LEAD IN SOIL, PLANTS, INSECTS, AND SMALL MAMMALS ALONG THREE KANSAS HIGHWAYS

by

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INTRODUCTION

An estimated 350,000 metric tons of lead in the form of an anti-knock agent, tetra-ethyl lead, are burned annually in internal combustion engines in the northern hemisphere and introduced into the atmosphere (Goldberg, 1970). This lead fallout has been shown to be an important environmental contaminant. The concentration of this lead fallout was investigated in the soil and biota from 3 Kansas roadsides, each with a different traffic volume. The biota analyzed for lead concentrations were vegetation, insects, and small mammal liver tissue and stomach tissue with contents. The 3 traffic volumes were 1,050, 7,255 and 10,181 vehicles per day (vpd). The 3 small mammal species for which tissue lead concentrations were analyzed were the short-tailed shrew (*Blarina brevicauda*), the prairie vole (*Microtus ochrogaster*), and the deermouse (*Peromyscus maniculatus*). Sampling was done seasonally, during the summer, 1978; fall, 1978; winter, 1979; and summer, 1979. The lead levels in plants and insects at 9, 12 and 15 m from the highway, were also measured.

Since ingestion is a major route of entry for lead into small mammals, a food habits study was conducted to determine the relative frequency of plant and animal matter in the diet. The relationship between diet and lead levels in animal tissue was explored.

The specific objectives of this study were to determine:

1.the levels of lead in the roadside soil and biota,

2. the relationship between small mammals diet and tissue lead levels,

3. the influence different seasons might have on lead levels, and

4. if the vegetation and insect lead levels decreased with distance from the highway.

LITERATURE REVIEW

General

Among the many sources of lead in our environment are: storage battery casings, fallout from lead smelters or lead mines, fallout from auto exhaust, use of lead-based paints, oil wastes, putty, linoleum, and pesticides (Aronson, 1972). One kilometer from a zinc smelter soil contained 2000 ppm of lead (Buchauer, 1973). Old orchard soils containing residues of insecticide sprayings had 191 ppm of lead while 2.8 ppm was the highest lead in vegetables grown there (Kenyon et al., 1979). Marten and Hammond (1966) measured lead levels in soil samples from near a battery smelter, a highway, and a greenhouse. The samples contained 680, 59, and 12 ppm lead, respectively.

The major andropogenic source of atmospheric lead is automobile emissions. Lead fallout from automobile exhaust has been linked to the increased lead levels in roadside vegetation and soil isotopic studies. Chow (1970) showed that the isotopic composition of lead in the roadside surface soil was identical to the isotopic composition of the gasoline lead. The lead combustion products along roadsides have been shown to be mainly responsible for high lead levels in plants, insects, soil, and animals living near roads (Cannon and Bowles, 1962; Motto et al., 1970; Jefferies and French, 1972; Giles et al., 1973).

Automobile emissions contain approximately 60-65% lead salts, 30-35% iron oxides,and 2-3% soot and carbonaceous particles (Habibi, 1973). Lead is exhausted principally as mixtures of

PbClBr, NH_4Cl 2PbClBr, and $2NH_4Cl$ PbClBr (Hirschler et al., 1957; Habibi, 1973; Biggins and Harrison, 1979). These vehicle-emitted compounds mix with the atmosphere to form atmospheric sulfates, of which $PbSO_4(NH_4)_2SO_4$ is usually the major lead component (Biggins and Harrison, 1979). Greater than 50% of soil lead compounds were identified as lead sulfates by Olson and Skogerboe (1975).

In general, the lead content of roadside soil and plants is positively correlated with traffic volume and negatively correlated with perpendicular distance from the roadway. Significant variations occur, however, due to many additional variables. The higher the speed or the heavier the load, the greater the rate of lead emission (Hirschler et al., 1957). Therefore, any incline where drivers would accelerate will have greater amounts of lead emitted there (Habibi, 1973; Daines et al., 1970; Ter Haar et al., 1971). Since lead accumulates in the soil, road age is important. For example, a highway which was opened in 1920 and carries 24,000 vpd has 3 times as much lead (403 to 60 ppm) in the 5 to 15 cm soil depths as a highway built in 1954 and carrying 56,000 vpd (Chow, 1970).

Climate greatly influences lead levels. Rainfall can bring about large and rapid fluctuations in the level of lead on plants. Ho and Tai (1979) measured a doubling of vegetation lead levels in one week without rain, and a decrease by two-thirds during a week with a rainfall of only 13 mm during a similar time period. The pattern of lead accumulation on mature coniferous needles also has been shown to vary with precipitation (Heichel and Hankin, 1976). The direction of the prevailing wind has a significant effect on lead content of plants close to major highways. The plants on the leeward side of the highway have higher lead values than similar plants on the windward side (Page et al., 1971; Chow, 1970; Daines et al., 1970). Other important variables which can cause a deviation from the generalized correlations include soil type and different plant species (see Literature Review for Soil and Vegetation).

Soil

Determination of total cumulative lead in the soil provides an index of environmental pollution which has occurred over time. Siccama and Smith (1978) in their study of a hardwood forest found soil to be a primary sink for lead. Coello et al. (1974) indicated that lead tends to accumulate in surface and upper soil strata, with little if any tendency for downward movement through the soil. This observation is consistent with those of other studies which have found vertical lead concentration gradients in surface soils. Chow (1970) found lead concentrations of 122 to 39 ppm in the top 5 cm of soil up to 30 m from a roadway carrying 56,000 vehicles per day (vpd). In soil deeper than 5 cm for Chow's study site, the lead levels dropped to 17 ppm and lower. Motto et al., (1970) noted a marked decrease in soil lead concentrations when they compared the 15 to 30 cm depth to the upper 15 cm of soil. Another study (Lagerwerff and Specht, 1970), measured lead concentrations at four traffic volumes in the range of 7,500 to 48,000 vpd and reported that lead concentrations declined with increasing soil depth (0 to 15 cm). This tendency of lead to be relatively immobile in the soil is due to its reduced solubility. The divalent cationic nature of lead causes it to bind to organics in the upper horizons and to react with sulfate, phosphate or carbonate anions reducing its solubility and restricting downward migration in the soil (Smith, 1976). The major form of roadside soil lead is insoluble lead sulfate (Olson and Skogerboe, 1975).

Numerous research studies have analyzed the relationship between traffic volume and soil lead levels (Chow 1970; Edwards et al., 1971; Williamson and Evans, 1972; Motto et al., 1970; Lagerwerff and Specht, 1970; Goldsmith et al., 1976; Burton and John, 1977). In addition to the fact that lead is concentrated in the surface soil there are two major points which are made in the research studies. First, as distance from the lead source, the roadway, increases the concentration of lead in the soil decreases. Soil lead levels decreased from 122 to 63 ppm at increasing distances of 7.6 to 30 m from the Baltimore- Washington Parkway with 56,000 vpd (Chow 1970). In New Jersey, lead levels in soil decreased gradually from 134 ppm at 7.5 m to 58 ppm at 67.5 m from a road with 12,800 vpd (Motto et al., 1970). Goldsmith et al., (1976) measured lead in soil for four traffic volumes from 21,040 to 1,085 vpd and at four distances, 3 to 50 m, and soil lead levels decreased significantly in all traffic areas as distance from the highway increased. The majority of lead contamination appears to be within a narrow zone of approximately 30 m from the roadside (Motto et al., 1970; Edwards et al., 1971; Williamson and Evans, 1972). The second major point made in previous research is that cumulative soil lead levels and accumulation rates are directly related to traffic volume, that is, as traffic density increases, lead concentrations in roadside soils increase (Burton and John, 1977). Traffic volumes of 1,085 vpd, 8,120 vpd, 21,040 vpd, and a study area combining 11,905 and 11,640 vpd had soil lead concentrations of 26 ppm, 47 ppm, 87 ppm and 127 ppm, respectively (Goldsmith et. al., 1976). However, when interpreting soil lead contamination considerations must be made for the road age, slope, erosion, and any factor which might influence lead levels (see general literature review).

In summary, the literature makes 5 major points concerning lead in soil along roadways,

1) lead is relatively immobile in soil, a primary sink,
2) an extreme vertical lead concentration gradient exists in soil,
3) as distance from the roadway increases, lead concentrations in soil decrease,
4) environmentally significant lead levels are concentrated in a narrow zone of approximately 30 m from the source,and
5) lead levels increase with increasing traffic volume when consideration is given to variables that influence lead levels.

Vegetation

Lead becomes associated with plants through the roots and foliage. Foliage is contaminated by lead from the atmosphere whereas the major source of root contamination is the soil. Root uptake of lead from the soil is minimal due to the extremely low availability of soluble lead cations. Of the total lead in the soil only 0.003 to 0.005% is estimated to be available for plant uptake (Wilson and Cline, 1966). This minimal lead availability is the result of soil adsorption of lead. The ability of soil particles to adsorb lead makes large differences in the extractable lead necessary to detect differences in plant uptake (Zimdahl and Arvik, 1973). As an example of soil lead adsorption, bromegrass (*Bromus inermis* L.) grown in a greenhouse in 4 soil treatments with lead levels of 680, 95, 59 and 12 ppm contained respective concentrations of 12.5, 3.0, 3.5 and 3.9 ppm (Marten and Hammond, 1966). The second year of bromegrass harvest from the soils in Marten and Hammond's (1966) study contained lead levels which were not significantly different from the control levels. The adsorption of lead by soil or, conversely, the soil lead available to plants is a function of the soil's content of organics, phosporous and calcium, and of soil pH (Zimdahl 1976; Simon, 1978). As the soil's organic content, in the treatment form of manure, increased from 1.3 to 10%, the uptake of lead by corn plants decreased (Zimdahl, 1974). Arvik and Zimdahl (1974) found lead uptake by plants from the soil was dependent upon solution pH, and not upon metabolic inhibitors or low temperatures, indicating that the uptake is a passive process. High phosphorous content, 500 ppm, in soil reduced lead availability by formation of relatively insoluble lead phosphate

(MacLean et al., 1969). Liming of soil and high calcium content have also been effective in decreasing available soil lead (MacLean et al., 1969; Cox and Rains 1972; John and Van Laerhoven, 1972; Simon, 1978). Corn, beans, lettuce and radishes expressed lead toxicity at lower lead concentrations in acidic soil than in calcareous soil (Page and Ganje, 1972).

Generally, little translocation of lead from the roots to the above-ground parts occurs (Keaton, 1937; Jarvis et al., 1977). This is due to the lead precipitates which form on and in the roots, preventing the passive movement of the lead (Simon, 1978). The lead which is translocated to the above-ground parts forms insoluble lead granules. Bittell et al. (1974) observed that mitochondria precipitated dense lead granules. Electron dense precipitates identified as lead have been observed in various plant organelles, i.e., inside the plasma membrane, within vesicles or vacuoles, chloroplasts, mitochondria, microbodies and plasmodesmata (Ophus and Gullvag, 1975). The insoluble lead granules are enclosed by dictyosome vesicles which eventually fuse with the cell wall (Malone et al., 1974). The occurrence of these lead granules and widespread deposition of lead within cells may explain lead's low toxicity in plants (Peterson, 1978).

In addition to plant contamination by lead in soil, the atmosphere is a source of lead contamination for plants. Large amounts of lead are deposited on plant surfaces from atmospheric sources. However, most of it remains as surface lead contamination (Schuck and Locke, 1970). A range of 30 to 90% of the lead associated with plant leaves can be washed off (Zuber et al., 1970; Motto et al., 1970; Davies and Holmes, 1972; Lerche and Breckle, 1974; Ward et al., 1975; Collet, 1978). Washing tends to reduce differences between species, and Haney et al. (1974) further concluded that more thorough washing would eliminate significant differences.

The amount of surface lead contamination has been correlated with leaf characteristics such as area, shape and surface texture (Little and Wiffen, 1977). In vegetative types with different canopy structures, Lerche and Breckle (1974) found lead to be retained according to the receiving leaf area per unit volume. Broad-leaved plant species like sugarbeet and turnip-rape collect more lead per dry weight than grasses (Ervio, 1977). Greater amounts of lead are found on crops with hairy, rough surfaces than smooth surfaces (Page et al., 1971). Using leaves from 11 species of trees, Little and Wiffen (1977) showed in wind tunnel experiments that rough or pubescent leaf surfaces collect up to 8 times more exhaust lead than smooth leaf surfaces. Haney et al. (1974) reported that species exposed to the same level of contamination will have significant differences in lead concentrations. The significant differences due to species all but disappear when leaves have the same surface structure (Lerche and Breckle, 1974).

Two trends in plant lead concentrations have been observed for atmospheric sources. The first pattern is a decrease in lead contamination in plants with increasing distance from the lead source (Chow, 1970; Motto et al., 1970; Page et al., 1971; Graham and Kulman, 1974; Lerche and Breckle, 1974; Ward et al., 1975;

Goldsmith et al., 1976). Leaves of vegetable crops had decreasing lead concentrations as did potato and carrot roots with increasing distance from the road source of lead. Lead in vegetation was 21.3, 12.5 and 7.5 ppm, respectively, at distances of 8, 16, and 32 m from a Missouri highway carrying 7,500 vpd (Lagerwerff and Specht, 1970). With a traffic volume of 56,000 vpd, the Baltimore-Washington Parkway had lead concentrations of 48, 41 and 24 ppm in plants at 7.6, 15 and 30 m distances, respectively, from the highway (Chow, 1970). At a Virginia intersection of a 11,905 vpd road and a 11,640 vpd highway, vegetation lead levels declined sharply from 70 to 30 ppm at 6 to 12 m from the intersection, then declined more gradually to 20 to 25 ppm at 18 and 50 m distances (Goldsmith et al., 1976). The highest concentrations of lead occur within approximately 30 m of the roadside (Motto et al., 1970; Edwards et al., 1971; Williamson and Evans, 1972).

The second trend observed in plant contamination by atmospheric lead source is a direct correlation between lead levels and traffic volume. Motto et al. (1970) observed that the overall lead concentrations of grasses and crops, growing along 9 highways with traffic volumes ranging from 12,800 to 54,700 vpd, generally increased with traffic volume. Minor lead accumulations were measured on crops close to roadways with less than 5,000 vpd compared to substantial lead accumulations near highways with 35,000 or greater vpd (Page et al.,1971). However, correlations such as traffic volume and distance with lead concentrations in plants should be made with consideration for road age, slope, wind, precipitation patterns and plant surface structure all of which are factors influencing lead levels (see general literature review).

