ECOLOGICAL IMPLICATIONS OF HEAVY METAL CONTAMINATION OF ROADSIDE HABITATS

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Abstract: Heavy metal (lead, cadmium, and zinc) concentrations were found in increase with traffic volume in soil, vegetation, earthworms, and small mammals recovered from roadside areas. Concentrations of all elements generally declined in soil, vegetation, and earthworms as distance from the highway increased. Shrews had higher levels of heavy metals than plant consuming rodents (*Microtus* and *Peromyscus*). Problems of interpreting data on road side contamination and of the ecological significance of such contamination are discussed.

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In recent years there has been considerable recognition of the value of roadside habitats for wildlife production. This is especially the case in midwestern prairie states and the importance of habitat along roadsides for pheasants (*Phasianus colchicus*) has been documented (Linder et al. 1960, Chesness et al. 1968, Baxter and Wolf 1973.) Such habitats are also important to some species of nesting waterfowl (Oetting and Cassel 1970) and cottontail rabbits (*Sylvilagus floridanus*) (Beule and Studholme 1942). The roadsides are particularly attractive to raptors because of the abundance of small rodents present and the edge effect created which facilitates aerial predation (Ferris 1974). Unfortunately, roadsides are not without major disadvantages for resident wildlife populations. Considerable direct mortality of a wide range of species occurs and a substantial amount of pollutants is released into highway ecosystems as a result of automobile traffic. Major components of these pollutants are hydrocarbon combustion products as well as the heavy metals lead, cadmium, nickel, and zinc which are released as a result of combustion of leaded gasoline, combusion of lubricating oils (nickel), and wear of tires (cadmium and zinc). Some idea of the magnitude of problems involved with highway right-of-way management may be gained from the extent of land involved (3.04 x 10^7 ha) and the volume of leaded gasoline consumed (220 x 10^6 kg lead in 1970) (Smith 1976).

This report discusses ecological problems associated with heavy metal contamination of roadsides in light of data gathered on lead, cadmium, nickel, and zinc concentrations in the several levels of food chains associated with highways of different taffic volumes.

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MATERIALS AND METHODS

Study areas were located in Fairfax, Montgomery and Craig Counties, Virginia. Highways with mean daily traffic counts were selected as study areas as follows: (traffic counts from Virginia Department of Highways 1975):

I 95 (Fairfax Co.)	92,400 vehicles/day
US 460 (Montgomery Co.)	24,095 vehicles/day
VA 114 (Montgomery Co.)	7,510 vehicles/day
VA 42 (Craig Co.)	525 vehicles/day

Control areas were located in Montgomery County, and in Fairfax County, Virginia. Each control area was at least 500 m from any roadway.

Samples of soil, vegetation, earthworms, and small mammals were collected from the 4 roadside areas of different traffic volumes and from the control areas. Sampling was conducted 4 times (to represent all 4 seasons) during a 1-year period in all areas. Soil, vegetation, and earthworms were collected at 3, 6, 12, 24, and 48 m from the highway edge. Mammals were snap-trapped within 24 m of the highway edge. Soil was sampled to a depth of 2.5 cm and 5 replicate samples per distance line were taken in each season. Five samples each of all above ground parts present of grass and forbs were taken each season on each sample line. Earthworms (up to 10) were taken on each sample line but were not always available due to soil conditions and seasonal constraints. Snap trapping was conducted using museum special snap traps. Earthworms were allowed to cast soil prior to processing.

Samples were returned to the laboratory (soil in prepared boxes, other materials in plastic bags), soil was ovendried at 80 C. Biological materials were freeze dried, all were ashed in a muffle furnace, and reduced to solution in nitric and hydrochloric acid. Levels of lead, cadmium, nickel, and zinc were determined in all samples using an Instrumentation Laboratories Model 351 atomic absorption spectrophotometer. Content of all 4 elements were expressed in terms of ug/g dry weight (d.w.) of the original samples.

RESULTS

Data are presented in Table 1 which show significant differences among areas, among

TABLE 1. Statistically significant differences revealed by analysis of variance of heavy metal levels in soils.

