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Seasonal variations of lead concentration and loading rates in residential house dust in northern Idaho

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Abstract

Although lead hazards to humans have been known since ancient times and many regulatory actions and lead risk reductions have been achieved over the past century, lead contamination and exposure remain significant problems worldwide. The focus of this study was to investigate whether residential house dust lead concentrations and lead and dust loading rates in non-contaminated or "background" communities in northern Idaho are significantly affected by seasonal variations. House dust samples were obtained from 34 houses in five towns of northern Idaho from March to November 1999. There was evidence of significant seasonality of lead concentration in house dust in some towns, but no evidence in other towns. Because of the high variability between the towns and small sample sizes, it was difficult to make firm conclusions about seasonal patterns observed in house dust lead levels. A linear relationship between precipitation rates and dust loading rates was detected.

Keywords: House dust; Lead concentration and loading; Seasonality; Northern Idaho

1. Introduction

Metals are one of the earliest medicines and poisons known to mankind [1]. As toxicants that cause adverse health effects on people, they are unique because they occur naturally and are ubiquitous in the environment [2]. Lead, one representative of this family of toxicants, is considered a poison with human health effects that have been recognized since the 2nd century BC and remain a concern for modern society [3–9].

This study was conducted concurrently with a study of background dust and soil lead levels in northern Idaho homes [10]. Both studies allow comparison to dust and soil lead levels measured at the Bunker Hill Superfund Site (BHSS), described in Spalinger et al. [10].

House dust, an environmental material to which human beings are commonly exposed [11], has been recognized as a significant source of lead exposure, particularly for children. It has become an issue in the scientific world during the last several decades [12,13]. Young children are the most vulnerable to lead exposure, and house dust is the most available exposure medium [14–19]. Carpets and rugs have been found to be a large reservoir of house dust and act as significant sources of dust lead exposure [20].

Seasonal variations in blood lead levels, particularly among children, have been studied and well documented [21–26]. However, the reason for seasonal variations is not clear. Blood lead variations could be a result of seasonal variations of lead levels in environmental media (e.g., air, soil, floor dust, furniture dust, and windowsill dust) and/or of altered human physiology (e.g., Vitamin D and calcium levels in the body) [21–23,27,28,25].

Some, of the findings of these studies are not consistent. To better understand the phenomenon of seasonality of blood lead levels and environmental media (such as air, dust, and soil lead levels) more studies are necessary, covering a larger population, geographic area, and socio-economic conditions [21,25].

The variety of remedial efforts that have occurred at the BHSS resulted in significant declines of lead levels; however,

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the remedial action objectives (RAO) for house dust have not yet been achieved. Von Lindern et al. [29] suggest that the compliance is currently 90%. Several explanations for not meeting the dust RAO are possible. First, there was no information on house dust lead levels in non-contaminated or "background" communities when the RAOs for house dust were developed. The concurrent study by Spalinger et al. [10] showed that background lead levels in northern Idaho had a geometric average of 120 mg/kg by the vacuum cleaner bag method, and a geometric average of 95 mg/kg by the dust mat method, much lower than the levels outlined in the house dust RAO. Moreover, the USEPA did not explicitly state whether the RAO was an annual average or seasonal maximum, as there could be a seasonal effect on lead in house dust. All the environmental samples at the BHSS have been collected during the summer and fall months, when levels are considered to be at their peak.

This investigation of the seasonal effect on house dust lead was an important step in the complex risk reduction program at the BHSS. Specifically, this investigation provides the following:

- information about lead levels and their fluctuations over time in the five communities of northern Idaho;
- insight on whether seasonal variation is a significant factor affecting lead levels in house dust.

Finally, if a seasonal variation is confirmed to exist in house dust lead levels in background areas, a similar assumption could be made for the communities in the BHSS. It could also have an important impact on establishing risk-based house dust lead standards, measuring remedial effectiveness and better understanding the seasonality of blood lead levels of children living in the exposed communities of the BHSS.

2. Materials and methods

2.1. Study population and study areas

The study reported here on seasonal effects on lead concentration and loading in residential house dust, and the survey on background house dust lead levels in northern Idaho [8] were initiated concurrently. The five towns involved in the study were chosen based on their location and similarities of socio-demographic characteristics of the resident population with the population from the BHSS towns of Kellogg, Smelterville, and Pinehurst. Demographic information and selection of the five towns is detailed in Spalinger et al. [10]. The selected background towns were Bovill, Coeur d'Alene, Moscow, Post Falls, and Potlatch.

The study population included selected residents who volunteered to participate. The survey team randomly picked a house in the block or town, moving door-to-door until a participant agreed. A house was included in the study if the vacuum cleaner was not used outside the home. An introductory statement was made and participants were asked to complete and sign a consent form before the sampling procedure was started. A questionnaire was completed for each participating house, requesting information about the house age, general conditions of the home, number of people living there, residents' habits, activities and occupation, presence of pets, household income, and education. The consent forms and questionnaires were documented in the Work Plan in Petrosyan [30].

2.2. Sampling methods

Methods for sampling during the background and seasonal house dust surveys were identical to those used since the 1970s in the BHSS [29]. Three types of environmental samples were collected from each house—a composite yard soil sample, a vacuum cleaner dust sample, and a floor mat dust sample. Spalinger et al. [10] details the sampling methods used.