Insect

Insects are an important link in the food chain of many ecological communities. Energy flow through herbivorous insects in an old field community was 4 times greater than through mice, and 7 times greater than through sparrows (Odum et al., 1962). Therefore, insects exposed to lead in their environment may constitute a significant source of lead for predatory animals which ingest them. Price et al. (1974) showed a tendency for increasing lead levels from sucking, to chewing, to predatory insects in high lead areas (an area in close proximity to a traffic volume of 12,900 vpd in their study), whereas low emission areas (less than 2,000 vpd) did not show such a trend. Udevitz et al. (1980), who sweep netted insect samples near a highway with 7,422 vpd, found an average of 50 ppm of lead compared to 15 ppm in insects far from heavily traveled roads. Dung beetles collected along the same highway had 13.1 ppm lead, more than twice the levels of dung beetles collected far from heavily traveled highways. In another study, the predatory European mantid (*Mantis religiosa*) was analyzed and found to concentrate lead. In an area with 13,000 vpd, the imago stage of the mantis contained 14.8 ppm of lead which was 4 times the level sampled in the imagos 39 days earlier and 7 times the lead level of the control samples (Giles et al., 1973). However, Giles et al.(1973) in the same study found the plant chewing Japanese beetle

(*Popillia japonica*) and the predatory damselfly (*Agrion maculatum*) did not accumulate lead. Grasshoppers likewise did not concentrate lead. In areas with 21,040 and 1,085 vpd grasshoppers had 3.8 and 3.4 ppm lead, respectively (Goldsmith et al., 1977).

Due to the significant lead concentrations that have been found in some insects, trophic studies have been carried out to detect biomagnification. A study of the food chain (vegetation - dung - dung beetle) did not show any obvious biomagnification (Robel et al., 1981). In another study, the tissue levels of lead in small mammals were less than many of their ground-living invertebrate prey (Williamson and Evans, 1972).

Research has also been conducted to determine if the abundance of insects living near highways versus far away from highways is different. This information would be useful as an indication of the effect of lead on the survival and distribution of insects. Williamson and Evans (1972) found that lead contamination levels in soil and vegetation had little if any effect on the abundance of 22 groups of ground-living invertebrates. Also, the addition of inorganic lead to the soil to produce concentrations of lead from 165 ppm to 19,000 ppm resulted in no detectable effects on the distribution and abundance of soil fauna (Williamson and Evans, 1973). However, the effects of lead on individual species have not been examined. Habitat variations seemed to be responsible for the population changes which were observed in the Williamson and Evans'studies.

Small Mammals

Animals in the upper trophic levels are often used as indicator species of toxic substances. However, in the case of lead, predators, for example, often contain less of the heavy metal than their prey. Wolves (*Canis lupus*) preying upon caribou (*Rangifer* spp.) and reindeer (*Rangifer tarandus* which eat lichens with high lead concentrations as a primary food source) contain lower lead levels than their prey (Holtzman, 1968). Lack of biomagnification observed by Holtzman (1968) is attributed to the tendency for lead to be concentrated in bone more than any other tissue. The predator consumes the flesh of its prey leaving behind the bones which contain high lead levels (Mierau and Favara, 1975; Groyer et al., 1970). However, several studies on small mammals feeding upon insects and/or plants have shown lead accumulations which were correlated with the level of lead exposure. Concentrations ranging from 2.6 to 31.7 ppm for 8 species (*B. brevicauda*, *C. parva*, *P. maniculatus*, *P. leucopus*, *R. megalotis*, *M. ochrogaster*, *M. musculus* and *S. tridecemlineatus*), with few exceptions showed a direct correlation between lead concentration in whole bodies and the areas of high (>12,000 vpd), medium (2,000 - 6,000 vpd), and low (400 vpd) exposure to lead (Rolfe and Haney, 1975). Accumulations of lead in the deermouse liver, kidney, and bone, but not in brain, lung, stomach and muscle were related to both traffic volume (which ranged from 4,200 - 38,000 vpd for 4 sites) and nearness to the highway (Welch and Dick, 1975). Getz et al. (1977) found lead concentrations were higher in small mammals living 5 - 10 m from a highway with 19,600 vpd than in populations near lower traffic-volume roads e.g. 1,360 and 340 vpd. *M. pennsylvanicus*, *P. leucopus* and *B. brevicauda* captured at 0 - 10 m from a highway with 12,470 vpd had significantly (P>0.05) higher whole body lead concentrations than the control (animals living 1.3 km from nearest road) but individuals trapped 25 - 45 m from the road were not significantly different from control levels (Quarles et al., 1975).

The trophic level of some small mammals has been correlated with the animals' lead concentration. Three species of shrews (*Blarina brevicauda*, *Cryptotis parva*, and *Sorex cinereus*) all generally had higher lead levels (body lead without stomach was analyzed) than 7 species of mammals at a lower trophic level e.g. rodents (Goldsmith and Scanlon, 1977). The levels of body lead in the shrews had means (± S.E.) which ranged from 34.8±9.5 to 6.5±1.4 ppm compared to a rodent range of 16.6±2.6 to 5.0±0.6 ppm.

There are many factors in addition to traffic volume and proximity to the highway which affect the accumulation of lead in small mammals. Diet and behavior are two such factors. Jefferies and French, 1972) attributed the 1.8 and 2.0 times more lead in *Microtus agrestis*'s body than *Clethrionomys glarolus* and *Apodemus sylvaticus* to *Microtus*'s habits of feeding on vegetation (the most highly contaminated food of the verge) and its use of grass for cover (keeping it near the verge and out of the less contaminated fields). Along heavy-use roads (>12.000 vpd) species which require dense vegetation and do not range out into cultivated fields (*Microtus ochrogaster*, *Blarina brevicauda*, *Cryptotis parva* and *Reithrodontomys megalotis*) had higher lead concentrations than species that extended their ranges into cultivated fields and thus more than 50 m from roads (*Peromyscus maniculatus* and *Mus musculus*) (Getz et al., 1977). Low calcium levels in the diet have been found to enhance lead toxicity (Six and Goyer, 1970) while 1 ppm chromium in the drinking water of rats appears to protect against lead toxicity (Schroeder et al., 1970). The sex and age of the individuals being studied can be correlated with lead levels. The body lead concentrations in the meadow vole, were significantly greater (4.2 ppm) for adults than for juveniles (2.7 ppm) though not in excess of diet levels (Quarles et al., 1974). Schlesinger and Potter (1974) observed a direct relationship between body weight (for *P. leucopus* and *B. brevicauda*) and lead concentrations in the body (body without stomach contents and embryos). The increase in weight with age to maturity (Layne, 1968) may account for increases in body lead accumulation with age. Several studies have reported a trend for mean body-lead levels of female rodents and shrews to be greater than in males (Clark, 1979; Jefferies and French, 1972; Quarles et al., 1974), however none of the studies has shown this trend to be significant statistically. Clark (1979) reported *Eptesicus fuscus*, big brown bats, to have significantly higher lead concentrations in males (46.6 ppm) than females (31.5 ppm), the reason for this difference being unknown.

Species differences also influence the results of lead studies. The treatment of rabbits with nicotinic acid greatly limited the effect of 200 mg of lead acetate (Pecora et al., 1966). However, in rats a 10-fold increase in niacin intake did not affect the development of lead toxicity (Kao and Forbes, 1973). Even where species, age, sex, diet, and lead exposure have been controlled, a pronounced variation between members of the same experimental group of wild mice has occurred. This suggests that much of the variation observed is due to individual differences in physiological processing of lead (Mierau and Favara, 1975).

The two pathways by which environmental lead can enter the body are inhalation and ingestion. Guinea pigs and rabbits living with about 2.5 g/m^3 lead in the air for 4 years in a laboratory had increases in bone levels of 30 to 60% over the control levels in guinea pigs and rabbits living under the same conditions, but breathing filtered air (Smith et al., 1970). Human populations also have shown the effect of atmospheric lead with higher blood levels resulting from long-term lead exposure (Goldsmith and Hexter, 1967). The efficiency of the small intestine in cattle to absorb lead is estimated to be less than 10% (Dinius et al., 1973). Quarles et al.(1975) found the lead contamination in small mammals caught near a highway to be several times larger than the controls (caught 1.3 km from nearest road) and concluded that diet was probably the most important route of lead uptake in his study. Quarles et al. (1975) based their conclusion on the fact that test animals had several times more lead than controls whereas laboratory studies of lead inhalation showed test animals to be less than 60% greater than controls (Smith et al., 1970). However, Young et al. (1978) showed bone lead elevated only 93% over control levels (0.8 ± 0.2 ppm) in laboratory housed guinea pigs after 100 days during which animals were fed crown vetch (89 ppm) harvested from a roadside. Mierau and Favara (1975) found that fecal lead plus 10% absorptive loss accounted for half the lead dosage required to produce similar bone lead concentrations in experimentally dosed deer mice. Therefore, Mierau and Favara (1975) concluded that both inhalation and ingestion may be equally important. The relative importance of each route is undecided and study of small mammals in their natural habitat prevents a clear separation of the relative importance of inhalation and ingestion of lead. Absorption of inorganic lead through the skin probably does not occur (Tepper, 1966) although the animal undoubtedly ingests some lead during grooming.

The relative magnitude of lead concentration in small mammals shows bones to have the highest concentration; kidney and liver are intermediate, and most other tissues have low concentrations (Mierau and Favara, 1975; Goyer et al., 1970; Young et al., 1978). The relative sensitivity of indicators of lead poisoning have been established in laboratory rats by Goyer et al.(1970). The most sensitive index is intranuclear inclusion bodies within the kidney proximal convoluted tubule cells. The next most sensitive index of lead accumulation was a decrease in body weight. This was followed in sensitivity by renal edema and increased urinary delta-aminolevulinic acid (ALA) excretion, with neuropathy, osteopathy and anemia as the least sensitive indicators (Goyer et al., 1970). Deermice, P. maniculatus, collected along a highway carrying 19,800 vpd had a mean bone lead concentration of 52.1±33.8 ppm which was similar to deer mice fed 0.1% lead acetate. Five times this amount (0.5%, similar to an estimated traffic volume of 100,000 vpd) of lead acetate fed to deermice for 26 weeks was required to show some development of inclusions in the proximal tubule cell nuclei of the kidney, though none of the less sensitive indices (all but neuropathy and osteopathy were examined) was significantly different from the controls (deermice which were not fed lead acetate) (Mierau and Favara, 1975). The environmental lead encountered by most roadside populations would be too low to produce toxic symptoms in small mammals.

Laboratory studies have shown lead can adversely affect reproduction. Rats fed 5μg of lead acetate for 30 days refused to mate with estrous females, and cessation of spermatogenesis was reported. Females given 5μg of lead daily experienced irregular estrus while females given 100μg of lead daily had persistent estrus and a decrease in corpora lutea formed (Hilderbrand et al., 1972). Decreases in litter size, birth weight and survival were the observed results of mating second-generation lead intoxicated rats (fed 1% lead acetate). The degree of placental transport of lead has not been studied extensively. Clark (1979) reported 0.17 ppm and 0.11 ppm in 2 litters of voles within 18 m of a Maryland road (35,000 vpd) and 0.11 ppm in a litter of voles 0.61 km from this roadside. Conflicting evidence has been reported for lead transmission during lactation (Calvery et al., 1938; Hardy et al., 1971). Although there is an apparant lack of visible effects of environmental lead on animals, there may be more subtle effects. Research reports indicate that in most instances an organism under stress is weakened and cannot withstand other stresses imposed upon it as well as a nonstressed organism. Under conditions of stress such as illness, starvation or senility, lead may be reabsorbed from bone and distributed to soft tissues (Williams, 1958). Mice exposed to low levels of lead for 30 days showed no clinical signs of lead toxicity but did show an increased susceptibility to bacterial infection (Salmonella typhimurium) (Hemphill et al., 1971). Lead exposed rats, all with less than 0.01 ppm in their blood, displayed less aggressiveness in a shock-elicited aggression test while having little effect on general activity or cognitive function (Hastings et al., 1977).

Food Habits

Ingestion of contaminated food materials is one of the major routes for entry of foreign material lead into the body. Quarles et al. (1973) suggested that the diet of small mammals was probably the most important factor influencing body lead levels. Because of the relationship between diet and body lead levels, the food habits of the 3 small mammals used in this study, deermice, short-tailed shrews and prairie voles are reviewed here.

Food consumed by deermice may contain large amounts (more than 50%) of animal matter with the abundance of arthropods varying with season (Jameson, 1952; Johnson, 1961; Whitaker, 1966). Johnson (1961) found the arthropod frequency in deermouse stomachs varied from a low of 78% in April to high of 95% in June for animals trapped from April to August. Butterfly (Lepidoptera) larvae peaked (34.5% by volume) during the summer months and decreased in deermice during the colder months when the supply of butterfly larvae is lowest (Whitaker, 1966). High energy food such as seeds and arthropods are taken preferentially over leaves, flowers, fungus and other miscellaneous vegetation (Vaughan, 1974). In Colorado, seeds reached a peak in the deermouse diet in late autumn and winter while arthropods and plant foods other than seeds were highest in spring and early summer (Flake, 1973). The mean percent volume of plant matter in the year-round diet was 59.4±1.3 (Flake, 1973). In general, the deermouse is highly opportunistic, eating those food items which are most available (Hamilton, 1941; Jameson, 1952; Williams, 1959; Johnson, 1961; Whitaker, 1966; Flake, 1973).

Habitat influences the availability of various food items and this is reflected in the diet of small mammals. Food habits of deermice, white-footed mice and house mice caught in cultivated fields showed increased amounts of the cultivated crop in their diet; in comparison, greater amounts of miscellaneous seed and vegetation occurred in animals trapped in weedy or grassy fields (Whitaker, 1966). The availability of food items is so important in determining diet in *Peromyscus* that Hamilton (1941) found no apparent differences between diets of white-footed mice (*P. leucopus*) and deermice (*P. maniculatus*) caught in the same habitat.

The food of the short-tailed shrew is made up of nearly 50% insects by volume, while next in abundance is vegetable matter (11.4%), followed by annelids, crustacea, molluscs, vertebrates, centipedes, inorganic matter, arachnids and millipedes in the order named (Hamilton, 1930). Hamilton (1930) also reported that winter diets of short-tailed shrews contained nearly 60% insect matter. The short-tailed shrew stores food (Merriam, 1886; Hamilton, 1930) which can be eaten during the winter, and also these shrews very likely prey upon dormant insects for winter food.

In Indiana, prairie vole stomachs contained 95% by volume plant material and about 5% insect matter (Zimmerman, 1965). The most common food (15.8%) was Poa compressa which was also most abundant on plots studied by Zimmerman (1965). Martin (1956) suggested that the food of prairie voles consisted mainly of those plants most common in the habitat.

In summary, the three principal small mammals used in this study were: (1) the deermouse whose diet is composed of about 40% animal matter and 60% plant material, (2) the prairie vole whose diet consists of 5% animal matter and 95% plant, and (3) the short-tailed shrew whose diet consists of about 90% animal matter plus 10% plant material.

SITE DESCRIPTIONS

General Description

The areas studied are located in the rural environment of the Northeastern Flint Hills region of Kansas. The largest town in the area, Manhattan, with a population of 30,305 is approximately 16 km from the nearest site. The elevation is between 330 and 390 m above sea level. The soils have been described as having developed from wind-deposited materials (loess) and from underlying massive, flinty, and cherty Permian limestones and interbedded shales (Fly, 1949; Eikleberry et al., 1950). The roadside areas studied cannot be classified further according to soil type because land operations have generally destroyed soil profiles. Disturbed soil layers result in a decreased organic layer which causes increased water runoff. All of my study sites had areas of exposed clay soil, as well as areas with topsoil and vegetation.

