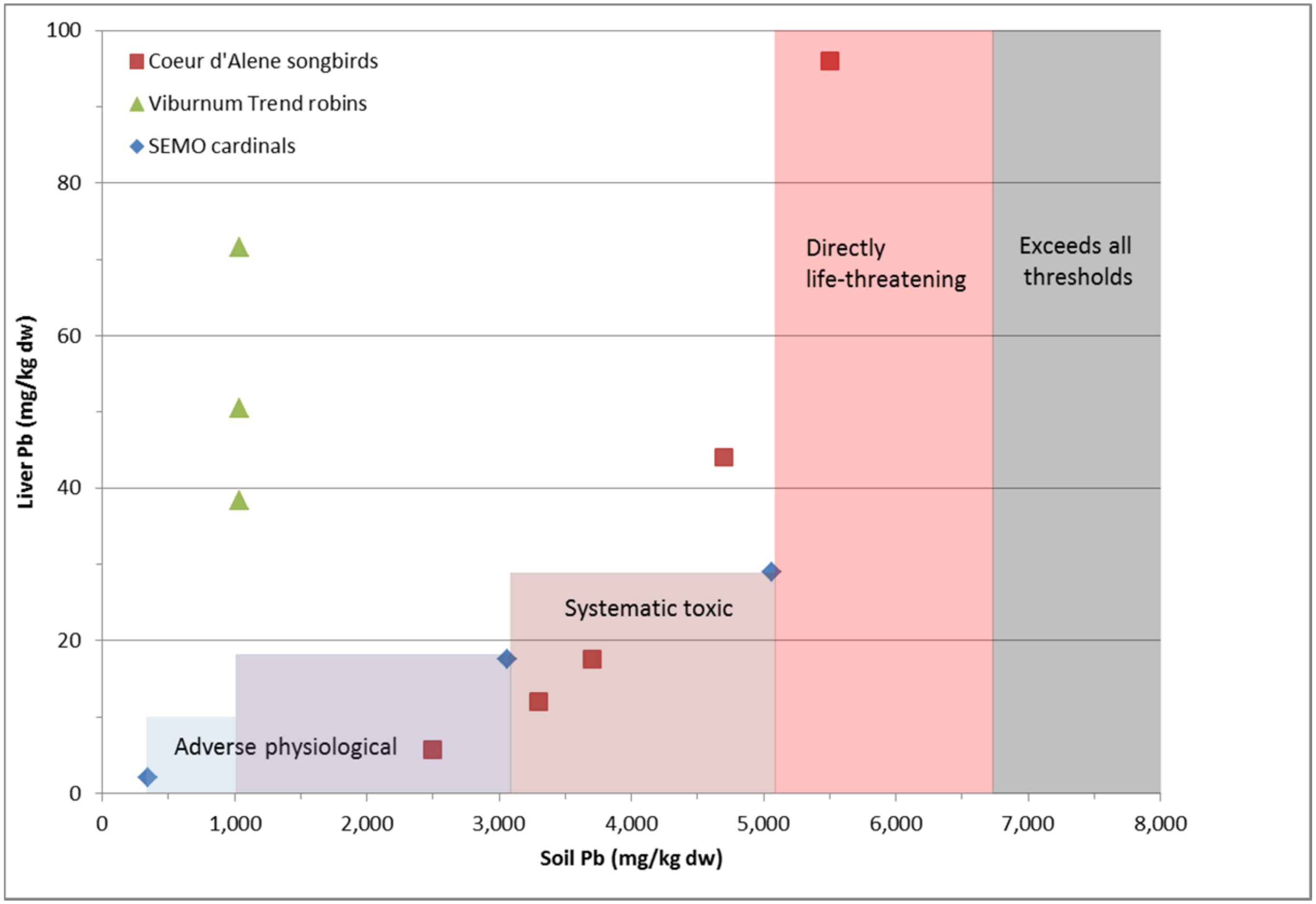


Figure 3.13. Suggested bins for soil lead concentrations based on calculated liver lead concentrations and associated adverse effects on songbirds. Not shown: liver lead of 293 mg/kg at 6,700 mg/kg soil lead from Coeur d'Alene. Liver lead concentrations from the three robins collected at Viburnum Trend suggest that these bins may underestimate injuries to robins.

Sources: Sample et al., 2011; Beyer et al., 2013.