Soil sampling was only performed in March 1999. Soil sampling was not repeated seasonally because lead, an extremely stable and immobile metal, is persistent in the soil and is assumed to be independent of seasons [21,31,32]. House dust lead levels could vary with season because different amounts of soil and dust can enter the home during different seasons. Moreover, soil is not the only source contributing to lead levels in house dust; factors which significantly influence the house dust lead levels, such as personal habits, profession and hobbies, could also vary during different seasons [33].

Vacuum cleaner dust sampling was repeated every 2 months from March to November 1999. Carpet floor mat dust sampling was also repeated every 2 months from March to November 1999. All the soil samples, vacuum cleaner bag dust samples, and dust samples obtained from floor mat vacuuming were sent to the Northern Analytical Laboratories, Inc., where they were analyzed in accordance with the U.S. EPA Contract Laboratory Program, "Statement of Work for Inorganic Analysis" IML04.0.

2.3. Study design

A randomized block (RB) design was applied to examine the seasonal variations in vacuum cleaner bag and mat dust lead concentrations, as well as in both dust and lead loading rates. For this design, the main factor of interest was the season having four to five fixed levels or sampling periods. Table 1 shows the sampling periods used.

The levels were fixed because the sample collection periods were decided during the planning of the study. To isolate variation attributable to individual houses (a nuisance variable), the house effect was included as one of the factors in the study by a blocking procedure. The individual houses could be blocked because each was observed under all the conditions (seasons) in the study (i.e., repeated measures on the houses were obtained). The proper experimental design models for the seasonal study were mixed models where the treatment levels were fixed and blocks (houses) were chosen randomly [34]. The assumptions underlying the statistical analyses were checked using a normal probability plot, residuals plot, and sphericity condition. Tukey's test for nonadditivity was also applied.

Table 1
Seasonal sampling periods used in dust collection study

Sampling periods	Months when vacuum cleaner bag dust samples collected	Periods when floor mat dust samples collected
1	Mid-March	Mid-March–mid-May
2	Mid-May	Mid-May–mid-July
3	Mid-July	Mid-July–mid-September
4	Mid-September	Mid-September–mid-November
5	Mid-November	–

Table 2
Number of houses sampled in background towns in Idaho

Towns	Number of houses sampled				
	March	May	July	September	November
Bovill	10	5	5	5	5
Coeur d'Alene	10	5	5	5	5
Moscow	10	9	9	9	9
Post Falls	10	8	8	8	8
Potlatch	10	9	8	7	7
Total	50	36	35	34	34

3. Results and discussion

3.1. Participation

The field sampling started in March and ended in November of 1999. During the first round of sampling, 10 houses were sampled in each of the five towns in the study. Seasonal dust sampling was repeated every 2 months. The participation rate gradually decreased from 50 to 34 houses because participation was voluntary and the study duration was quite long (9 months) (Table 2). Some participants lost interest; others moved to another house.

3.2. Environmental sampling results

A significant interaction between time and towns was observed. The data were examined by individual town for the available four types of environmental data: vacuum cleaner bag dust lead concentration, floor mat dust lead concentration, dust loading rate and lead loading rate (Figs. 1–4). To meet the basic assumption of RB repeated measures analyses of variance, a log transformation of the dependent variables was performed and outliers were excluded from the data. In some cases it was difficult to meet all of the statistical assumptions due to small sample sizes. In those cases, the graphical evidence was examined along with the results of statistical analyses to make reliable conclusions. Geometric means are discussed throughout the remainder of this paper because the data were log-normally distributed.

One house in Coeur d'Alene was excluded from the vacuum cleaner bag dust lead concentration analysis of seasonal variations because the vacuum cleaner was used in the basement where the homeowner was casting lead. As a result, the lead concentrations at this house for two sampling periods were abnormally high (2040 and 1410 mg/kg in May and July, respectively). After contacting the residents the vacuum cleaner was not used in the basement and the concentration dropped below 150 mg/kg. Based on a discussion with the resident, lead particles were most likely not tracked to the rest of the house from the casting area.

Additionally, precipitation data for Coeur d'Alene, Helmer, Moscow and Potlatch were obtained from the Idaho Climate Center to compare with the environmental sampling results obtained during this study. The Helmer station data were used to describe the precipitation rates in Bovill because this station was closest to the town. No precipitation data were available for Post Falls. Precipitation rates were calculated for four sampling periods (16 March–15 May, 16 May–15 July, 16 July–15 September, and 16 September–15 November) in four towns (Fig. 5).

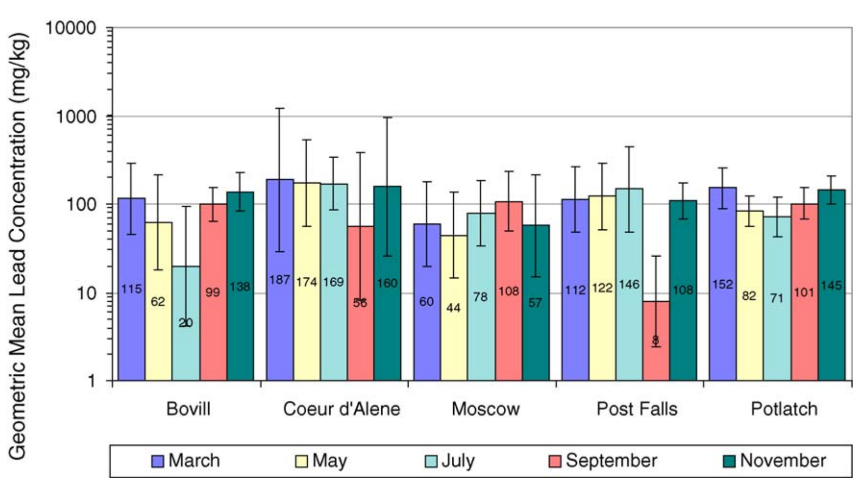

Fig. 1. Vacuum cleaner bag dust lead concentration by town and by sampling period.