The annual rainfall in Kansas is approximately 80 cm. The average annual temperature in the Flint Hills area is 13°C (NOAA, 1978; NOAA, 1979). Kansas winds are variable but generally south or southwesternly in the growing season.

Alta Vista, Konza and Paxico

Three roadside areas were studied: Alta Vista, Konza and Paxico. The Alta Vista site borders the west side of K 177 near the town of Alta Vista (a population of 435) and 16 km south of I 70 in Geary County. K 177 is a 2-lane state highway constructed in 1955. It's average annual daily traffic (AADT) was 1,050 vehicles per day (vpd) during this study. The land bordering this roadside area is used for cattle grazing.

The Konza site borders the north side of the westbound lanes of I 70 and the Konza Prairie Research Natural Area in Geary County. The nearest town, Manhattan, with a population of 30,305, is 16 km north of the site. The section of I 70 near Konza is a 4-lane interstate highway constructed in 1964 and had a traffic volume of 7,620 vpd during this study. The land adjacent to this roadside area is natural tallgrass prairie.

The Paxico site borders the south side of the west bound lanes of I 70 about 1.6 km from the town of Paxico, with a population size of 174. The adjacent land area is woodland, part of a reststop area between the west and east bound lanes of I 70. This section of I 70 was constructed in 1955 and had a AADT of 10,400 vpd during this study.

The Alta Vista and Konza sites were mowed the 18th of October by the Kansas Department of Transportation. For information on the Kansas mowing policy, see Appendix Table 1.

Plant Composition

Vegetation analyses were done using the canopy-coverage method (Daubenmire, 1959) with modifications by L. Hulbert (a seventh class, a 0-1% class was added). Ten plots, each 10 m^2, were used at each site to estimate the area occupied by the vegetative canopy.

The dominant grass on the study sites was *Bromus inermis*

(Leyss.) (smooth bromegrass; 60% coverage). Smooth bromegrass is seeded along Kansas roadsides by the Kansas Transportation Department. Other abundant grasses included Andropogon geraldi (Vitman) (big bluestem; 11%), Andropogon scoparius (Michx.) (little bluestem; 3%), Panicum virgatum (L.) (switchgrass; 7%), and Sporabulus asper (Michx.) Kunth (tall dropseed; 14%). The common forbs were Ambrosia psilostachya (DC.) (western ragweed; 5%), Artemisia ludoviciana (Nutt.) (Louisiana sagewort; 3%), and Aster ericoides (L.) (heath aster; 4%). Melilotus (Mill.) spp. (sweetclover; 11%) was an abundant legume on all sites in 1978 but was scarce in 1979. Coronilla varia (L.) (crownvetch; 7%), was common on the Paxico site only. A wide variety (63) other plant species occurred occassionally (less than 2%) on one or more of the roadside areas studied (Appendix Table 2).

GENERAL MATERIALS AND METHODS

Glassware, Chemicals and Metal Standards

A 150-ml borosilicate beaker covered with a ribbed watch glass was used for wet digestion of samples. Whatman 42 ashless filter paper in a 65-mm filtering funnel was used to remove silica from the acid-digested samples. The extraction of lead into organic solvent was done in 20-ml screw cap test tubes. All glassware was washed with detergent solution, rinsed once with tap water, once with distilled water, then finally, with double distilled - deionized water. Subsequently, glassware was soaked for 24 hrs in 5% nitric acid, rinsed with copious amounts of double distilled - deionized water and then air dried.

Ammonium pyrrolidine-carbodithioate (APDC) was obtained from Aldrich Chemical Company. All other chemicals were analytical grade quality. A fresh solution of 2% APDC (aqueous) was prepared on the day of lead assay. Fisher Scientific's lead stock solution of 1000 ug/ml (ppm) was used in preparing a working standard of 100 ppm in 1% nitric acid. Standard curves were constructed on the day of assay using a reagent blank and three different metal concentrations. The highest lead sample in aqueous solution was within 10% of the highest lead standard used, which was 10 ug/ml. This is well within the linear working range for lead which is approximately 20 ug/ml in aqueous solution (Perkin-Elmer, 1968) for standard conditions (see Instrumentation).

Instrumentation

A Perkin-Elmer Model 603 atomic absorption spectrophotometer fitted with a 3 slot-burner was used to assay for lead. The 283.3 nm wavelength and 0.7 nm slit width were used with a lead - hollow cathode lamp. An air - acetylene flame was adjusted to obtain maximum absorption. Three aspiration readings were taken of each sample. Water saturated methyl isobutyl ketone (MIBK) was aspirated to achieve a baseline for the extracted samples. Double distilled - deionized water was used to establish a baseline for all other samples.

Sample Digestion and Assay

A measured amount, two grams maximum of dried prepared sample were digested in a 150-ml beaker with 30 ml of acid mixture. All samples were whole except the soil and the vegetation samples, which were ground (see respective materials and methods sections). The digestion solution was composed of nitric acid and 72% perchloric acid in a 4:1 ratio (V:V) (Toth et al., 1949). This mixture was added to the prepared sample 1 to 18 h before heating. This step allowed the acid to dissolve the dried prepared sample and reduced foaming during digestion (Middleton et al., 1972). The beaker of sample and acid mixture was heated at approximately 200 °C on a hot plate. During heating a ribbed watch glass was placed on the beaker when the nitric-perchloric acid mixture began fuming. The digestion was completed to dryness if the sample was clear and colorless. If the solution was not clear, an additional 5 to 10 ml of acid mixture was added and the digestion continued.

The beaker covered by the watch glass was then removed from the hot plate and cooled to room temperature. The inside of the cooled beaker and watch glass were rinsed with double distilled - deionized water, and all rinse water collected in the beaker being rinsed. The beaker of rinse water and sample residue was then heated on a hot plate until all but approximately 5 ml of solution had evaporated. This 5 ml of solution was rinsed with double distilled - deionized water from the beaker into a 20-ml screw cap test tube.

The digested samples were divided into two groups for assay based upon the expected lead content: a high lead group including soil and vegetation; and a low lead group including all animal tissue (liver, stomach and insects). The high lead group, plant and soil digested samples, were diluted to 20 ml with double distilled - deionized water, filtered through prewetted Whatman 42 ashless filter paper to remove silica (Graham and Kalman, 1974), then assayed for lead by atomic absorption spectroscopy (AAS) using standard conditions (see Instrumentation). The sensitivity of this analytical method is 0.5 ppm lead for 1% absorption (Perkin-Elmer, 1968). The low lead digested samples (stomach, liver and insects) were extracted to concentrate the lead for AAS measurements. These digested samples were adjusted to pH 8.5 with ammonium citrate buffer. The lead was chelated with 2% APDC solution and extracted into 2 ml MIBK as described by Yeager et al. (1971). The lead content of the MIBK layer was then measured by AAS. This method's sensitivity is 0.1 ppm of lead at 1% absorption (Penumarthy, 1979). During sample analyses, replicate and recovery analyses were also performed to insure repeatability and accuracy of lead results. The lead concentration in prepared samples was calculated by the formula: [ppm of Pb - background] X [sample volume (ml) / dry weight (g)] = ppm dry weight of Pb in sample.

MATERIALS AND METHODS

Soils

Soil samples were collected for lead analysis on the last day of each season's trapping period. Six soil samples were collected at 30 m intervals along a transect line in each trapping location. The transect line was parallel to and 12 m from the roadside at each trapping site. Each soil sample consisted of a pool of six 3-cm deep corings made with a polyvinylchloride (PVC) tube 1.2 cm in diameter. The 6 corings per sample were taken in circular soil areas of 0.2 sq m. After each soil coring was made , it was pushed into the opposite end of the tube with a plastic rod and another coring was taken until a sample size of 6 corings filled the tube. The ends of the tubes containing 6 soil corings each were sealed with parafilm. Six tubes of soil were collected in this manner from each trapping site and placed in dated site-specific plastic bags for transport to the laboratory. These soil samples were stored at room temperature for 5 to 17 months until analyzed for lead content.

Prior to analysis for lead content, the 6 corings of a tube were removed and pooled. The pooled sample was then thoroughly mixed and crushed with a mortar and pestle before being sifted through a plastic 2-mm mesh screen. Soil components e.g. stones which did not pass through the sieve were discarded. The pestle, mortar, and screen were acid washed, rinsed with double distilled - deionized water and dried between samples.

From each ground air-dried soil sample a small amount was placed in a numbered acid-washed beaker from which the site and time of collection could be identified. These soil samples in beakers were dried in an oven at 100 C for 3 hours, placed in dessicators to cool for an hour, then weighed on a Mettler analytical balance to 0.1 mg. The dry soil weight was calculated by subtraction of the beaker prerecorded weight from the oven-dried dessicated sample plus beaker weight. The prepared soil sample, with a maximum dry weight of 1 gram, was then digested and assayed (see General Materials and Methods).

Vegetation Materials and Methods

Vegetation samples for lead analysis were collected on the last day of each season's trapping period. Six samples were collected from each of three 150 m transect lines each parallel to and 9, 12, and 15 m from the roadway. Along each transect, vegetation was cut from within areas approximately 0.2^2m and 30 m apart. Vegetation from 2 adjacent areas on a transect was combined, producing 3 samples per transect. The vegetation was cut approximately 2.5 cm above ground level using teflon-coated clippers. The 9 vegetative samples collected from each trapping site were placed in individual plastic bags labeled with the date, transect line (9, 12, or 15 m), and site from which the sample was collected. The vegetative samples were transported to the laboratory and stored at room temperature for 5 to 17 months until analyzed for lead content. In the laboratory dead brown vegetation was separated from the living green vegetation. This separation was not done for the winter vegetation samples which were almost entirely dead vegetation.

Prior to analysis for lead, each air-dried vegetative sample was cut with teflon-coated clippers into approximately 2.5 cm lengths, then ground in a plastic grinder fitted with a 1-mm mesh stainless steel screen. As a sample was ground it was delivered into a plastic vial labeled with the sampling date, transect and site. After grinding a sample the labeled vial containing air-dried ground vegetation was capped and the grinder vacuumed to remove any remaining plant material. As an additional precaution against contamination between samples, the first bit of ground material for a sample was discarded.

Each ground air-dried vegetative sample was placed in a numbered acid-washed beaker and oven dried at 100 °C for 3 h, placed in dessicators to cool for 1 h, then weighed to 0.1 mg on a Mettler analytical balance. The dry vegetation weight was calculated by subtraction of the beaker prerecorded weight from the oven dried, dessicated sample plus beaker weight. The prepared vegetative sample, with a maximum dry weight of 1.2 g, was then digested and assayed (see General Materials and Methods).

Insect

Insect traps were set on the last day of the summer and the fall trapping periods for small mammals, after soil and vegetation samples had been collected. Insect trapping was not conducted during the winter. Six pitfall traps per site were set. Two traps were placed randomly on each of 3 transect lines parallel to and 9, 12 and 15 m from the roadway. Traps lying on the same transect line were separated by 30 m or more. The pitfall traps used were 480 ml plastic cups, (approximately 15 cm high and a mouth diameter of 9 cm) sunk into the ground so that the mouth was flush with the ground surface. Each trap contained a smaller inner cup for easy removal of trapped insects. This inner cup was filled with a mixture of water and soap. A removable funnel was placed in the mouth of the 480 ml cup. The traps were emptied after 3 days and covered with lids between collection periods. The insects were stored in plastic containers labeled with the date, transect line (9, 12 or 15 m) and site of collection. In the laboratory the insects were thoroughly rinsed with distilled-deionized water to remove soap and soil.

The insects belonging to the Carabidae family, ground beetles, were identified using Borror et al.'s (1976) key. The beetle samples were stored at $-20\,^{\circ}C$ in labeled plastic containers until analyzed for lead content. Ground beetles were chosen for lead analysis because of their abundance in the collected field samples as well as in the small mammal diets. Ground beetles composed an estimated 50% or more of the pitfalls contents. The commonest species in pitfalls are the large predatory ground beetles (Obrtel, 1971). Beetles were present in 95% of the deermouse and short-tailed shrew diets analyzed (Table 18).

Prior to lead analysis each frozen insect sample was thawed and oven-dried in a numbered acid-washed beaker from which the site, transect line and date of collection could be identified. All the collected ground beetles for a given site were dried whole in a beaker at 100 °C for 18 h, placed in dessicators to cool for 1 h, and then weighed to 0.1 mg on a Mettler analytical balance. The dry insect sample weight was calculated by subtraction of the beaker pre-recorded weight from the oven-dried dessicated beaker plus sample weight. The dried insect sample, with a maximum weight of 0.6 g, was then digested and assayed (see General Materials and Methods).

Small Mammals

The deermouse, an omnivore, the prairie vole, a herbivore, and the short-tailed shrew, an insectivore (Johnson and Groepper, 1970) were selected as target species due to their contrasting feeding habits and their relative abundance in Kansas (Gier and Bradshaw, 1957; Gier, 1967). Three sites, Alta Vista, Konza and Paxico, were snap-trapped in a time span of 23 to 47 days each season, for 3 to 7 days at a time. Six to 10 animals of each target species were desired for each site and season combination. Along two lines parallel to the road, 50 to 75 snap traps were set each night. The trap lines were spaced approximately 10 and 16 m from the road. Each trap's location was marked with a red flag. Traps were set preferentially in locations which had evidence of small mammal presence, such as, droppings, nests or runways. The

Museum Special snap traps were set before sunset with a mixture of peanut butter and rolled oats as bait. The trapped animals were collected within 2 h following sunrise and the traps disengaged.

In the laboratory the animals were identified using Swartz et al. (1968). Of the *Peromyscus*, 95% were positively identified as *P. maniculatus*, the remainder being either *P. leucopus* or *maniculatus*. After identification the animals were weighed and labeled with site and season information and individually numbered. All animals were classed by body weight as adults or juveniles. Voles were considered to be juvenile if they weighed less than 22 g (Myers and Krebs, 1971). Deermice were classed as juveniles if they weighed less than 18 g (Flake, 1971). Short-tailed shrews were classed as juveniles if they weighed less than 6.7 g. The 6.7 g value was calculated by taking 70 % of the body weight of the lightest pregnant shrew. The vole weight of 22 g is also 70 % of the lowest weight at which a pregnant vole was collected. Each animal was then dissected and sexed. The liver, the stomach with contents, and the small and large intestines were removed using acid washed stainless steel surgical instruments. Each liver and stomach was subsequently rinsed with deionized-distilled water, followed with a 0.1 M HNO_3 rinse and a final rinse with deionized-distilled water (Skogerboe et al., 1977). The washes were done to remove hair, blood and any other foreign particles from the outside of the organ to be analyzed for lead. The intestines were rinsed with water only, for the purpose of a food habits study. The organs were then stored individually in polyethylene bags at -20 °C. The plastic bags were labeled with the site, season species and code number of the small mammal donor. The remaining carcass was likewise labeled and frozen.