Element	Significance Lead	Cadmium	Nickel	Zinc
Differences among areas	$p<0.0001$	$P<0.0001$	$P<0.0001$	$P<0.0001$
Differences among distances from highways	$P<0.0001$	$P<0.0001$	$P<0.0001$	$P<0.0001$
Differences among sampling times (Seasons)	$P<0.05$	$P<0.0001$	$P<0.05$	$P<0.0001$

distances from highways, and among sampling times for all 4 elements in soil showing differences between areas in each of the sampling periods. Lead and zinc levels were consistently higher in the areas with higher traffic volumes (Table 2). The patterns for nickel and cadmium were less consistent though there was a tendency for cadmium concentrations to be greater near those highways with higher traffic volumes (Table 2).

Data in Table 3 show the effects of distance from highways on heavy metal levels. Concentrations of lead and zinc greatly decreased as distance from highways increased. The same general trend was evident with cadmium and nickel though patterns were not always clear in areas of low traffic volume.

Table 4 presents data on significant differences in concentrations of heavy metals in vegetation. Differences among areas were seen with all elements, among distances from the highways with all elements except nickel, and among collection periods with all elements except cadmium. Overall means for each element for all areas for all sampling periods are given in Table 5. All elements generally decreased as traffic volume decreased. The effect of distance from the highway on contaminant levels in vegetation is shown in Table 6. Lead and zinc levels declined as distance from the highway increased. Cadmium levels declined except in 1 area while nickel levels tended to decline with distance from the highway though the patterns were not consistent in all areas.

TABLE 2. Overall means of heavy metal content (ug/g,d.w.) of soils in different areas at different sampling periods.

Element	Area	Sampling Periods			
		Aug/Sept	Nov./Dec	Feb/Mar	Jun/July
Lead	I 95	605.83a	521.22a	261.02a	252.12a
	Fairfax control	21.65b	14.94b	23.78c	21.19c
	UA 460	138.55b	78.17b	136.62b	149.07b
	Va 114	101.06b	83.56b	27.07c	42.43c
	Va 42	40.62b	32.95b	21.24c	19.56c
	Montgomery Control	20.09b	11.61b	20.10c	20.40c
Cadmium	I 95	1.44b	0.29b	0.39b	0.36a
	Fairfax Control	2.33a	0.02b	0.23b	0.24a
	US 460	2.54a	0.11b	0.86a	0.24a
	Va 114	1.68b	1.33a	0.38b	0.28a
	Va 42	0.51c	0.11b	0.73a	0.33a
	Montgomery Control	0.76c	0.69b	0.22b	0.25a
Nickel	I 95	3.22b	3.08ab	3.02b	2.09b
	Fairfax Control	4.82b	2.03b	1.34c	1.39b
	US 460	8.12a	4.71a	3.08b	2.69b
	Va 114	3.34b	3.86ab	1.40c	1.78b
	Va 42	1.92b	2.23b	4.77a	4.05a
	Montgomery Control	2.03b	1.58b	1.68bc	2.34b
Zinc	I 95	93.49a	109.64a	61.96a	45.44a
	Fairfax control	27.32c	18.14c	12.00c	14.37b
	US 460	92.45a	68.48b	45.25b	43.67a
	Va 114	29.49c	35.37c	18.72c	20.59b
	Va 42	68.21ab	57.04bc	34.60b	32.25ab
	Montgomery Control	29.77bc	13.72c	17.08c	16.26b

a,b,c: Column means with different superscripts withing the same sampling period and for the same element are significantly different ($P<0.05$).

Data on significant differences of heavy metal concentrations in earthworms are given in Table 7. Time of sampling did not affect concentrations of any element. Distance from highway influenced cadmium and zinc concentrations and significant differences among areas were seeen for lead, cadmium, and zinc. Mean concentrations of lead in earthworms from different areas and different distances from the highway are given in Table 8. Substantial concentrations of lead were found in the high traffic volume areas. Cadmium concentrations in earthworms decreased with distance from the roadway in the 2 areas with highest traffic volumes. Mean cadmium concentrations in earthworms were less than 14 ug/g d.w. in the I95 area, while the corresponding controls had 11 ug/g d.w. Cadmium concentrations were considerably less in other traffic areas. Nickel concentrations in earthworms did not vary with area or distance from highways.