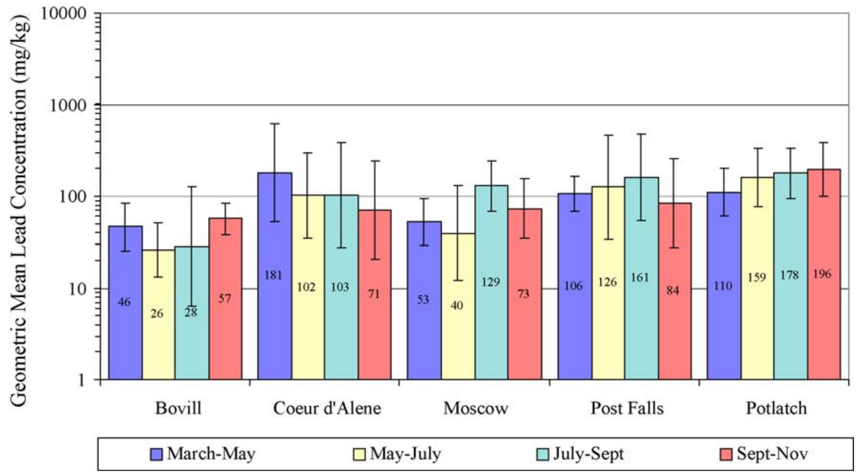

Fig. 2. Floor mat dust lead concentration by town and by sampling period.

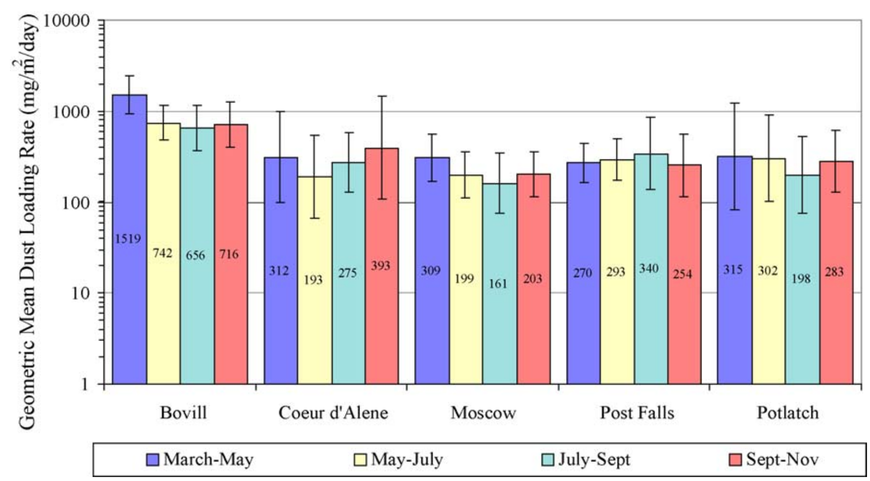

Fig. 3. Dust loading rates by town and by sampling period.

3.3. *Yard soil lead concentrations*

Composite yard soil samples were collected from all 50 houses in the five towns in March 1999 as part of the concurrent study and are only summarized here. The overall geometric mean soil lead concentration was 48 mg/kg. The geometric mean soil lead concentration observed in Bovill (112 mg/kg) was two to five times higher than those observed in Coeur d'Alene, Moscow,

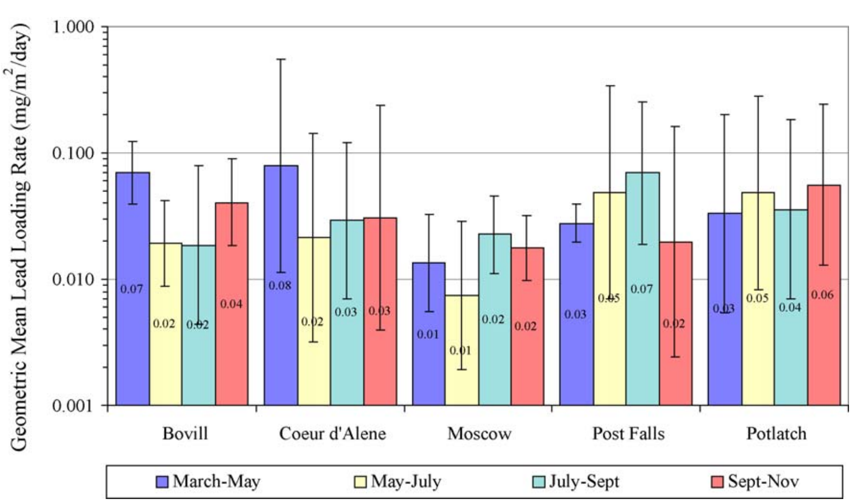

Fig. 4. Lead loading rates by town and by sampling period.