Ecology (2011) calculated a soil lead threshold of 251 mg/kg dw, which would be protective of American robins. For the Coeur d'Alene site, Sample et al. (2011) suggested a PRG of 490 mg/kg dw, which would be protective of songbirds. In the Record of Decision (ROD) for the Jacobsville Neighborhood Soil Contamination Site in Indiana, the U.S. EPA (2009a) calculated a soil lead PRG of 380 mg/kg dw, which would be protective of American robins. Similarly, in the ROD for the Raleigh Street Dump Site in Florida, the U.S. EPA (2009b) calculated a soil lead remedial goal option of 605 mg/kg, which would be protective of insectivorous birds.

Selection of what might constitute the Trustees' preferred HEA model is, in part, a function of the statistical distribution of soil lead concentrations over the spatial extent of exposure. For example, depending on the distribution of soil data, injury quantification and scaling may be relatively insensitive to some of the specifics regarding model selection and parameterization. Moreover, the selection of a HEA scaling model should consider the Trustees' preferences regarding preferred restoration alternatives. Certain restoration alternatives may be more or less "scalable" or may necessitate less discrimination between degrees of injury.

This proposed SEMO HEA model benefits from site-specific data and from relatively recent research in Coeur d'Alene. Many terrestrial injury assessments rely on risk-based thresholds for estimating natural resource injuries, often focusing on resources other than birds. For example, in the uplands near the smelter in Anaconda, Montana, Kapustka (2002) used vegetation as the scaling metric. Based on a literature review, Kapustka (2002) estimated that 100 mg/kg lead in soils would be phytotoxic to sensitive species, and 1,000 mg/kg lead in soils would be phytotoxic to many species. Similarly, Industrial Economics (2006) used phytotoxicity as the metric for scaling service loss from metals in soils at Arkansas River/California Gulch in Colorado. Rather than using risk-based thresholds, however, they used actual phytotoxicity test results from site soils contaminated with several metals. Therefore, they did not include a specific threshold for injury based on lead concentration in soils.

At the Former Indian Refinery site in Lawrenceville, Illinois, the Illinois Natural Resource Trustees (2008) calculated site-specific thresholds estimating potential risk of vegetation and biota to lead based on the U.S. Environmental Protection Agency Ecological Soil Screening Levels (Eco-SSLs). The lowest threshold, 25 mg/kg, was protective of omnivorous wildlife (woodcock). The Trustees used this 25 mg/kg threshold as an indicator of injury. They then scaled service loss based on a generic dose-response curve, with service loss bins (25%, 50%, 75%, and 100%). For lead in soils, 100% service loss occurred when lead concentrations exceeded 240 mg/kg.

The soil lead concentration bins for scaling service loss proposed here are considerably higher than those used at the Former Indian Refinery. In fact, the proposed threshold for service loss (345 mg/kg) is higher than the concentration assigned to be 100% service loss at the Former Indian Refinery. However, the metric used to scale service loss is different. As mentioned previously, natural resource service loss (and service gain) in a HEA is simply a scaling metric to ensure that habitat restored is equivalent to habitat injured. Thus, while the Illinois Trustees scaled service loss using a metric that assumed 100% service loss at a relatively low soil lead concentration, they scaled service gains from restoration using the same metric, resulting in a high restoration credit per acre restored. The net result was an estimate of required restoration to make the public whole that both the Illinois Trustees and the responsible party agreed was appropriate compensation for the injuries.

Different approaches with different injury thresholds are common in NRDA. The habitat and resource equivalency method is probably the most common tool for estimating compensable damages based on equivalent restoration. The methods for estimating service loss vary widely from site to site, based on factors such as availability of site-specific data, restoration preferences and goals, settlement goals, the amount of time and effort that the Trustees and responsible parties want to dedicate to the assessment, and many other factors. In this report, we have proposed a stepwise function for estimating the severity of natural resource injuries at SEMO based on soil lead concentrations. The steps, or bins, in this function were derived primarily from site-specific tissue lead concentrations in American robins and northern cardinals (Beyer et al., 2013), with bins at the highest soil lead concentrations derived from Coeur d'Alene songbird data (Sample et al., 2011). At the discretion of the Trustees, the Beyer et al. (2013) and Sample et al. (2011) data could be used to create an alternative continuous injury/service loss function, rather than the stepwise function proposed here. Regardless of whether the Trustees prefer a stepwise or continuous service loss function, the site-specific songbird and soils data provide a useful metric for scaling natural resource injuries to songbird habitat.

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