Prior to lead analysis the stomachs with contents and the livers were thawed. Each organ was oven-dried in a numbered acid-washed beaker. The whole organ was dried in a beaker at 100 ^{o}C for 18 h, placed in a dessicator to cool for 1 h and then weighed to 0.1 mg on a Mettler analytical balance. The dry tissue weight was calculated by subtraction of the beaker pre-recorded weight from the oven-dried dessicated beaker plus sample weight. The whole dried liver and stomach samples were then digested individually and assayed (see General Materials and Methods).

Food Habits

The small and large intestines of snap-trapped animals were removed, rinsed with water, and frozen individually at -20 ^{o}C in labeled polyethylene bags (see materials and methods for small mammals). For analysis, the contents of the thawed small and large intestines were tweezed onto a 200 mesh (0.1 mm openings) screen. This material was next washed over the 200 mesh screen (Sparks and Malechek, 1968) to remove the smallest fragments and gastric juices. The washed contents were floated in a petri dish of water and animal material present was identified to Order under a binocular microscope at 10x. Higher magnification was used when necessary.

After arthropod identification, the intestinal material was strained over a 200 mesh screen to remove the water. A small amount of the sample (enough to fill a 1 mm deep and 6 mm wide hole in a metal template) was placed on a 25x75 mm glass slide. Hoyer's solution (Baker and Wharton, 1952), a mounting medium, was stirred into the sample with the point of a dissecting needle. The mixture was evenly spread over 2/3 of the slide and covered with a 22x44 mm glass slip. The slide was heated over an alcohol burner until the Hoyer's started to boil. The bottom surface of the slide was then immediately wiped with a cold, damp sponge to draw out air bubbles trapped in the Hoyer's solution. The cover slip was then gently pressured with the wooden end of the dissecting needle to squeeze out excess mounting medium. The edges of the cover slip were sealed with a ring of Hoyer's solution and placed in an oven at 55°C for 2 to 3 days until dry (Hansen, 1971).

Beginning with the upper left side of a slide every second microscope field (excluding blank fields) was examined at 100x until 10 fields had been studied. The relative occurrence (frequency) of various items (animal and plant matter), i.e. the % occurrence of one item in relation to all occurrences (Hansson, 1970) was calculated as an index of the proportion of animal material versus plant in the intestine. Therefore, the calculation used for quantifying the animal material was Relative % occurrence = (Number of microscope fields containing animal material)/ (Number of microscope fields containing animal material + number of microscope fields containing plant material) x100. This calculation was also used for plant material with the modification that the numerator equaled the number of microscope fields containing plant material. The relative % occurrence is based upon the examination of 10 microscope fields for each animal intestine. All seasons and sites were represented in the food habits examined for each species.

Separation of plant and animal material by means of identification was achieved generally by noting the lack of cell structure and translucence of the animal material (Harris, 1950). The animal material often had attached appendages, chiton, spiracles, and hair, for example, which aided in identification. References used for insect identification were Borrow et al. (1976), Peterson (1951), and Harris (1950). Plant material was discernible by the presence of structures such as asperites, stomates trichomes and guard cells (Davies, 1959; Brusven and Mulkern, 1960; Howard and Samuel, 1979).

RESULTS AND DISCUSSION

Soils

The upper 3 cm of soil had mean lead levels with standard errors (S.E.), based on dry weight (d/w) samples, of 41.9±2.4 ppm, 61.9±2.2 ppm, and 66.9±2.3 ppm for Alta Vista, Konza, and Paxico roadsides respectively. These means are representative of data collected from July, 1978 to March, 1979. The sampling time was found to be nonsignificant therefore either July, 1978 or July, 1979 data could have been used for the year-round lead means. Alta Vista with 1,050 vpd had a statistically significant ($p=0.05$) lower year-round soil lead level of 41.9 ppm than Konza or Paxico. Konza with 7,255 vpd, and Paxico with 10,181 vpd had year-round lead means of 61.9 ppm and 66.9 ppm respectively which were not significantly different ($p=0.05$, Table 1). The year-round soil mean for a site is positively correlated with the site's traffic volume. which is consistent with the literature (Burton and John, 1977). However, as pointed out these differences in lead levels between Paxico (10,181 vpd) and Konza (7,255 vpd) are not significant. Two physical factors at the Paxico site are thought to be contributing to the absence of a significant difference in soil lead between the Paxico and Konza sites. First, the Paxico area slopes toward from the roadside and may be subject to erosion. Lead is largely adsorbed on to particulate matter and is mobile in water as a function of particulate mobility (Scott and Wylie, 1980). Therefore, erosion would remove lead from the site. Secondly, the Paxico site bordering the west bound lanes of I 70

Table 1. Mean lead concentrations (ppm, dry weight), standard errors (S.E.) and ranges in soil collected at 0-3 cm depth 12 m from Kansas roads with different traffic volumes (vehicles per day). Means are the result of July, 1978 to March, 1979 sampling.

Site	Traffic Volume	Soil Lead (Mean ± S.E.)	Range
Alta Vista	1,050	$41.9^{a} \pm 2.0$	26.8 - 58.7
Konza	7,255	$61.9^{b} \pm 2.0$	44.0 - 80.1
Paxico	10,181	$66.9^{b} \pm 2.0$	52.1 - 88.0

Means with common superscripts within a column are not significantly different (p=0.05).
N=18 for each mean.

is separated by approximately 200 m of woodland from the east bound lanes that carry half of the 10,181 vpd attributed to this site. Therefore, Paxico has an effective lead source less than 10,181 vpd.

Table 2 presents the results of seasonal sampling for all 3 study sites combined. The independent variable season or time was found to be nonsignificant in the ANOVA Model LEAD = SITE SEASON SITE*SEASON for the soils lead data. One year of sampling did not detect a significant change in seasonal soil lead for Alta Vista, Konza and Paxico. The surface soil lead, 54.8 ppm, 58.4 ppm, 57.5 ppm and 59.9 ppm for seasons, summer 1978, fall 1978, winter 1979 and summer 1979, respectively, do gradually increase with time as expected. Many studies have found lead to accumulate in surface soil (Oliver et al., 1974; Motto et al., 1970; Siccama and Smith, 1978).

The fall 1978 lead mean at 58.4 ppm represents the greatest increase of any of the seasons over the sampling period prior to it, summer 1978 at 54.8 ppm, in this case. The months of September, October, and November, all high lead months, represent the period of the year when wind velocity and atmospheric mixing depths are at a minimum (Daines et al., 1970). Therefore, atmospheric lead would be scattered over less distance, increasing lead concentrations along the roadside more than in other months. July and August are peak traffic volume months for all 3 sites with the fall months being higher than the winter and spring (Anonymous, 1977). The interaction, site*season, like season was nonsignificant in the ANOVA Model LEAD = SITE SEASON SITE*SEASON

Table 2. Mean lead concentrations (ppm, dry weight), standard errors (S.E.) and ranges in soil collected 0 to 3 cm depth 12 m from Kansas roads with different sampling times (seasons).

Season	Soil Lead (Mean ± S.E.)	Range
Summer 1978	54.8 ± 2.3	27.8 - 83.3
Fall 1978	58.4 ± 2.3	29.1 - 88.0
Winter 1979	57.5 ± 2.3	32.3 - 73.8
Summer 1979	59.9 ± 2.3	36.6 - 80.4

N=18 for each mean.
Seasons are defined as: summer (June - July), fall (Oct - Nov), and winter (Feb - Mar).

(Appendix Table 3).

The soil lead values reported here are similar to those reported elsewhere (Goldsmith et al., 1976; Quarles et al., 1974; Davies and Holmes 1972; Motto et al., 1970) for similar traffic volumes. The range of soil lead concentrations in this study (26.8 to 88.0 ppm) are all above the generally accepted natural background level of 16 ppm (Committee on Biologic Effects of Atmospheric Pollutants, 1972; Shacklette et al., 1971; Swaine, 1955).

Vegetation

The analysis of vegetation for lead contamination for 3 roadside sites (Alta Vista, Konza and Paxico) with traffic volumes of 1,050, 7,255, and 10,181 vpd resulted in mean lead levels (S.E.) of 17.3±0.9, 22.2±0.9, and 36.5±0.9 ppm, respectively. These values are all significantly different from each other ($p=0.05$, the probability level used for significance in all comparisons)(Table 3). The lead contamination mean for a site is positively correlated with the site's traffic volume. The tendency of the vegetation lead means to increase with traffic volume has been noted in other studies as well (Motto et al., 1970; Lerche and Breckle, 1974; Page et al., 1971). The vegetation lead means reported here are similar to those reported elsewhere (Goldsmith et al., 1976; Lagerwerff and Specht, 1970; MacLean et al., 1969) for similar traffic volumes.

Mean lead concentrations for vegetation at 3 distances (9, 12, and 15 m) were determined for each site. The lead

Table 3. Mean lead concentrations (ppm, dry weight), standard errors (S.E.) and ranges for vegetation collected within 15 m from roads with different traffic volumes (vehicles per day). Means are the result of June 1978 to March 1979 sampling.

Site	Traffic Volume	Vegetation Lead (Mean ± S.E)	Range
Alta Vista	1,050	17.3[a] ± 0.9	6.2 - 43.0
Konza	7,255	22.2[b] ± 0.9	7.4 - 47.2
Paxico	10,181	36.5[c] ± 0.9	5.8 - 99.9

Means with common superscripts within a column are not significantly different (P =0.05).
N=27 for each mean.

concentrations at each distance were statistically analyzed for individual sites (Table 4). The site data were then combined for a single mean lead value representing each distance (Table 5). These combined data for the 3 sites show mean lead concentrations of 23.7±0.9, 20.5±0.9, and 18.9±0.9 ppm for distances of 9, 12, and 15 m, respectively. The lead concentration at 9 m is significantly higher than the 12 and 15 m distances, which are not significantly different from each other. For individual sites (Table 4) only the Paxico area has any significant differences with the vegetation at 9 and 12 m having significantly higher lead levels than at 15 m. Previous studies generally use a minimum of 8 m between samples compared to the maximum of 6 m used in this study. Perhaps this accounts for the absence of statistically different lead concentrations at the three distances on Alta Vista and Konza. The data (Tables 4 and 5) generally show a trend for lead values to decrease with increasing distance from the roadway. This inverse relationship between distance and plant lead levels is consistent with the literature (Chow, 1970; Motto et al., 1970; Page et al., 1971; Graham and Kalman, 1974; Goldsmith et al., 1976).

The seasonal lead means for vegetation were 13.2±1.1, 12.2±1.1, 50.5±1.1, and 8.1±1.1 ppm for summer (1978), fall (1978), winter, and summer (1979), respectively, (Table 6). The summer (1978) and fall (1978) were not significantly different from one another, but both were significantly lower than the winter. The summer (1979) vegetation lead was significantly lower than the other sampling times. The summer months, July and August, are

Table 4. Mean lead concentrations (ppm, dry weight), and standard errors (S.E.) for vegetation collected at three distances from Kansas roads with different traffic volumes (vehicles per day). Means are for 4 sampling times from July 1978 to July 1979.

Site	Vegetation Lead (Mean ± S.E.) Distance from road (meters) 9	12	15
Alta Vista	16.2[a] ± 1.6	13.2[a] ± 1.6	14.1[a] ± 1.6
	(3.4 - 43.0)	(4.3 - 28.7)	(4.5 - 38.9)
Konza	20.4[a] ± 1.6	16.8[a] ± 1.6	19.1[b] ± 1.6
	(7.4 - 46.8)	(5.3 - 47.2)	(7.6 - 42.3)
Paxico	34.5[b] ± 1.6	31.4[b] ± 1.6	23.5[c] ± 1.6
	(7.8 - 99.9)	(6.8 - 97.5)	(5.8 - 78.0)

Means with common superscripts within a column are not signifi cantly different (p=0.05); and underlined values are not significantly different.
N=9 for each mean.

Table 5. Mean lead concentrations (ppm, dry weight), standard errors (S.E.) and ranges for vegetation collected at three distances from Kansas roads at 3 sites and 4 collection dates.

Distance	Vegetation Lead (Mean ± S.E.)	Range
9 m	23.7[a] ± 0.9	3.4 - 99.9
12 m	20.5[b] ± 0.9	4.3 - 97.5
15 m	18.9[b] ± 0.9	4.5 - 78.0

Means with common superscripts within a column are not significantly differen (p=0.05).
N = 36 for each mean.

Table 6. Mean lead concentrations (ppm, dry weight), standard errors (S.E.) and ranges for vegetation collected within 15 m from roads at 3 sites and 4 sampling dates.

Season	Vegetation Lead (Mean ± S.E.)	Range
Summer 1978	$13.2^{a} \pm 1.1$	5.8 - 28.4
Fall 1978	$12.2^{a} \pm 1.1$	7.4 - 23.3
Winter 1979	$50.5^{b} \pm 1.1$	25.6 - 99.9
Summer 1979	$8.1^{c} \pm 1.1$	3.4 - 15.2

Means with common superscripts within a column are not significantly different (P=0.05).
N =27 for each mean.
Seasons are defined as follows: summer (June - July); fall (Oct - Nov); and winter (Feb - Mar).

peak traffic volume months for all 3 sites with the fall months being higher than winter and spring (Anonymous, 1978). However, from May to August plant growth is rapid and the amount of organic matter per dried leaf increases (Everett et al., 1967). This rapid growth and increased volume to surface ratio dilutes the plant lead concentration when it is determined on a dry weight basis. Also, of the sampling times studied, summer is when the vegetation is the youngest and has had the shortest exposure time to lead sources. Consequently, the summer lead levels should be low compared to other seasons. The fall (1978) lead concentration of 12.2 ppm is not statistically different from the summer (1978) concentration of 13.2 ppm. A majority of the study sites' plants are grasses (see vegetation composition results) whose seeds would be expected to have a low lead content (Motto et al., 1970; Page et al., 1971), the inclusion in vegetation samples of seeds would lower fall lead levels. Also, the fall vegetation lead mean may have been lowered artificially due to the green vegetation being sampled was that which was too low to be moved and/or new growth protected from aerial contamination somewhat by the standing dead. The winter lead concentration of 50.5 ppm was significantly higher than all other seasons studied. Even though March (the winter data collection time) has one of the lowest traffic volumes (Anonymous, 1978) during the year, the plants collected are the oldest of all the samples. Therefore, winter vegetation lead values appear to represent a plant's annual accumulation of this heavy metal. Zimdahl (1976) noted that plant age is a very important determinant of lead content.

The summer (1978), with 13.2 ppm, had significantly higher lead levels than the summer (1979), with 8.1 ppm. This significant difference may be the result of the late start of the 1979 growing season after an unusually harsh and extended winter, as well as the increased usage of lead-free gasoline in motor vehicles in 1979. In 1978, 68% of the gasoline used in the United States was leaded compared to only 60% in 1979 (personal communication, Kansas Petroleum Council). Also, preceeding the vegetation sample collection date of July 28, 1978 there were 5 rainless days whereas in 1979, 2 rainless days preceeded the sample collection of vegetation (NOAA, 1979). A combination of these factors, growing season, gasoline usage, and precipitation patterns may have yielded these results.