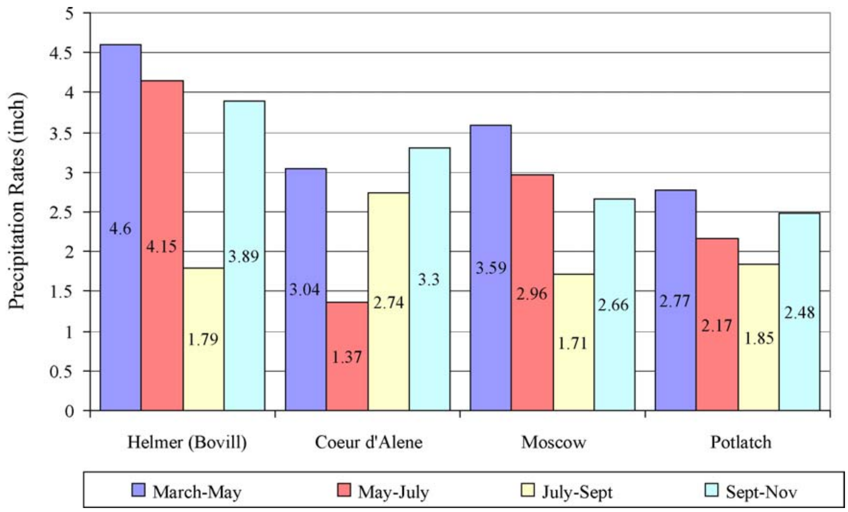

Fig. 5. Precipitation rates by town and by sampling period.

Post Falls, and Potlatch. The higher soil lead levels in Bovill were most likely due to older housing (built before 1960) in the community or from deviations in the yard soil sampling protocol. Because of the high snow cover, the Bovill samples could only be obtained from areas closer to the house, possibly affected by leaded paint if present [10].

3.4. House dust lead concentrations (vacuum cleaner bag sampling method)

Vacuum cleaner bag dust samples were collected for five sampling periods: March, May, July, September, and November 1999 (Fig. 1). In March, 49 vacuum cleaner bag dust samples were collected from 50 houses. In May, 29 samples were collected from 36 houses. In July, 34 vacuum dust samples were collected from 35 houses. In September and November, 29 and 27 samples, respectively, were collected from the remaining 34 participating houses. Because of broken vacuum cleaners or empty vacuum cleaner bags, dust samples were not available from all the participating houses. Only 20 houses did not have any missing data, a necessary condition for the repeated measures analysis. The data for the vacuum cleaner dust lead concentrations, presented in Table 3 and Fig. 1, are discussed below.

Bovill. The statistical analysis of vacuum dust lead concentration data for Bovill ($n = 4$) showed a marginally significant difference from season to season ($P < 0.05$); July concentrations were significantly different from the concentrations obtained during March, September and November. The highest geometric mean concentrations were observed during March and November (115 and 138 mg/kg, respectively) and the lowest geometric mean concentration was observed during July (20 mg/kg). When one house was excluded from the analysis because it did not meet the statistical assumptions, the seasonal variation lost significance. However, the trend in seasonal variation did not change.

Coeur d'Alene. The sample size for Coeur d'Alene was extremely small ($n = 2$). The highest vacuum dust lead concentrations were observed in March (187 mg/kg), and the samples collected in September showed the lowest concentrations (56 mg/kg).

Moscow. This town had the largest sample size of seven houses. The seasonal variability in lead concentration was not significant ($P > 0.05$). However, the highest geometric mean lead concentration of 108 mg/kg was observed in samples obtained during September, and the lowest geometric mean lead concentration of 44 mg/kg was detected in samples collected in May.

Post Falls. It was difficult to meet some of the statistical assumptions for the data obtained from Post Falls, possibly due to the small sample size ($n = 3$). Nevertheless, the graphical evidence suggests an apparent difference between the September lead concentrations and the other four sampling periods ($P < 0.05$). Two of the three dust samples collected during September had lead concentrations below the practical quantitative levels of 5 and 10 mg/kg. A possible explanation of this phenomenon was not identified. The geometric lead concentrations for the other four sampling periods ranged from 108 to 147 mg/kg.

Potlatch. A significant difference in lead concentrations ($P < 0.05$) was found from season to season for Potlatch ($n = 4$). The results for May and July were significantly different from March and November. The highest lead concentrations were observed in March and November (152 and 145 mg/kg, respectively) and the lowest house dust lead concentrations were noted in July (71 mg/kg). The trend of seasonal variations observed in Potlatch was similar to the one detected in Bovill.

Bovill and Potlatch. It was possible to describe the effect of different seasons on the data from Bovill and Potlatch combined. The resulting sample size was seven (one house was excluded to avoid the violation of basic statistical assumptions) and combining these data sets increased the power of the test. The results were almost identical; the May and July vacuum dust lead concentrations were significantly different from the March and November levels, following the same trend. The similarity

Table 3
Vacuum cleaner bag dust lead concentration (mg/kg) data by town and by season