Details of zinc concentrations in earthworms are given in Table 9. Very high concentrations of zinc were found in earthworms from all areas.

Heavy metal concentrations in small mammals are shown in Tables 10 and 11. Table 10 contains data on differences between species within areas. Shrew species had higher concnetrations of lead, cadmium, and zinc in all areas though the differences were not always significant. Nickel concentrations did not vary among species.

TABLE 3. Overall mean heavy metal levels (ug/g, d.w.) in soil at different distances from highways.

Area	Distance from Road (m)	Overall Mean Levels			
		Lead	Cadmium	Nickel	Zinc
I 95	6	735.82a	0.71a	4.53a	151.70a
	12	273.46b	0.47b	2.41b	47.44b
	24	140.21c	0.35b	1.93b	28.66c
	48	81.42c	0.30b	1.76b	18.91c
Fairfax Control	-	21.66	0.39	1.71	14.78
US 460	6	140.44b	0.40c	4.83a	72.38a
	12	264.54a	0.90b	3.91a	76.29a
	24	87.57b	0.33c	2.70b	28.38b
	48	55.84b	1.10a	2.47b	24.78b
Va 114	3	307.62a	0.32b	9.22a	56.94a
	6	78.56b	0.96a	2.22b	31.63ab
	12	28.30b	0.51b	1.55b	21.91ab
	24	19.67b	0.37b	1.61b	14.69b
	48	15.00b	0.47b	1.37b	14.82b
Va 42	3	30.58a	0.73a	4.03a	36.48abc
	6	23.13a	0.52b	4.04a	50.55a
	12	20.59a	0.49b	4.07a	22.24c
	24	19.36a	0.43b	4.54a	49.47ab
	48	19.77a	0.33b	3.74a	29.82bc
Montgomery Control	-	19.65	0.32	1.98	17.51

a,b,c: Column means with different superscripts within each area are significantly different ($P<0.05$)

TABLE 4. Statistically significant differences revealed by analysis of variance of heavy metal levels in vegetation.

Element	Significance Level			
	Lead	Cadmium	Nickel	Zinc
Differences among areas	$P<0.0001$	$P<0.0001$	$P<0.0001$	$P<0.0001$
Differences among distances from highways	$P<0.0001$	$P<0.0001$	N.S.	$P<0.0001$
Differences among sampling times (seasons)	$P<0.0001$	N.S.	$P<0.0001$	$P<0.005$

Within species the higher concentrations of lead, cadmium, and zinc were found at the higher traffic volume areas (Table 11). No significant differences in nickel concentrations wre seen.

TABLE 5. Overall means of heavy metal content of vegetation in different areas at different sampling periods (ug/g,d.w.).

Element	Area	Aug/Sept	Nov/Dec	Feb/Mar	Jun/July
		Sampling Periods			
Lead	I 95	72.29a	184.84a	289.97a	77.00a
	Fairfax Control	7.55b	8.25b	15.37c	4.22c
	US 460	29.51ab	150.89a	219.37b	36.75b
	Va 114	19.11b	32.71b	49.67c	8.52c
	Va 42	6.88b	16.14b	16.08c	4.15c
	Montgomery Control	3.28b	10.07b	13.45c	3.98c
Cadmium	I 95	0.39ab	0.48bc	0.60a	0.49a
	Fairfax Control	0.28bc	0.65ab	0.42b	0.35b
	US 460	0.29bc	0.12d	0.29c	0.30b
	Va 114	0.49a	0.33c	0.31c	0.35b
	Va 42	0.18c	0.10d	0.18d	0.54a
	Montgomery Control	0.22bc	0.84a	0.18d	0.16c
Nickel	I 95	2.95a	1.96a	2.77a	2.31a
	Fairfax Control	2.05ab	1.36ab	1.53c	2.18ab
	US 460	0.82c	1.21ab	2.16b	1.43c
	Va 114	1.77b	0.82b	1.64c	1.38c
	Va 42	0.53c	0.76b	1.63c	1.31c
	Montgomery Control	0.66b	0.71b	1.13c	1.51bc
Zinc	I 95	88.61a	93.67a	142.38a	97.93a
	Fairfax Control	60.46b	60.75bc	57.41d	44.52c
	US 460	60.34b	65.39b	85.18b	59.64b
	Va 114	81.83a	49.71c	67.34c	47.77c
	Va 42	50.94b	73.79b	30.01e	43.52c
	Montgomery Control	47.49b	21.32d	25.68e	45.13c