The SITE*SEASON interaction analysis (Table 7) supports the same general relationships discussed for the season variable (Table 6). The ANOVA model used to analyze the vegetation lead data was LEAD = SITE SITE*DISTANCE DISTANCE SEASON SITE*SEASON. All the independent variables were significant in the model, and each is represented in a table (3,4,5,6,7).

Natural lead levels in vegetation are probably less than 5 ppm (Motto et al., 1970). All 3 sites had lead values greater than 5 ppm; only Alta Vista, with the lowest traffic volume (1,050 vpd) had any values less than 5 ppm.

Insect

The average lead concentrations in the insects collected from Alta Vista, Konza, and Paxico were 3.5, 2.2, and 5.6 ppm,

Table 7. Mean lead concentrations (ppm, dry weight) and standard errors (S.E.) for vegetation within 15 m from roads with different traffic volumes (vehicles per 24 hr.) and different sampling times (seasons). Ranges of lead concentrations are in parentheses.

Site	Traffic Volume	Vegetation Lead Concentration (Mean ± S.E.)			
		Summer 1978	Fall 1978	Winter 1979	Summer 1979
Alta Vista	1,050	$8.9^{a} \pm 1.8$	$11.6^{a} \pm 1.8$	$31.2^{a} \pm 1.8$	$6.3^{a} \pm 0.7$
		(6.2 - 14.3)	(8.7 - 15.4)	(25.6 - 43.0)	(3.4 - 9.7)
Konza	7,255	$14.2^{b} \pm 1.8$	$12.3^{a} \pm 1.8$	$40.0^{b} \pm 1.8$	$8.5^{a} \pm 1.8$
		(11.3 - 19.1)	(7.4 - 23.3)	(27.5 - 47.2)	(15.3- 14.3)
Paxico	10,181	$16.4^{b} \pm 1.8$	$12.9^{a} \pm 1.8$	$80.2^{c} \pm 1.8$	$9.6^{a} \pm 1.8$
		(5.8 - 28.4)	(9.5 - 22.6)	(56.1 - 99.9)	(6.5- 15.2)

Means with common superscripts within a column are not significantly different (p=0.05); values with on-level underlining are not significantly different.
N = 9 for each mean.
Seasons are defined as: summer (Jun - Jul); fall (Oct - Nov); and winter (Feb - Mar).

respectively (Table 8). These levels were not significantly different in the statistical analyses. The lead concentrations reported here are generally lower than those reported by Giles et al.(1973), Price et al.(1974), and Williamson and Evans (1972) for predatory insects near roadways. Low lead levels in carabids might be due in part to the shedding of the exoskeleton by the larval stage. It has been suggested by Giles et al. (1973) that lead may be stored in the exoskeleton which when shed would lower the insect's lead concentration. Also, the traffic levels at the Konza, Alta Vista, and Paxico sites are lower than those reported in other lead studies of predatory insects. Price et al.(1974) examined a site near a highway with 12,900 vpd, Giles et al.(1973) reported on a site with 13,000 vpd, and Williamson and Evans (1972) did not report their traffic volumes.

Generally, the lead concentrations of 3.5, 2.2, and 5.6 ppm in ground beetles from areas with traffic volumes of 1,050, 7,255, and 10,181 vpd are similar to or lower than insect lead concentrations far from major highways reported in other studies. Some examples of mean control lead levels in other studies are 2.0 ppm (Giles et al., 1973), 3.3 ppm (Price et al., 1974), and 6 ppm (Robel et al., 1981). However, the studies which have been done on insects are few compared to their abundance and diversity, as well as importance, of these animals in the environment. At least partly due to the limited number of insect lead studies, direct comparisons between studies are tenuous due to differences in 1) insect groups, 2) traffic volumes, and 3) methods of preparing samples for lead analysis, especially with respect to washing

Table 8. Mean lead concentrations (ppm, dry weight) and standard error (S.E.) for ground beetles within 15 m from roads with different traffic volumes (vehicles per day) and different sampling times (seasons). Ranges of lead concentrations are in parentheses.

Site/ Traffic Volume	Ground Beetle Lead (Mean ± S.E.)			
	Summer 1978	Fall 1978	Summer 1979	Average Lead
Alta Vista /1,050	3.1 ± 1.8 (0.0 - 12.0)		3.8 ± 1.8 (1.0 - 13.9)	3.5
Konza /7,255	*2.6 ± 1.6 (0.5 - 6.5)	1.9 ± 1.8 (0.9 -3.3)	2.1 ± 1.8 (0.2 - 3.3)	2.2
Paxico /10,181			*5.6 ± 1.6 (1.5 - 16.3)	5.6

N = 5 for all means except those with an asterisk (*).
* N = 6
Seasons are defined as follows: summer (Jun - Jul); fall (Oct - Nov).

samples. Two studies which are most similar to the present in the above 3 categories are discussed here. Williamson and Evans (1972) reported beetles collected from pitfall traps and washed with 70% ethanol before lead analysis had 11.0 ppm at 11 m from a roadway with an unreported traffic volume. Robel et al.(1981) studied dung beetles, which were rolled on damp towels and tweezed to remove dung before analysis. The dung beetles had 13.0 ppm at 50 m from a highway with 7,422 vpd. This study site was in the same general area as the Konza site.

Mean lead concentrations for insects at 3 distances (9, 12, and 15 m) were determined, based on all samples collected. These means, 2.1±1.3, 4.3±1.2, and 3.1±1.2 for the 3 distances (Table 9), were not significantly different. Although significant differences have been reported for lead levels near highways versus far from major highways, only one other study has examined insect lead levels at varying distances near a roadway. Williamson and Evans (1972) measured lead levels in beetles (Coleoptera) at 5 distances, 3 to 53 m, from the roadway at 2 sites, and found a negative relationship between distance and beetle lead levels at only 1 of the sites.

The ANOVA model used in the analyses of the insect data was LEAD = GROUP DISTANCE. The independent variable, GROUP, was defined as site-season groupings of data. Statistical significance was p=0.05 in all analyses.

Small Mammals

The small mammal results are discussed in 3 sections. Each

Table 9. Mean lead concentrations (ppm, dry weight), standard errors (S.E.) and ranges for ground beetles collected at 3 distances from Kansas roads.

Distance	N	Lead Concentrations in Ground Beetles (Mean ± S.E.)	Range
9 m	10	2.1 ± 1.3	1.1 - 3.3
12 m	11	4.3 ± 1.2	0.2 - 16.3
15 m	11	3.1 ± 1.2	0.0 - 12.0

section represents the results from a different ANOVA analysis. Sufficient data for species such as *Peromyscus* (deermice) and *Microtus* (prairie voles) allowed a greater number of variables in the ANOVA model than for those with fewer samples, such as *Blarina* (short-tailed shrews).

Deermouse and Prairie Vole: The mean lead concentrations for year-round data showed prairie voles had significantly higher lead levels in their livers (2.0±0.2 ppm) than the deermice livers (1.5±0.1 ppm) (Table 10). Correspondingly, the stomachs of prairie voles also contained significantly higher lead levels (7.5±0.9 ppm) than deermice stomachs (3.5±0.5 ppm). Other studies have reported higher body lead levels in voles (*Microtus*) than in mice (*Peromyscus*) (Quarles et al., 1974; Getz et al., 1977).

Generally, Paxico (10,181 vpd) had the highest lead levels for the species studied (Table 11). The prairie vole's stomach lead levels were significantly higher in species from the Paxico site (11.1±1.1 ppm) than from the Alta Vista (5.8±1.4 ppm) or Konza site (5.8±1.1 ppm). The prairie vole with its small home range size (0.024 ha) would be expected to be the best indicator of the relative lead contamination at roadsides. The Alta Vista site has small mammal lead levels which are almost equal to or greater than Konza's or Paxico's, even though it has 1/7 to 1/10 the traffic volume at these two sites. This phenomenon might stem from the severely overgrazed condition of the fenced rangeland which begins 20 m from the road, offering no cover or food. Therefore, the small mammals at Alta Vista could be restricted to

Table 10. Species comparison of mean lead concentrations (ppm, dry weight in organs of prairie voles and deermice from three Kansas roadside sites.

Species	Liver Mean ± S.E. (N) Range	Stomach with Contents Mean ± S.E. (N) Range
Prairie vole	2.0[a] ± 0.2 (103) 0.0 - 8.3	7.5[a] ± 0.9 (105) 0.0 - 35.5
Deermouse	1.5[b] ± 0.1 (106) 0.0 - 8.3	3.5[b] ± 0.5 (109) 0.0 - 19.0

Means with common superscripts within a column are not significantly different ($p=0.05$).
N = sample size

Table 11. Site comparison of the mean lead concentrations (ppm, dry weight) in organs of prairie voles and deermice from Kansas roadsides at 4 combined collection periods.

Site /Traffic Volume	Prairie Vole	Deermouse
	Lead Concentration in Liver	
	Mean ± S.E. (N) Range	Mean ± S.E. (N) Range
Alta Vista /1,050	2.2^{ab} ± 0.3 (27) 0.2 - 8.3	1.9^{a} ± 0.2 (28) 0.0 - 8.3
Konza /7,255	1.7^{a} ± 0.2 (38) 0.0 - 4.2	1.2^{b} ± 0.2 (48) 0.0 - 3.6
Paxico /10,181	2.3^{b} ± 0.3 (38) 0.0 - 3.0	1.4^{ab} ± 0.2 (30) 0.0 - 3.1
	Lead Concentration in Stomach with Contents	
	Mean ± S.E. (N) Range	Mean ± S.E. (N) Range
Alta Vista /1.050	5.8^{a} ± 1.2 (26) 0.0 - 15.2	3.1^{a} ± 0.8 (29) 0.0 - 10.3
Konza /7,255	5.8^{a} ± 0.9 (38) 0.9 - 10.5	3.0^{a} ± 0.6 (49) 0.3 - 18.0
Paxico /10,181	11.1^{b} ± 1.1 (41) 1.1 - 35.5	4.3^{a} ± 0.9 (31) 1.0 - 19.0

Means with common superscripts within a column are not significantly different (p=0.05).
N = sample size

living within 20 m of the road, in contrast to the Konza site which is contiguous with tall grass prairie, and the Paxico site which has woodland about 30 m from the highway. Of this study's mammals only the prairie voles might be restricted by woodland.

The prairie vole and deermouse lead data were analyzed by season. The liver data did not show a significant seasonal trend whereas the stomach data did (Table 12). The highest mean lead levels for stomachs of deermice and prairie voles generally occurred during the winter and the lowest during the summers. The prairie vole's mean level of lead (10.6±1.2 ppm) for its stomach during the winter was significantly higher than during the two summers and the fall. The vole's winter food had been exposed to atmospheric lead contamination longer than vegetation during the growing seasons. No correlation between lead concentrations in small mammals and season of the year has been previously reported. Getz et al.(1977) studied 8 tissues from each of 8 species and found no correlation between lead level and season. Significantly higher levels of lead have been found in livers of racoons (*Procyon lotor*) collected during October-December compared to July-September (Sanderson and Thomas, 1961).

Stomachs from adult prairie voles (5.9±0.4 ppm) had lower levels of lead than stomachs of juveniles (9.1±1.7 ppm) and, correspondingly, livers from adult voles (1.1±0.1 ppm) had significantly lower levels of lead than juveniles' livers (2.9±0.4 ppm) (Table 13). Age comparisons within deermice were nonsignificant for stomach and liver lead concentrations. Schlesinger and Potter (1973) observed lead accumulation in the

Table 12. Season comparison of the mean lead concentrations (ppm, dry weight) in organs of prairie voles and deermice from 3 Kansas roadsides.

Season	Prairie Vole	Deermouse
	Lead Concentration in Liver*	
	Mean ± S.E. (N) Range	Mean ± S.E. (N) Range
Summer 1978	2.0 ± 0.3 (25) 0.0 - 4.2	1.9 ± 0.2 (23) 0.6 - 8.3
Fall 1978	2.0 ± 0.2 (34) 0.2 - 8.3	1.5 ± 0.2 (35) 0.0 - 6.1
Winter 1979	2.3 ± 0.3 (27) 0.0 - 4.2	1.4 ± 0.3 (24) 0.2 - 3.0
Summer 1979	1.9 ± 0.3 (17) 0.3 - 2.6	1.1 ± 0.2 (24) 0.0 - 3.1
	Lead Concentration in Stomach with Contents	
	Mean ± S.E. (N) Range	Mean ± S.E. (N) Range
Summer 1978	5.4[a] ± 1.1 (30) 0.7 - 12.5	2.7[a] ± 0.9 (22) 0.6 - 10.3
Fall 1978	8.0[b] ± 1.1 (32) 0.0 - 19.0	3.8[a] ± 0.7 (36) 0.3 - 19.0
Winter 1979	10.6[c] ± 1.2 (26) 1.3 - 17.8	4.7[a] ± 1.0 (23) 0.5 - 11.7
Summer 1979	6.2[ab] ± 1.3 (17) 0.9 - 35.5	2.8[a] ± 0.9 (23) 0.0 - 18.0

* Season comparison of the mean lead concentrations for liver was not significant.
Means with common superscripts within a column are not significantly different (p=0.05).
N = sample size

Table 13. Age comparison of the mean lead concentrations (ppm, dry weight) in organs of prairie voles and deermice from Kansas roadsides.

Age	Prairie Vole	Deermouse
	Lead Concentration in Liver	
	Mean ± S.E. (N) Range	Mean ± S.E. (N) Range
Juvenile	2.9^{a} ± 0.4 (9) 0.6 - 8.3	1.6^{a} ± 0.2 (31) 0.0 - 8.3
Adult	1.1^{b} ± 0.1 (93) 0.0 - 4.2	1.4^{a} ± 0.1 (76) 0.0 - 4.4
	Lead Concentration in Stomach* with contents	
	Mean ± S.E. (N) Range	Mean ± S.E. (N) Range
Juvenile	9.1 ± 1.7 (9) 1.0 - 12.5	3.6 ± 0.9 (30) 0.3 - 9.0
Adult	5.9 ± 0.4 (97) 0.0 - 35.5	3.3 ± 0.5 (75) 0.0 - 19.0

* Age comparison of the mean lead concentrations for stomach was not significant.
Means with common superscripts within a column are not significantly different (p=0.05).
N = sample size

bodies of deermice and short-tailed shews to increase with age. Schroeder and Tipton (1968) and Hardy et al. (1971) found lead accumulated more rapidly in young humans than in adults. Young growing rats retained 2 or 3 times the amount of lead arsenate retained by adult or nearly mature rats (Shields et al., 1939b). The observation in my study of higher lead levels in young prairie vole livers compared to adults is consistent with other studies which show young growing mammals accumulate lead at very high rates.