	March	May	July	September	November
Bovill ($P = 0.046$)					
N	4	4	4	4	4
Minimum	38.0	14.0	BL[a]	66.0	90.0
Maximum	337.0	289.0	114.0	160.0	242.0
Average	157.8	107.0	41.6	106.5	151.3
Standard deviation (S.D.)	133.7	124.3	50.0	46.1	74.7
Geometric mean	115.1	61.8	19.8	99.0	137.6
Geometric S.D.	2.6	3.5	5.0	1.6	1.7
Coeur d'Alene ($P = 0.237$)					
N	2	2	2	2	2
Minimum	58.0	86.0	110.0	17.0	52.0
Maximum	604.0	352.0	260.0	187.0	492.0
Average	331.0	219.0	185.0	102.0	272.0
Standard deviation (S.D.)	386.1	188.1	106.1	120.2	311.1
Geometric mean	187.2	174.0	169.1	56.4	160.0
Geometric S.D.	5.2	2.7	1.8	5.5	4.9
Moscow ($P = 0.127$)					
N	7	7	7	7	7
Minimum	BL[b]	11.0	31.0	48.0	BL[a]
Maximum	830.0	864.0	898.0	704.0	1080.0
Average	162.3	153.9	177.7	187.1	201.4
Standard deviation (S.D.)	295.6	314.2	318.9	243.1	389.2
Geometric mean	59.8	44.3	78.1	107.5	57.2
Geometric S.D.	4.5	4.5	3.2	2.9	6.0
Post Falls ($P = 0.003$)					
N	3	3	3	3	3
Minimum	53.0	63.0	70.0	BL[a]	70.0
Maximum	240.0	283.0	440.0	20.0	162.0
Average	134.3	149.3	204.0	10.8	114.3
Standard deviation (S.D.)	95.9	117.4	205.0	8.8	46.1
Geometric mean	111.9	122.1	146.5	7.9	108.0
Geometric S.D.	2.1	2.6	2.6	2.9	1.5
Potlatch ($P = 0.016$)					
N	4	4	4	4	4
Minimum	63.0	45.0	33.0	56.0	80.0
Maximum	240.0	122.0	128.0	176.0	206.0
Average	170.8	88.5	80.0	109.8	154.0
Standard deviation (S.D.)	79.5	35.0	41.3	50.0	53.7
Geometric mean	151.9	82.5	71.0	101.2	145.4
Geometric S.D.	1.8	1.6	1.8	1.6	1.5

BL: below practical quantitation limits (PQL) (lead concentrations, if present, were not quantifiable; half the PQL is used for all means and statistics).
[a] PQL is <5 mg/kg.
[b] PQL is <10 mg/kg.

between these two towns was not surprising because they had similar socio-economic conditions, small population size, and primarily older houses (built before 1960) according to the 1990 census.

Overall, a significant seasonal effect on lead in vacuum cleaner bag dust samples was detected in three of the five towns sampled. However, it is difficult to make a generalization for all five towns, because of high variability from town-to-town, differences in general trends from season-to-season in each town, and small sample sizes. Because of the small number of houses in each town, even one house could significantly change the results of the analyses. Some possible explanations of these variabilities could be weather differences, house age, personal habits, road conditions, and traffic density.

3.5. *House dust lead concentrations (floor mat sampling method)*

Floor mat dust samples were collected for four sampling periods: March–May, May–July, July–September, and September–November 1999 (Fig. 3). The first floor mat dust samples were available in mid-May only, whereas the first vacuum cleaner samples were collected in mid-March. During the first round of sampling 47 of the 50 placed mats were collected, during the second round all 36 mats placed were collected, and during the third and fourth rounds 33 of 34 placed mats were collected. Some dust mats could not be collected because of either unavailability of residents or improper mat handling by residents. As a result, data from only 31 houses were available

Table 4
Floor mat dust lead concentration (mg/kg) data by town and by season

	March–May	May–July	July–September	September–November
Bovill ($P = 0.339$)				
N	5	5	5	5
Minimum	22.0	8.0	BL[a]	44.0
Maximum	114.0	46.0	146.0	110.0
Average	53.6	30.0	54.1	60.8
Standard deviation (S.D.)	35.5	14.2	56.5	28.4
Geometric mean	46.0	25.9	28.3	56.7
Geometric S.D.	1.8	2.0	4.6	1.5
Coeur d'Alene ($P = 0.034$)				
N	5	5	5	5
Minimum	46.0	30.0	10.0	12.0
Maximum	1280.0	644.0	594.0	475.0
Average	387.0	194.2	201.0	147.2
Standard deviation (S.D.)	517.9	258.2	230.9	191.7
Geometric mean	181.0	102.2	102.5	70.9
Geometric S.D.	4.1	3.4	4.5	4.1
Moscow ($P = 0.006$)				
N	8	8	8	8
Minimum	21.0	BL[a]	60.0	23.0
Maximum	280.0	920.0	775.0	840.0
Average	76.0	150.8	199.0	153.5
Standard deviation (S.D.)	85.6	312.7	242.9	278.0
Geometric mean	52.7	39.6	129.2	73.3
Geometric S.D.	2.3	5.6	2.5	2.9
Post Falls ($P = 0.298$)				
N	7	7	7	7
Minimum	51.0	14.0	30.0	BL[b]
Maximum	228.0	3530.0	3220.0	1220.0
Average	121.6	594.0	558.4	237.3
Standard deviation (S.D.)	65.5	1296.6	1174.9	435.8
Geometric mean	106.1	125.6	160.7	84.0
Geometric S.D.	1.8	5.9	4.3	4.4
Potlatch ($P = 0.269$)				
N	6	6	6	6
Minimum	32.0	39.0	74.0	80.0
Maximum	292.0	581.0	770.0	846.0
Average	135.3	221.5	243.2	276.5
Standard deviation (S.D.)	90.1	193.7	260.2	289.5
Geometric mean	109.9	159.5	177.7	196.0
Geometric S.D.	2.1	2.5	2.2	2.3

BL: below practical quantitation limits (PQL) (lead concentrations, if present, were not quantifiable; half the PQL is used for all means and statistics).
[a] PQL is <5 mg/kg.
[b] PQL is <20 mg/kg.

for repeated measures analyses. The data for floor mat dust lead concentrations, presented in Table 4 and Fig. 2, are discussed below.