a,b,c,d,e: Column means with different superscripts within the same sampling period and for the same element are significantly different ($P<0.05$).

DISCUSSION

The data presented in this report indicate the many problems involved in interpreting the significance of contamination of roadside environments to vertebrate forms using the area. A large volume of literature relates to soil and vegetation contamination by lead; rather less relates to cadmium, nickel, and zinc contamination of roadsides. The literature on lead contamination has been reviewed by Smith (1976) while Hiller (1978) reviewed literature on contamination by lead, cadmium, nickel, and zinc.

A major factor in most past work has been the failure to consider possible seasonal differences in contaminant levels of soil and vegetation. In this study seasonal differences in contaminant concentrations in soil were observed. This may be related to different leaching patterns of the contaminants at different seasons, different rates of decay of plant material at different seasons, or to the fact that loss of cover of plant material at times of the year might contribute to more direct deposition of contaminants on soil. Plant growth patterns probably affected heavy metals concentrations most and concentrations were highest in aerial plant parts when plant growth was least (winter season). Past research should be interpreted more rigorously due to seasonal differences in contaminant levels.

TABLE 6. Overall mean heavy metal levels (ug/g.d.w.) in vegetation at different distances from highways.

Area	Distance from Road (m)	Overall Mean Levels			
		Lead	Cadmium	Nickel	Zinc
I 95	6	286.97a	0.98a	2.55ab	219.08a
	12	167.07b	0.41b	2.39b	97.79b
	24	91.79c	0.38b	2.44ab	86.01c
Fairfax	48	84.92c	0.33b	3.03a	62.99d
Control -	–	10.12	0.40	1.80	53.83
US 460	6	147.36a	0.48a	1.66ab	81.20a
	12	101.02b	0.23b	1.26b	70.53b
	24	108.56b	0.21b	1.48ab	68.09b
	48	57.39c	0.19b	1.86a	52.15c
Va 114	3	33.26a	0.26b	1.99a	55.05b
	6	39.08a	0.28b	1.28b	57.86b
	12	17.28a	0.26b	1.80ab	70.68a
	24	14.80a	0.26b	1.37ab	70.11a
	48	10.57a	0.62a	1.13b	38.95c
Va 42	3	13.91a	0.50a	1.42a	45.20b
	6	8.16a	0.33b	1.31a	53.81a
	12	9.78a	0.33b	1.07a	39.37bc
	24	7.82a	0.34b	1.31a	34.04c
	48	6.60a	0.25b	1.43a	32.93c
Montgmery Control	-	7.02	0.24	1.21	38.15

a,b,c,d: Column means with different superscripts within each area are significantly different ($P<0.05$).

TABLE 7. Statistically significant differences revealed by analysis of variance of heavy metal levels in earthworms.

Element	Significance level			
	Lead	Cadmium	Nickel	Zinc
Differences among areas	$P<0.001$	$P<0.0001$	N.S.	$P<0.0001$
Differences among distances from highways	N.S.	$P<0.05$	N.S.	$P<0.0001$
Differences among sampling times (seasons)	N.S.	N.S.	N.S.	N.S.