Analysis of the lead data for both species according to sex showed males to have significantly higher lead (1.9±0.2 ppm) in their liver than females (1.1±0.2 ppm)(Table 14). However, this elevated lead level for males was due to the high lead concentrations in juvenile males (2.3±0.3 ppm) and not adult males (1.5±0.2 ppm) (Table 15). The adult male's lead concentration was not significantly higher than that of the adult and juvenile females. The juvenile male prairie vole also had significantly higher lead (3.8±0.6 ppm) in the liver than the juvenile females (2.1±0.5 ppm), adult males (1.2±0.2 ppm), and adult females (1.1±0.2 ppm) (Table 15). The stomach lead levels of juvenile male deermice and prairie voles, though not significantly so, were higher than all other age-sex classes within their species, 4.2±1.0 and 10.8±2.9 ppm, respectively (Table 15). This would support the hypothesis that the juvenile males were selecting for food with higher lead contamination than was being consumed by other classes. The alternative hypothesis, that the juvenile males elevated stomach lead concentrations resulted from greater

Table 14. Sex comparison of the mean lead concentrations (ppm, dry weight) in organs of prairie voles and deermice from Kansas roadsides.

Sex	Prairie Vole	Deermouse
	Lead Concentration in Liver	
	Mean ± S.E. (N) Range	Mean ± S.E. (N) Range
Male	2.5[a] ± 0.3 (53) 0.0 - 8.3	1.9[a] ± 0.2 (60) 0.0 - 8.3
Female	1.6[b] ± 0.3 (50) 0.0 - 6.2	1.1[b] ± 0.2 (46) 0.0 - 3.1
	Lead Concentration in Stomach with Contents*	
	Mean ± S.E. (N) Range	Mean ± S.E. (N) Range
Male	8.4 ± 1.5 (51) 0.9 - 16.6	3.8 ± 0.6 (62) 0.0 - 19.0
Female	6.7 ± 0.9 (54) 0.0 - 35.5	3.1 ± 0.7 (42) 0.3 - 11.7

* Sex comparison of the mean lead concentrations for stomach was not significant.
Means with common superscripts within a column are not significantly different (p=0.05).
N = sample size

Table 15. Age-sex comparison of the mean lead concentrations (ppm, dry weight) in organs of prairie voles and deermice from Kansas roadsides.

Age-sex	Prairie Vole	Deermouse
	Lead Concentration in Liver	
	Mean ± S.E. (N) Range	Mean ± S.E. (N) Range
Juvenile male	3.8[b] ± 0.6 (3) 0.6 - 8.3	2.3[b] ± 0.3 (17) 0.8 - 8.3
Juvenile female	2.1[c] ± 0.5 (6) 0.8 - 6.2	0.9[a] ± 0.3 (15) 0.0 - 2.0
Adult male	1.2[ac] ± 0.2 (50) 0.0 - 3.0	1.5[a] ± 0.2 (43) 0.0 - 4.4
Adult female	1.1[a] ± 0.2 (44) 0.0 - 4.2	1.3[a] ± 0.2 (31) 0.2 - 3.1
	Lead Concentration in Stomach with Contents*	
	Mean ± S.E. (N) Range	Mean ± S.E. (N) Range
Juvenile male	10.8 ± 2.9 (2) 4.0 - 10.2	4.2 ± 1.0 (17) 0.7 - 18.0
Juvenile female	7.5 ± 1.7 (7) 1.0 - 12.5	3.0 ± 1.2 (13) 0.3 - 7.6
Adult male	5.9 ± 0.6 (49) 0.9 - 16.6	3.4 ± 0.6 (45) 0.0 - 19.0
Adult female	5.9 ± 0.6 (48) 0.0 - 35.5	3.2 ± 0.8 (29) 0.4 - 11.7

* Age-sex comparison of the mean lead concentrations for stomach was not significant.
Means with common superscripts within a column are not significantly different (p=0.05).
N = sample size

consumption of what the female and adults ate, is negated by the fact that the lead levels are in ppm, and therefore normalized for weight.

The ANOVA model used in the analyses of the deermouse and prairie vole data was LEAD = SPECIES SPECIES*SITE SPECIES*SEASON SPECIES*SITE*SEASON SPECIES*AGE SPECIES*SEX SPECIES*AGE*SEX.

Short-tailed Shrew: The short-tailed shrew data was analyzed for group (SITE*SEASON) and SEX only. Insufficient data prevented analysis of other variables such as season (only 1 shrew was caught on Paxico in the winter and for age (only 1 juvenile was trapped during this study).

No difference was found between male and female lead levels. The males and females both had mean liver values of 2.2±0.3 ppm. The mean stomach lead level for males was 5.2±3.8 ppm and for females, 5.4±3.9 ppm (Table 16). For the GROUP variable Paxico had the highest liver and stomach mean lead levels where the sample size was greater than 2 (Appendix Table 10 and 11). The ANOVA model used in the analysis of the short-tailed shrew data was LEAD = GROUP SEX. Statistical significance was p=0.05.

All Small Mammals: The mean lead concentrations for 3 species of small mammals collected from 3 roadside sites show the short-tailed shrew to have significantly higher lead levels in their livers (2.1±0.2 ppm) than the prairie vole (1.3±0.1 ppm) or the deermouse (1.5±0.1 ppm) (Table 17). Although lead concentrations in the livers of voles and mice were not

Table 16. Sex comparison of mean lead concentrations (ppm, dry weight) in organs of short-tailed shrews from Kansas roadsides.

Sex	Short-Tailed Shrew
	Lead Concentrations in Liver* Mean ± S.E. (N) Range
Male	2.2 ± 0.3 (37) 0.0 - 10.5
Female	2.2 ± 0.3 (41) 0.3 - 10.3
	Lead Concentrations in Stomach with Contents* Mean ± S.E. (N) Range
Male	5.2 ± 3.8 (32) 0.0 - 20.1
Female	5.4 ± 3.9 (34) 0.0 - 37.4

*Sex comparison of the mean lead concentrations for stomach and for liver was not significant.
N = sample size

Table 17. Lead content (ppm, dry weight) of small mammals taken from three Kansas roadside sites.

Species	Liver Mean ± S.E. (N) Range	Stomach with Contents Mean ± S.E. (N) Range
Short-tailed shrew	2.1[a] ± 0.2 (67) 0.0 - 10.5	7.2[a] ± 0.6 (75) 0.0 - 37.4
Prairie vole	1.3[b] ± 0.1 (103) 0.0 - 8.3	6.5[a] ± 0.5 (105) 0.0 - 35.5
House mouse	0.9[ab] ± 0.6 (5) 0.0 - 1.9	0.9[b] ± 2.3 (5) 0.0 -2.5
Deermouse	1.5[b] ± 0.1 (106) 0.0 - 8.3	3.5[b] ± 0.5 (109) 0.0 - 19.0
Western harvest mouse	0.6[ab] ± 1.0 (2) 0.0 - 1.1	0.9[ab] ± 3.6 (2) 0.1 - 1.6

Means with common superscripts within a column are not significantly different (p=0.05).
N = sample size

significantly different in this analysis, their stomach lead levels were significantly different at 6.5±0.5 and 3.5±0.5 ppm, respectively. The shrew had the highest stomach lead level at 7.2±0.6 ppm, which was significantly greater than that of mouse stomachs. Getz et al. (1977), and Goldsmith and Scanlon (1977) also found higher lead concentrations in shrews, including *Blarina*, than prairie voles and deermice living along roadsides. Short-tailed shrews have been reported to consume insects, annelids and sowbugs (Isopoda) (Hamilton, 1930), all of which can potentially concentrate high lead levels. Earthworms are reported to accumulate up to 331.4 ppm of lead (Gish and Christensen, 1973) and woodlice (Isopoda) have been reported to have lead levels up to 682 ppm (Williamson and Evans, 1972). Shrews also have very high metabolic rates which insure greater exposure to lead through higher respiration rates and greater food consumption on a body weight basis than mice and voles.

Along heavily used roads (19,600 vpd) shrews (insectivores) had the highest body concentrations of lead; prairie voles (herbivores) had intermediate levels while deer, white-footed and house mice (granivores) had the lowest accumulations (Getz et al., 1977). The animals in my study were trapped along roads which carried 1,000-10,200 vpd and these animals contained liver and stomach lead levels similar to levels of lead in liver and gut from specimens collected near medium (6,000-12,000) and low (<400) use roads studied by Rolfe and Haney (1975). The lead concentrations for the house mouse (*Mus musculus*) and the western harvest mouse (*Reithrodontomys megalotis*) were 0.9 ppm for all tissues, except the western harvest mouse liver which was 0.6 ppm (Table 17). These levels were not significantly different from those for the short-tailed shrews, deermice or prairie voles due to large variances. The mean lead levels reported here for liver and stomach are similar to those reported elsewhere for the same species (Rolfe and Haney, 1975; Welch and Dick, 1975; Goldsmith and Scanlon, 1977). LEAD = SPECIES, an ANOVA model, was used in the analysis of all small mammal data combined. Statististical significance was p=0.05.

Food Habits

Coleoptera (beetles) was the order of Arthropoda most common in the intestinal contents of deermice, occurring in 95 % of the animals examined (Table 18). Butterfly larva was the second most common arthropod in deermouse intestines, being represented in 40% of the deermice. Flake (1973) also reported beetles and butterfly larvae as the dominant and second most common arthropods, respectively, by volume in the diets of deermice. Grasshoppers (Orthoptera) are a common food item in the diets of deermice in this study and in other studies (Flake, 1973; Whitaker, 1966). The consumption of ants (Hymenoptera) by a small number of deermice (4%) indicates that ants may be ingested inadvertently with other food and not selected. Johnson (1961) also found a 5% frequency of ants in deermouse diets. None of the deermice contained pillbugs (Isopoda) whereas Hamilton (1941) found pillbugs occasionally in deermice. Likewise,, not a single leafhopper (Hemiptera) was found whereas Flake (1973) reported

Table 18. The presence of arthropods in the intestines of 83 deermice and 76 short-tailed shrews trapped June 1978-August 1979 on 3 roadside sites.

	Deermouse		Short-Tailed Shrew	
Arthropod	Presence	% of Total	Presence	% of Total
Spiders	6	7	11	14
Beetles	79	95	72	95
Flies	0	0	2	3
Leafhoppers	0	0	1	1
Ants	3	4	22	29
Pillbugs	0	0	15	20
Butterflies	33	40	26	34
Grasshoppers	17	20	17	22

Presence = Number of animals containing items of indicated arthropod.
% of Total = Number of animals with item of indicated arthropod/ Total number of animals examined.

leafhoppers to compose 12% of the volume of arthropods. Since Flake (1973) found leafhoppers to peak in late winter and early spring in deermouse diets, the severe and extended winter of 1978-79 may have delayed the first leafhoppers until after my Feb.-Mar. trapping thereby excluding them from the diets of the trapped animals.

In short-tailed shrews, beetles and butterfly larvae were found in 95 and 34%, respectively, of the animals examined. These results are similar to the values reported in this study for deermice. Of the shrews examined, 29% had consumed some ants. This relatively high proportion would seem to indicate that the ants were eaten intentionally or that ants are often associated with, and inadvertantly consumed with, selected foods. Pillbugs were contained in 20% (15 animals) of the short-tailed shrews. Hamilton (1941) found pillbugs frequently in the diets. Leafhoppers were represented in only one shrew's diet. It is possible as discussed for deermice that the shrews were not trapped during the time when the leafhoppers were most abundant relative to other insect foods. Grasshoppers (22%) and spiders (14%) were common in the shrews. Hamilton (1930) reported insects (47.8%) in general to be common, and spiders to be present in 2% of the 244 short-tailed shrews he examined.

The intestines from 12 prairie voles collected in summer and examined for animal material showed only trace amounts of beetles and butterfly larvae in 7 animals and none in the other 5. Because of this scarcity of animal material, the prairie vole was not examined for frequency of occurrence of plant and animal material on slides. The trace amounts of insect material found in voles during the summer, a season with abundant insects, suggests that the prairie vole may be ingesting insects inadvertently along with selected plant material.

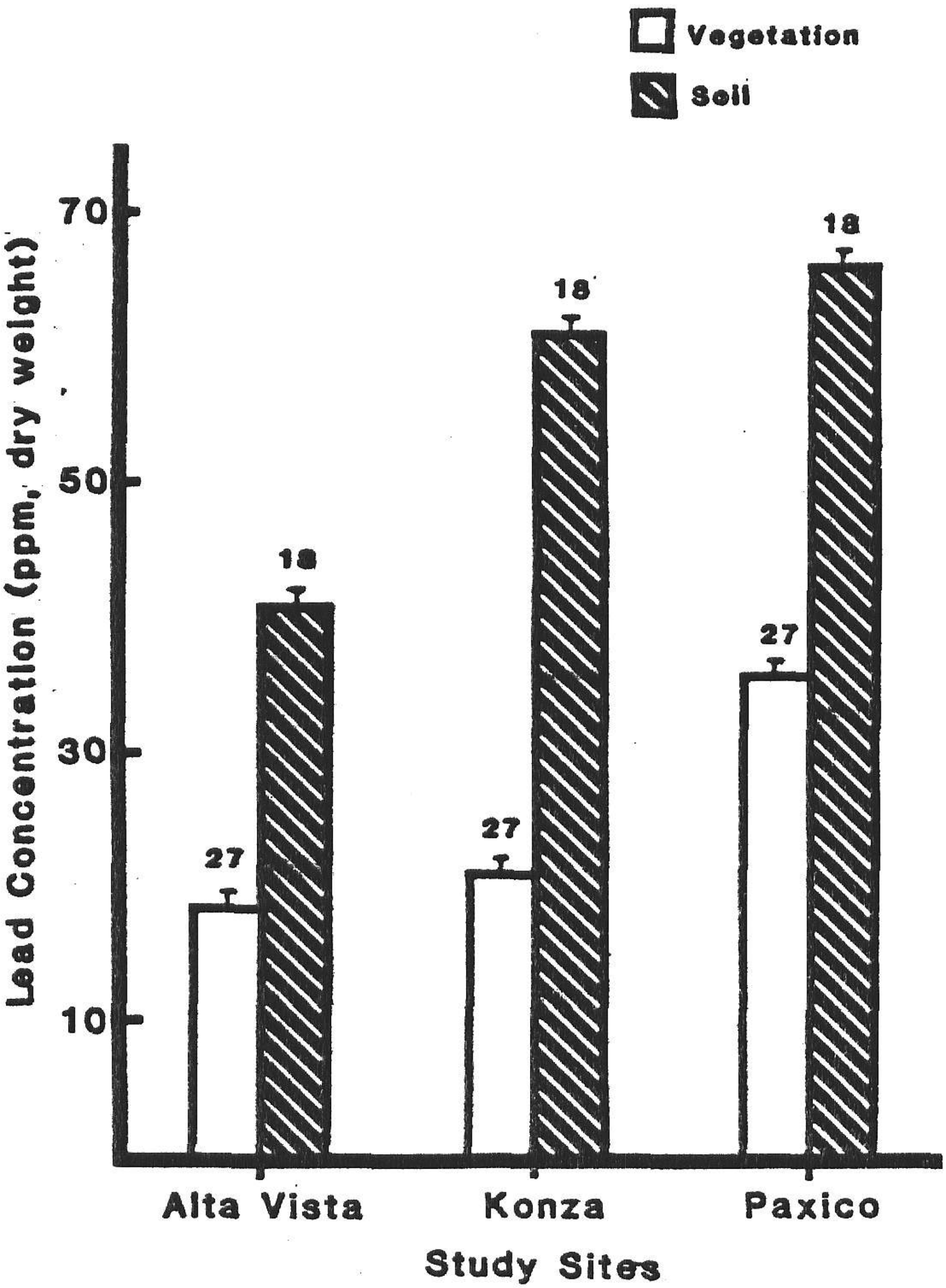
The mean relative frequencies (see food habits materials and methods) of animal and plant material were 50.7±2.7% and 49.3±2.7%, respectively for deermouse diets. Similarly, Flake (1973) reported the stomach contents of deermice consisted of 59.4±1.3% volume plant matter, throughout a year's study. The mean relative frequency of animal and plant material in 21 short-tailed shrew was 88.2±2.5% and 11.8±2.5%, respectively. Hamilton (1930) reported 78.7% by volume animal material and 11.4% by volume plant material in short-tailed shrew stomachs. The results of this food habits study support the classification of deermice as an omnivore; the short-tailed shrew as an insectivore; and the prairie vole as a herbivore in Kansas.