Bovill. A significant difference in mat dust lead concentrations between the four sampling periods was not detected ($P > 0.05$). Although there was no apparent difference between seasons, the lowest concentrations were observed during the second and third sampling periods (May–July and July–September, 26 and 28 mg/kg, respectively), and the highest concentrations were detected in the March–May and September–November sampling periods (46 and 57 mg/kg, respectively).

Coeur d'Alene. A decreasing trend over time was detected in the houses in Coeur d'Alene ($n = 5$). The results from September–November were the lowest (71 mg/kg) and significantly different from the highest concentrations detected during March–May (181 mg/kg) ($P < 0.05$). When one house recognized as an outlier was excluded, the results of the analysis became insignificant.

Moscow. House dust lead concentrations were available from eight floor mats in Moscow. A significant difference was detected between the lowest concentrations observed during March–May and May–July sampling periods (53 and 40 mg/kg, respectively) and the highest lead concentrations in July–September (129 mg/kg) ($P < 0.05$).

Post Falls. In the seven houses in Post Falls, no significant seasonal variation of mat dust lead concentrations was observed ($P > 0.05$). However, the highest geometric mean concentration

Table 5
Dust loading rate ($mg/m^2/day$) data by town and by season

	March–May	May–July	July–September	September–November
Bovill ($P = 0.035$)				
N	5	5	5	5
Minimum	895.4	362.4	267.3	322.0
Maximum	3402.5	1469.2	1196.0	1245.2
Average	1722.2	818.0	757.7	835.1
Standard deviation (S.D.)	1028.8	403.8	398.0	453.5
Geometric mean	1519.2	742.5	655.9	715.8
Geometric S.D.	1.7	1.7	1.9	1.9
Coeur d'Alene ($P = 0.331$)				
N	4	4	4	4
Minimum	72.2	60.7	95.4	84.4
Maximum	1190.1	501.0	598.0	1464.4
Average	488.3	279.2	331.6	677.8
Standard deviation (S.D.)	491.5	231.4	206.4	652.5
Geometric mean	311.9	192.6	274.7	393.4
Geometric S.D.	3.2	2.9	2.2	3.8
Moscow ($P = 0.254$)				
N	6	6	6	6
Minimum	171.6	63.9	33.0	59.9
Maximum	1314.9	449.5	424.8	399.5
Average	416.7	241.6	215.6	243.1
Standard deviation (S.D.)	443.4	146.9	142.3	132.8
Geometric mean	308.7	199.1	160.7	203.5
Geometric S.D.	2.1	2.1	2.6	2.1
Post Falls ($P = 0.876$)				
N	4	4	4	4
Minimum	171.3	173.0	87.5	110.1
Maximum	446.5	518.3	753.2	624.2
Average	296.4	326.9	436.7	323.1
Standard deviation (S.D.)	142.0	168.9	275.8	241.1
Geometric mean	270.1	293.4	339.9	254.1
Geometric S.D.	1.7	1.7	2.6	2.3
Potlatch ($P = 0.604$)				
N	5	5	5	5
Minimum	52.9	97.5	61.4	79.4
Maximum	2228.4	1224.5	801.6	709.6
Average	725.5	540.5	310.1	370.8
Standard deviation (S.D.)	921.9	566.5	307.1	268.8
Geometric mean	315.4	302.1	197.7	282.9
Geometric S.D.	4.7	3.5	3.0	2.4

(161 mg/kg) was detected during July–September and the lowest was observed in September–November (84 mg/kg).

Potlatch. The data obtained from Potlatch ($n = 6$) did not show significant seasonal variation in lead concentrations ($P > 0.05$). Nevertheless, the trend was opposite the one observed in Coeur d'Alene: the lowest geometric mean lead concentration was detected during March–May sampling period (110 mg/kg) and the highest one was detected during September–November (196 mg/kg).

Only in Coeur d'Alene and Moscow were significant seasonal variations of mat dust lead concentrations evident. As in the case of vacuum cleaner bag dust lead concentrations, because of the high variability between the towns and small sample sizes, it is difficult to make generalizations of the results and to suggest a common pattern in seasonal variability for all the towns. On average, the lowest mat dust concentrations were observed in Bovill, whereas the highest concentrations were observed in Potlatch.

3.6. Dust and lead loading rates

In addition to providing dust lead concentrations, the floor mat technique also yielded information on dust and lead loading rates expressed in mass/area/day units. Several mats were vacuumed or shaken while inside the houses, and some amount of dust was lost. Because of these deviations from the protocol, these dust mats were excluded from further analyses. As a result, data from only 24 and 23 houses were available for repeated measures analyses on dust and lead loading rates, respectively. The repeated measures analyses of dust loading rates, conducted by town, are presented in Table 5 and Fig. 3. The lead loading rate analyses are presented in Table 6 and Fig. 4.