Among mammals, considerably higher concentrations of contaminants were found in shrew species than in such plant consuming species as *Peromyscus* and *Microtus*. Concentrations in *Microtus* generally exceeded those in *Peromyscus* and may have reflected different food habits. This result confirms other work such as that of Quarles et

TABLE 8. Mean lead levels (ug/g,d.w.) in earthworms by area and distance from highways.

Distance from highway (m)	Study Area					
	I 95	US 460	Va 114	Va 42	Fairfax Control	Montgomery Control
3	--	--	--	17.32a	--	--
6	272.58ax	98.78ay	28.25ay	8.98ay	--	--
12	275.07ax	168.44abx	12.47ay	9.46ay	--	--
24	197.89ax	53.58bx	7.16ax	8.28ax	--	--
48	98.61ax	25.34bx	6.73ax	13.79ax	--	--
					72.03	8.04

a,b: Means with different superscripts in the same column are significantly (P<0.05) different.
x,y: Means with different superscripts in the same row are significantly (P<0.05) different.

TABLE 9. Mean zinc levels (ug/g,d.w.) in earthworms by area and distance from highways.

Distance from highways (m)	Study Area					
	I 95	US 460	Va 114	Va 42	Control	Montgomery Control
3	-	-	-	-	-	-
6	654.07ax	784.61ay	514.75ax	479.01bx	-	-
12	593.98ax	893.74ay	518.68ax	227.18cz	-	-
24	1475.21bx	537.52by	417.36ay	433.08by	-	-
48	646.11ax	462.02bx	427.19ax	391.47bcx	-	-
					361.72x	222.52x

a,b,c: Means with different superscripts in the same column are significantly (P<0.05) different
x,y,z: Means with different superscripts in the same row are significantly (<0.05) different

al. (1974) and Goldsmith and Scanlon (1977), and indicated that those species high on the food chains are particularly vulnerable to heavy metal contamination. Higher concentrations were found in shrews in control areas also. The extremely high concentrations of heavy metals in earthworms may have been a source of contamination for the shrew species. This also prompts speculation as to whether vulnerability of earthworms to predation is increased by contamination, or whether their behavior is altered thereby influencing vulnerability. One may also speculate whether earthworm viability is adversely influenced by contamination. Further questions are posed by the available data on shrew food habits which are thought to center largely on insects. Low concentrations of lead were found in insects by Goldsmith and Scanlon (1977) and they

TABLE 10. Mean heavy metal levels (ug/g,d.w.) in mammal species together with differences between species, from 6 study areas.

Area	Species	N	Lead	Cadmium	Nickel	Zinc
I 95	Microtus	15	23.07a	.37ab	2.47a	119.03a
	Peromyscus	23	21.96a	.81a	1.00a	109.99ab
	Blarina	11	72.56b	1.71c	1.59a	139.20c
	Mus	4	64.25b	.16b	1.62a	99.26b
US 460	Microtus	48	16.63a	0.19a	1.63a	102.51a
	Peromyscus	13	13,38a	0.30a	1.06a	104.12ab
	Blarina	15	35.13b	0.46a	1.56a	122.45bc
	Mus	2	21.73ab	0.06a	.45a	84.98a
	Cryptotis	9	17.16	0.52a	1.38a	110.71abc
	Rattus	5	27.95ab	0.54a	1.60a	135.06c
Va 114	Microtus	27	7.21a	0.22a	2.16a	105.46a
	Peromyscus	18	5.24a	0.20a	1.06a	90.23ab
	Blarina	10	12.03a	0.47a	1.01a	122.88a
	Mus	1	11.32a	0.11a	.23a	50.94b
	Cryptotis	13	6.66a	0.80a	1.29a	123.46a
	Sorex	1	9.65a	1.09a	.72a	146.18a
Va 42	Microtus	38	2.29a	0.15a	1.34a	97.52a
	Peromyscus	4	1.85a	0.19a	1.48a	104.61a
	Blarina	7	4.40a	0.29a	1.53a	100.01a
	Cryptotis	4	3.44a	0.20a	1.45a	109.08a
Fairfax	Microtus	44	3.92a	0.18a	1.76a	107.11ab
Control	Peromyscus	6	2.39a	0.40a	1.14a	83.33b
	Blarina	22	7.28a	0.66a	1.36a	112.18a
	Cryptotis	12	3.38a	0.34a	0.84a	109.26a
	Sorex	1	4.00a	0.93a	0.93a	106.68a
Montgo-	Microtus	6	1.10a	0.11a	1.36ab	91.75a
mery	Peromyscus	10	2.60a	0.18a	3.07b	106.87a
Control	Blarina	37	2.70a	0.47a	1.27a	105.71a
	Cryptotis	3	5.38a	0.26a	1.14a	117.69a
	Sorex	3	2.87a	0.44a	4.19b	114.81a