GENERAL RESULTS AND DISCUSSION

The soil lead means of 41.9, 61.9, and 66.9 ppm for Alta Vista, Konza, and Paxico sites, respectively, were greater than the corresponding vegetation lead means of 17.3, 22.2, and 36.5 ppm. The soil lead levels were expected to be higher than the mixed vegetation lead levels because the soil accumulates pollution which has occurred for many years whereas the green vegetation sampled attained its lead concentration primarily from exposure to the atmosphere for less than one year (Fig. 1) The amount of lead which is translocated from the soil to the plant's above-ground parts is considered to be insignificant (Keaton, 1937; Jarvis et al., 1977). Although most of the vegetation lead levels were lower than those of the soils, the highest vegetation lead level (99.9 ppm) was in a sample collected during winter from the Paxico site and was greater than the Paxico winter soil high of 73.8 ppm. This indicates a atmospheric lead contamination for this particular vegetation sample, though the relative contribution of soil and atmospheric fallout sources of lead to the vegetation samples was not addressed in this study. Quarles et al.(1974) provided evidence for the aerial route when the soil lead content was 12.8 ppm but the plant lead content was 84.2 ppm, a concentration too high to have come from the soil lead alone unless biomagnification occurs.

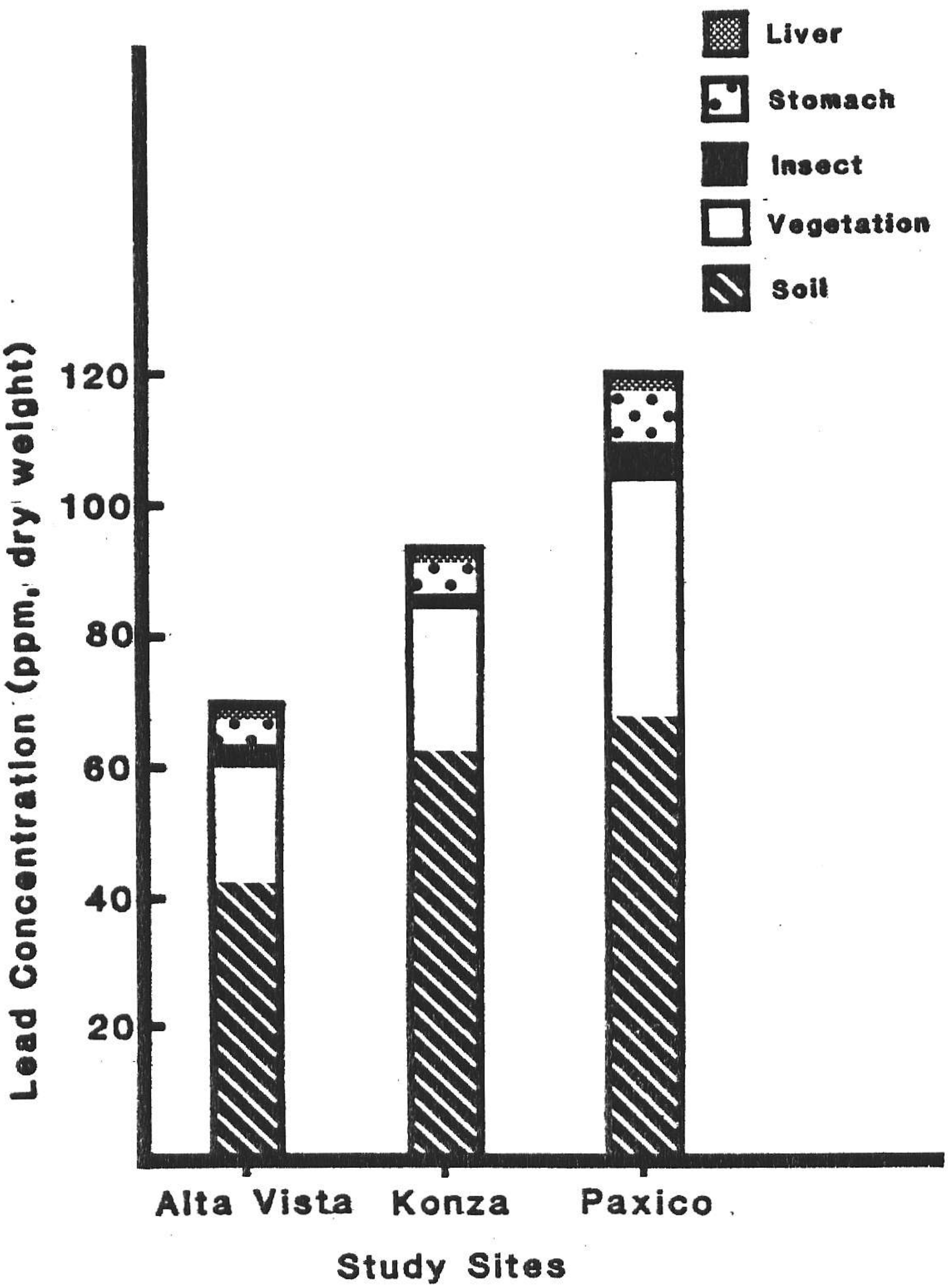
Generally, Paxico with the highest traffic volume (10,181 vpd) had the highest mean lead values, i.e., soil with 66.9 ppm, vegetation with 36.5 ppm, insects with 5.6 ppm, the stomachs of

Fig.1. Lead concentration (ppm, dry weight) in vegetation and soil on the 3 study sites. Mean lead concentration is represented by the height of each bar. One standard error is indicated by a T at one end of each bar. Sample size is indicated by the number above the standard error symbol.


Vegetation
Soil
Lead Concentration (ppm, dry weight)
70
50
30
10
18
18
18
27
27
27
Alta Vista
Konza
Paxico
Study Sites

short-tailed shrews with 10.1 ppm, of prairie voles with 11.1 ppm, and of deermice with 4.3 ppm, as well as the livers of short-tailed shrews with 5.1 ppm, and of prairie voles with 2.3 ppm (Fig. 2). The only lead mean for which Paxico was not highest was the lead liver level of deermice at 1.4 ppm on Paxico versus the high of 1.9 ppm on Alta Vista. These two liver means were not significantly different. The Konza site with 7,255 vpd and the Alta Vista site with 1,050 vpd varied as to which had the higher mean lead levels for the above categories (biota). Deviations in expected ranking of lead levels according to traffic volume could result from any number of influencing environmental conditions that may vary among sites. For example, if winds were moving in a northeastern direction as they generally do in Kansas, Paxico would be downwind from the east bound lanes and upwind from the west bound lanes which the site borders, Konza would be downwind and Alta Vista would be about parallel to the wind direction. The Paxico site which is upwind would be expected to receive the least amount of the lead fallout from its highway source and conversely, a leeward site, Konza, the greatest impact. Another possible influencing factor is slope. Alta Vista is situated on an uphill gradient that necessitates vehicles to increase fuel consumption to climb it and thus produce higher lead emissions (Habibi, 1973) than the level roadways would at Paxico and Konza. Also, the lead source at Paxico is probably somewhat less than expected from a traffic volume of 10,181 vpd since the site is physically separated from the eastbound lanes of I 70 by approximately 200 m of woodland. The relative importance of these

Fig.2. Lead concentration (ppm, dry weight) in soil and biota on 3 study sites. Stomach and liver lead levels are an average of the prairie vole and deermouse levels, all other represented levels are mean levels of lead. Lead levels are represented by the height of each bar. One standard error is indicated by a T at one end of each bar. Sample size is indicated by the number above the standard error symbol.



Liver
Stomach
Insect
Vegetation
Soil
Lead Concentration (ppm, dry weight)
120
100
80
60
40
20
Alta Vista
Konza
Paxico
Study Sites

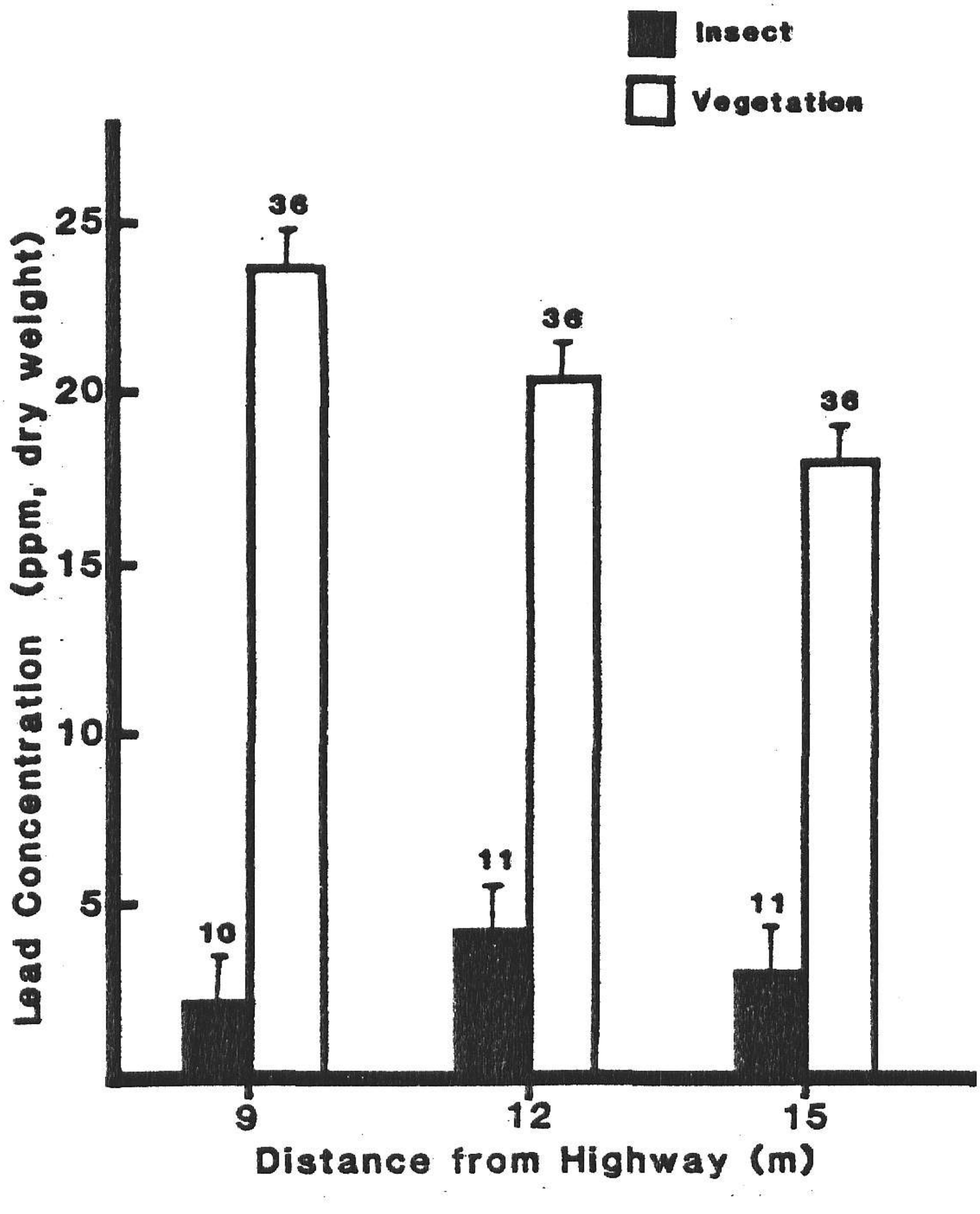
environmental variations on the lead levels at the sites was not addressed in this study.

Lead levels in insects at 9, 12 and 15 m from the highway were 2.1, 4.3 and 3.1 ppm, respectively. Insects (ground beetles) appear to be too mobile for detectable differences in lead within a range of 9 to 15 m (Fig. 3). Only Williamson and Evans (1972) have found insects (beetles) to show decreases in lead with increasing distance, 3 to 53 m, from the highway. The vegetation lead means for all sites combined decreased from 23.7 to 20.5 to 18.9 ppm for distances of 9, 12 and 15 m, respectively (Fig. 3). A Missouri highway carrying 7,500 vpd had similar levels of lead in vegetation, 21.3, 12.5 and 7.5 ppm, at distances of 8, 16 and 32 m from the highway (Lagerwerff and Specht, 1970). Goldsmith et al. (1976) reported narrow leaf grasses to contain lead concentrations of 21.0, 20.0 and 17.5 ppm at 3, 6 and 18 m from a road with 8,120 vpd.

As expected, the soil lead means for the 4 sampling times increased slightly with time. The sampling times, summer 1978, fall 1978, winter 1979 and summer 1979, had corresponding lead means of 54.8, 58.4, 57.5 and 59.9 ppm. There was no significant seasonal change in soil lead levels (Fig. 4).