Table 6
Lead loading rate (mg/m^2/day) data by town and by season

	March–May	May–July	July–September	September–November
Bovill ($P = 0.024$)				
N	5	5	5	5
Minimum	0.043	0.006	0.003	0.014
Maximum	0.167	0.053	0.126	0.108
Average	0.083	0.025	0.046	0.054
Standard deviation (S.D.)	0.057	0.019	0.055	0.040
Geometric mean	0.070	0.019	0.019	0.041
Geometric S.D.	1.913	2.421	5.214	2.471
Coeur d'Alene ($P = 0.127$)				
N	4	4	4	4
Minimum	0.022	0.003	0.006	0.008
Maximum	1.523	0.294	0.199	0.696
Average	0.404	0.082	0.064	0.182
Standard deviation (S.D.)	0.746	0.141	0.090	0.342
Geometric mean	0.080	0.021	0.029	0.031
Geometric S.D.	7.314	6.992	4.274	8.077
Moscow ($P = 0.067$)				
N	5	5	5	5
Minimum	0.007	0.001	0.008	0.009
Maximum	0.076	0.059	0.059	0.050
Average	0.022	0.017	0.029	0.022
Standard deviation (S.D.)	0.030	0.024	0.022	0.017
Geometric mean	0.013	0.007	0.023	0.018
Geometric S.D.	2.748	4.697	2.259	1.969
Post Falls ($P = 0.282$)				
N	4	4	4	4
Minimum	0.020	0.006	0.012	0.001
Maximum	0.039	0.697	0.282	0.180
Average	0.029	0.195	0.117	0.060
Standard deviation (S.D.)	0.010	0.335	0.118	0.082
Geometric mean	0.028	0.049	0.069	0.020
Geometric S.D.	1.431	7.260	3.783	8.526
Potlatch ($P = 0.620$)				
N	5	5	5	5
Minimum	0.004	0.007	0.005	0.006
Maximum	0.651	0.711	0.617	0.600
Average	0.156	0.193	0.145	0.156
Standard deviation (S.D.)	0.279	0.302	0.265	0.250
Geometric mean	0.033	0.048	0.036	0.056
Geometric S.D.	7.764	7.505	6.461	5.291

3.6.1. Dust loading rates

Bovill. The repeated measures analysis of dust loading rates observed in Bovill ($n = 5$) showed significant difference ($P < 0.05$) between the third (the lowest dust loading rate of 656 mg/m^2/day) and first (the highest dust loading rate of 1519 mg/m^2/day) sampling periods. The highest dust loading rates for Bovill were detected during March–May, when the precipitation rate was the highest (4.6 in.). During July–September the dust loading rates were the lowest, corresponding to the lowest precipitation rate of 1.79 in.

Coeur d'Alene. No significant seasonal variations were observed in the four houses in Coeur d'Alene ($P > 0.05$). However, the lowest dust loading rates were detected during May–July months (193 mg/m^2/day), and the highest during September–November (393 mg/m^2/day). The precipitation rate was the lowest (1.37 in.) during the months of the lowest dust loading rates.

Moscow. Dust loading rates did not vary significantly from season to season in Moscow ($P > 0.05$). The sample size was six, and the overall trend was similar to Bovill. The dust loading rates were three to four times lower in Moscow than in Bovill. The highest dust loading rates were detected during March–May (309 mg/m^2/day) and the lowest rate was observed during the third sampling period (161 mg/m^2/day). The highest and lowest dust loading rates corresponded with the highest and lowest precipitation rates (3.59 and 1.71 in., respectively).

Post Falls. Samples collected from four houses in Post Falls did not show significant seasonal variations ($P > 0.05$). The dust loading rates ranged from 254 to 340 mg/m^2/day. No increasing or decreasing pattern was detected when the data were examined graphically. Precipitation data were not available for Post Falls.

Potlatch. The data obtained from five houses in Potlatch did not show significant differences between the four sampling periods ($P > 0.05$). The dust loading rate during March–May was the highest (315 mg/m^2/day) and during July–September was the lowest (198 mg/m^2/day). The precipitation rate also was the lowest during July–September (1.85 in.). The overall pattern was similar to Moscow.

Because the trends noted in Moscow and Potlatch were similar the data sets were combined and re-analyzed to provide more power to the test. The results were the same—no significant difference was found from season to season ($P > 0.05$).

Examination of dust loading rates in the five towns revealed no significant seasonal variations in four towns. The rates observed in Bovill, where the difference between sampling periods was significant, were three to four times higher than in other towns. The roads in Bovill are mostly unpaved and there are no curbs and gutters. The dirt roads could considerably affect the amount of dust entering into houses in Bovill. The precipitation data obtained from the Helmer station, closest to Bovill, showed that the precipitation rates were higher than those in the other towns where precipitation data were available (Fig. 5) (ICC [35]). This could further suggest more mud and dust being brought inside the Bovill homes.

A positive linear relationship between dust loading rates and precipitation rates was observed when Coeur d'Alene, Moscow, and Potlatch data were examined ($r = 0.68$); because of very high dust loading rates, Bovill data were considered outliers.

3.6.2. Lead loading rates

The summary of lead loading rates by town, presented in Table 6 and Fig. 4, is discussed below.

Bovill. Lead loading results were available from five houses in Bovill. The repeated measures analysis detected significant variations from season to season ($P < 0.05$). The multiple comparison test showed that the lead loading rate during March–May (0.07 mg/m^2/day) was significantly higher than the rates observed during May–July and July–September months (0.019 mg/m^2/day).

Coeur d'Alene. The seasonal variability of lead loading rates for Coeur d'Alene were not statistically significant ($P > 0.05$). However, the highest geometric mean lead loading rate observed during March–May (0.08 mg/m^2/day) was three to four times higher than the rates detected during the three sampling periods from May through November.