a,b,c: Column means within areas with different superscripts are significantly different from each other ($P<0.05$).

speculated that high lead concentrations in shrews were the result of ingestion of other foods, probably earthworms.

From the standpoint of avian species utilizing roadsides further questions of possible contamination dangers are prompted. Birds preying on mammals in areas with traffic volumes in excess of 7,500 vehicles per day are probably subjected to substantial quantities of heavy metals. Studies of such effects on raptors or shrikes are non-existent but are badly needed to estimate the effects. Bird species utilizing earthworms would be at considerable risk if the majority of their food source were drawn from roadside areas.

TABLE 11. Mean heavy metal levels (ug/g.d.w.) in mammal species together with differences between areas recovered from 6 study areas.

Species	Area	N	Lead	Cadmium	Nickel	Zinc
Microtus	I95	16	23.07a	0.81a	2.47a	119.03a
	US460	48	16.63a	0.03ab	1.63a	102.50b
	Va114	27	7.21ab	0.20b	2.16a	105.46ab
	Va42	38	2.29b	0.19b	1.34a	97.52b
	Fairfax Control	44	3.92b	0.40ab	1.76a	107.11ab
	Montgomery Control	6	1.10b	0.18b	1.36a	91.75b
Peromyscus	I95	4	21.96a	0.37a	1.00a	109.99a
	US460	12	13.38a	0.19a	1.06a	104.12a
	Va114	18	5.24ab	0.22a	1.06a	90.23a
	Va42	4	1.85b	0.17a	1.48ab	104.61a
	Fairfax Control	6	2.39b	0.18a	1.14ab	83.33a
	Montgomery Control	10	2.60b	0.11a	3.07b	106.86a
Blarina	I95	11	72.56a	1.71a	1.59a	139.20a
	US460	14	35.13b	0.46b	1.56a	122.45ab
	Va114	10	12.03c	0.47b	1.01a	122.88ab
	Va42	7	4.40c	0.29b	1.53a	100.01b
	Fairfax Control	22	7.28c	0.66b	1.36a	112.18b
	Montgomery Control	39	2.70c	0.47b	1.27a	105.73b
Mus	I95	23	64.25a	0.16a	1.62a	99.26a
	US460	2	21.73b	0.06a	0.45a	84.98a
	Va114	1	11.32b	0.11a	0.23a	50.94a
Cryptotis	US 460	9	17.16a	0.52ab	1.38a	110.71a
	Va114	13	6.66a	0.80a	1.28a	123.46a
	Va42	4	3.44a	0.20b	1.45a	109.26a
	Fairfax C.	12	3.38a	0.34ab	0.84a	109.26a
Sorex	Va114	1	9.65a	1.09a	0.73a	146.18a
	Fairfax C.	1	3.98a	0.93a	0.93a	106.68a
	Montg. C.	3	2.87a	0.44a	4.19a	160.68a
Rattus	US 460	5	27.95	0.54	1.60	135.06a

a,b,c: Column means within species with different superscripts are significantly different ($P<0.05$).

Plant consuming species could develop heavy contaminant concentrations. A last means of contamination of birds is the use of contaminated grit from roadside areas. Contaminant concentrations are likely very high in areas with high traffic densities.

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