Moscow. The lead loading rates were not significantly different from season to season ($P > 0.05$). Graphical evidence does not show a constant increasing or decreasing pattern. The lowest rates were detected during May–July (0.007 mg/m^2/day) and the highest during July–September (0.023 mg/m^2/day).

Post Falls. The data obtained from Post Falls ($n = 4$) showed no significant seasonal variation of lead loading rates ($P > 0.05$). The lead loading rate peaked during July–September (0.07 mg/m^2/day).

Potlatch. The seasonal variability of lead loading rates in Potlatch was not significant ($P > 0.05$). No constant increasing or decreasing trends were observed for these data ($n = 5$). The highest rates were observed during September–November (0.06 mg/m^2/day) and the lowest during March–May (0.03 mg/m^2/day).

Similar to dust loading rates, seasonal variations in lead loading rates were statistically significant only in Bovill. The lowest lead loading rates were observed in Moscow, ranging from 0.007 to 0.023 mg/m^2/day, about three to four times lower than the other towns.

3.7. Comparison of two house dust sampling techniques

To compare vacuum cleaner bag and floor mat dust sampling methods, repeated measures analysis of variance specifying two factors (method and time) was applied by town. In four towns, no significant difference was detected between the vacuum cleaner bag and floor mat interior dust sampling methods ($P > 0.05$). Only the data for Bovill revealed a significant difference between the two techniques ($P < 0.05$). This difference could be due to the lead sources contributing to vacuum cleaner bag and floor mat dust lead levels. The vacuum cleaner bag method reflects more of what is inside the house (which acts as a reservoir) while the floor mat technique reflects what is coming from sources outside the house.

3.8. Discussion

Not many studies are available on seasonal variations of environmental lead levels. The limited literature suggests that seasonal variations of lead levels in environmental media could explain well-established blood lead variations. That is why this attempt to understand the seasonality of lead levels in the environment could be valuable. A few studies indicate about seasonal variations in atmospheric lead and floor dust mainly depending on weather conditions [21,28,27]. Weather conditions could possibly explain differences in seasonal patterns observed in different cities of the current study.

The study conducted in Boston from 1979 to 1983 [21] reported significant variations in floor dust with a peak in June. It is difficult to compare the Boston study with this northern Idaho house dust study because the units of reported data are different. In the Boston study, 1.0 and 0.5 square foot templates were used to collect dust wipes and lead was reported only as a total mass in μg instead of as a concentration in mg/kg.

The dust loadings found in the northern Idaho study were consistent with the findings of Yiin et al. [27]. During the months when observed precipitation rates were the highest, the dust loadings were the highest due to large amounts of mud and soil brought into the home on shoes or pets' feet. In all of the investigated towns of northern Idaho, except Post Falls, the highest dust loading rates were either during March–May or September–November, when the highest precipitation rates and snow fall were observed (Fig. 4). Yiin et al. [27] proposed that significant seasonal differences in house dust lead levels may not always occur because of the existence of leaded-paint in the homes, which contributes lead particles into house dust independent of season. However, it was difficult to compare the seasonal patterns in the Yiin et al. study to those in our study. The Yiin et al. study, conducted in Jersey City, grouped the results according to temperature into hot, warm, cool, and cold groups, mixing months across seasons.

4. Study limitations

The field sampling was limited to samples from early spring to late fall with a small sample size. This was an observational study, not a controlled experiment, and sample size became even smaller when some of the participants left the study. Some dust mats were not handled properly by participating residents resulting in less reliable data. To investigate the seasonal variations of house dust lead levels and loading rates more thoroughly, at least 12–24 months of continuous sampling and a larger number of samples would be necessary.

5. Conclusions

An observational study of seasonal effects on lead in house dust in 34 houses sampled in five towns in northern Idaho (Bovill, Coeur d'Alene, Moscow, Post Falls, and Potlatch) conducted between March and November of 1999 revealed the following:

- There was evidence of significant seasonality of lead concentration in house dust in some towns and no evidence in other towns.
- The patterns of seasonal variations in house dust lead concentrations, and lead and dust loading rates were different for different towns.
- A linear relationship between dust loading rates and precipitation rates was observed in the four towns for which precipitation data were available.
- There was no evidence of significant differences in lead concentration between vacuum cleaner bag and floor mat dust sampling techniques in four of the five towns (Bovill being the exception).

To better understand the differences between the two techniques of house dust sampling observed in Bovill, it would be interesting to conduct chemical mass balance source apportionment. This would show whether the two methods share the same sources of lead or if they reflect different sources contributing to lead levels in house dust.

The findings of our study do not suggest any firm conclusions on the seasonality of lead levels in house dust. Possible reasons for this could be house dust's dependence on many factors that are difficult to control, such as weather conditions, traffic density, house age, presence of leaded-paint, personal habits, and occupation of residents. Some of these factors could be dependent on season, while others could be independent of season.

Although the results of this study revealed a significant variability between towns, it should be recognized that the number of observations in each town was very small ($n = 2$–8). Therefore, a larger number of houses should be investigated, more frequent (e.g., monthly) measures should be taken from each home, and the sampling should continue for at least 12–24 months. This would allow better understanding of the nature of seasonal variations in house dust lead levels, and lead and dust loading rates, and would provide valid and practical information for establishing and determining compliance with risk-based house dust lead standards.

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