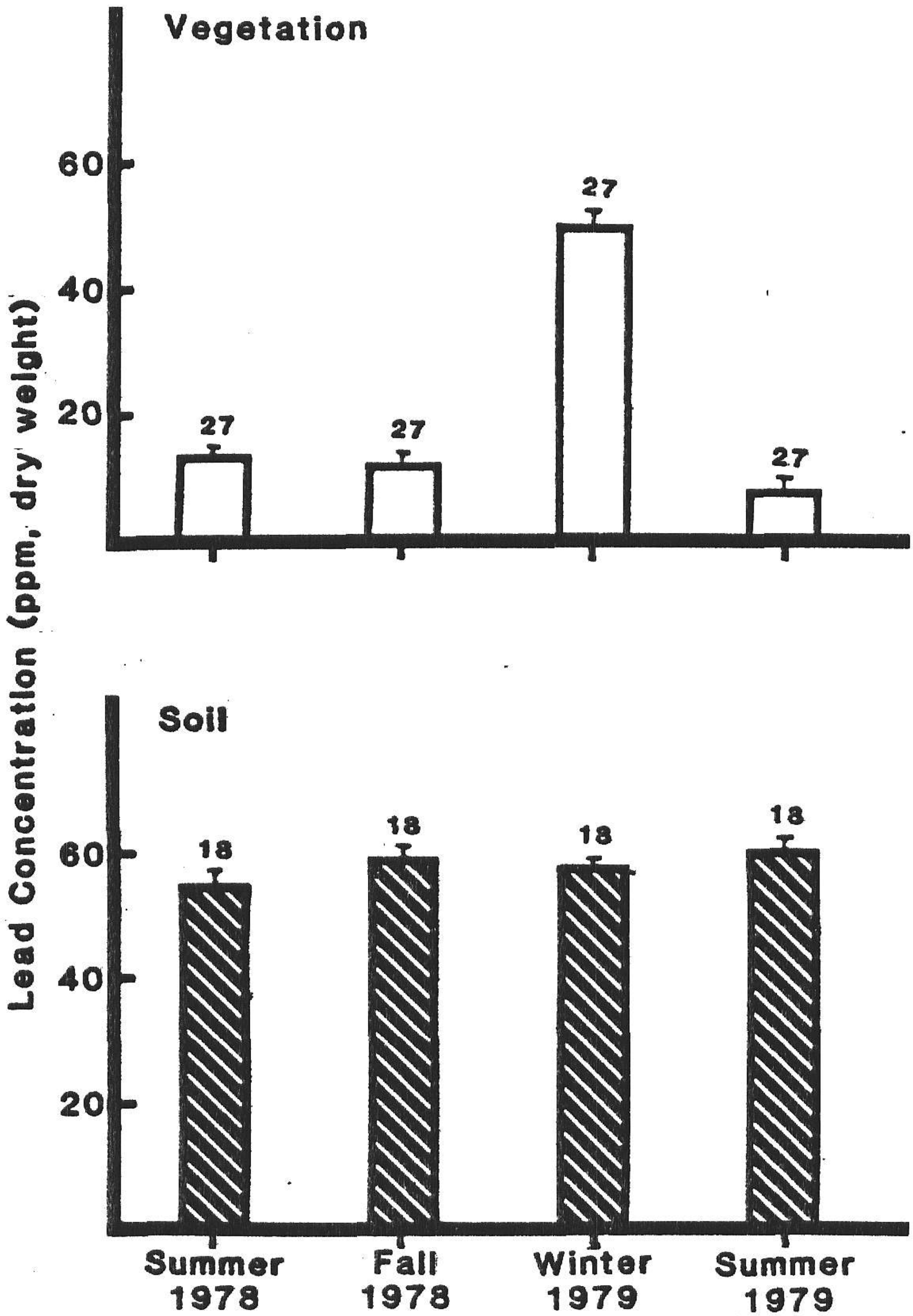
The vegetation lead levels again are not reflective of the soil lead concentrations. The vegetation lead means, (13.2, 12.2, 50.5 and 8.1 ppm, for the seasons) are about one-third the soil means and vary with exposure time to the lead fallout (Fig. 4). The fall lead concentration of 12.2 ppm is lower than expected, probably due to the green vegetation sampled being new growth

Fig.3. Lead concentration (ppm, dry weight) in insect and vegetation at 3 distances from the highways. Mean lead concentration is represented by the height of each bar. One standard error is indicated by a T at one end of each bar. Sample size is indicated by the number above the standard error symbol.



Insect
Vegetation
Lead Concentration (ppm, dry weight)
25
20
15
10
5
36
36
36
10
11
11
9
12
15
Distance from Highway (m)

Fig.4. Lead concentration (ppm, dry weight) in vegetation and soil at 4 sampling times. Mean lead concentration is represented by the height of each of each bar. One standard error is indicated by a T at one end of each bar. Sample size is indicated by the number above the standard error symbol.



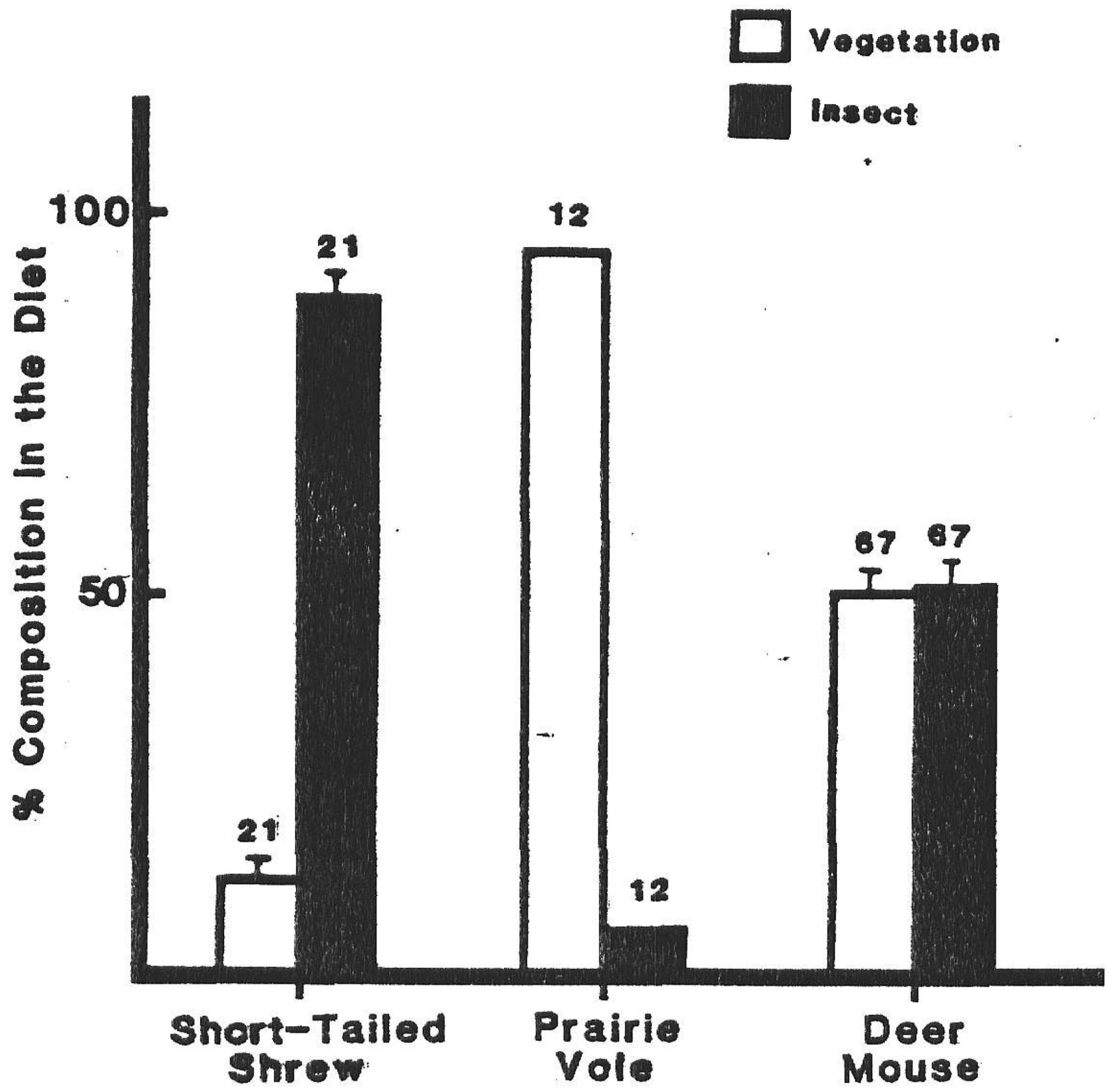
Vegetation
Soil
Lead Concentration (ppm, dry weight)
60
40
20
27
27
27
27
60
40
20
18
18
18
18
Summer 1978
Fall 1978
Winter 1979
Summer 1979

exposed only a short time as a result of recent mowing. Prior to mowing these young plants were protected somewhat from aerial lead deposition by the mature plants. The collection of vegetation during winter undoubtedly included standing dead from the two previous growing seasons, thus explaining why the winter vegetation lead concentrations were the highest. The summer of 1978 vegetation lead level of 13.2 ppm was significantly higher than the 1979 level of 8.1 ppm. The extended winter of 1978 is thought to have caused a later start of the 1979 growing season than in 1978. The later start of the growing season could have resulted in a shorter exposure period of the plants to lead contamination or may have adversely affected the abundance of plants with higher lead levels. There was also a decrease of 8% in leaded gasoline usage in the United States from 1978 to 1979 (personal communication, Kansas Petroleum Council). Another factor possibly contributing to the 1978 to 1979 summer vegetation lead decline was the number of rainless days preceding the sampling. In the week prior to the 1978 sampling there were 5 successive rainless days whereas 2 successive rainless days preceded the 1979 sampling date. The rainfall before the 1979 sampling was 4 to 2 times more intense than the last few rain days prior to the 1978 sample collection. The weather monitoring station at Manhattan, Kansas measured 13.9 cm of rain in July, 1979 compared to 7.9 cm in the same period of 1978, both years had 11 days of rain greater than trace, during the month of July (NOAA, 1978; NOAA, 1979). Therefore, the 1979 vegetation received more intense rainfalls which may have resulted in a greater loss of leaf surface lead. A combination of these factors may have influenced the results. Mitchell and Reith (1966) observed similar seasonal lead trends in pasture vegetation, 0.3 to 1.5 ppm during active growth (summer), 10 ppm at cessation of growth (late autumn), and 30 to 40 ppm before growth recommences (late winter or early spring).

The results of the diet analysis of the small mammal intestinal contents support the classification of the deermouse as an omnivore; the short-tailed shrew as an insectivore; and the prairie vole as an herbivore in Kansas (Fig. 5). The deermouse consumed 50.7% animal matter and 49.3% plant matter. Similarly, Flake (1973) reported the stomach contents of deermice consisted of 50.4±1.3% volume plant matter, throughout a year's study done in Colorado. The short-tailed shrew's diet consisted of 88.2% animal and 11.8% plant. Hamilton (1930) reported 78.7% by volume animal material and 11.4% by volume plant material in short-tailed shrew stomachs. The prairie vole contained only trace amounts of insect material in its plant diet. In Indiana, prairie vole stomachs contained 95% by volume plant material and about 5% insect matter (Zimmerman, 1965).

The mean lead concentrations in the stomachs of the prairie vole and deermouse were consistently lower than the mean vegetation lead concentrations. This indicates that small mammals do not select the same vegetation for food as the sampling method selected. The vegetation sampled for lead analysis was mixed vegetation cut on a grid. The type and quantity of plants sampled at each site was dependent upon the species present and their

Fig.5. The percent composition of insects and vegetation in the diet of 3 small mammals. Mean percent composition is represented by the height of each of each bar. One standard error is indicated by a T at one end of each bar. Sample size is indicated by the number above the standard error symbol.

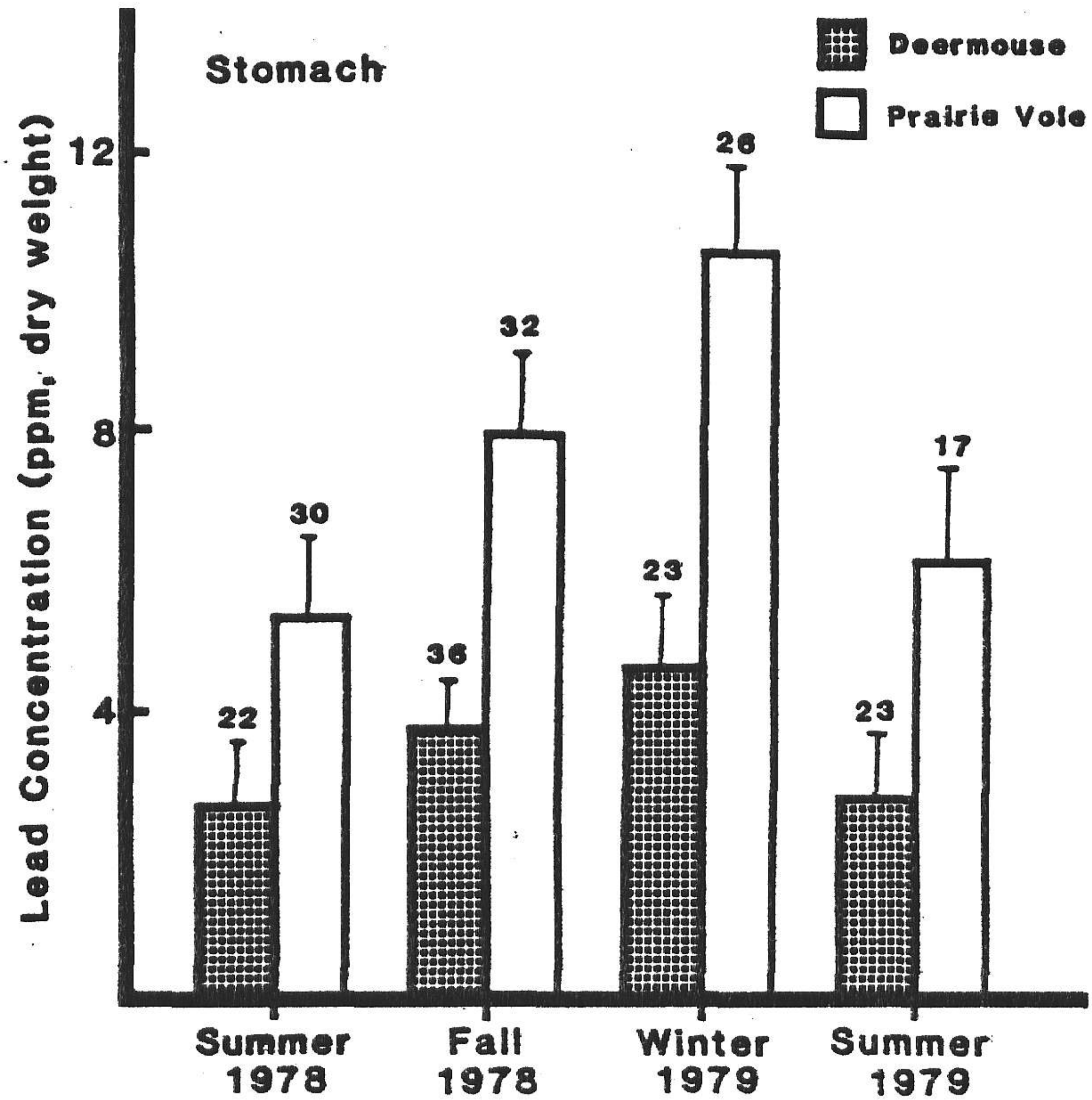

Vegetation
Insect
% Composition in the Diet
100
50
21
21
12
12
67
67
Short-Tailed Shrew
Prairie Vole
Deer Mouse

abundance. Though deermice are opportunistic feeders it may be that the animals are inadvertently selecting for plants with lower lead levels. The small mammals very likely are eating vegetation which is close to the ground and therefore less contaminated with aerial lead due to young age or to being covered by an upper plant canopy. Seasonally, the vole and deermouse stomach lead concentrations were lowest during the summer samplings, intermediate for the fall, and highest during the winter (Fig. 6). This is similar to the vegetation lead trend which was lowest during the summer of 1979, intermediate for the fall and summer of 1978 (which were not significantly different), and highest during the winter.

The deermouse had the lowest overall lead levels for stomach and liver. In an ANOVA analysis of all species, the deermouse's mean lead concentrations of 1.5 ppm for liver and 3.5 ppm for stomach were significantly lower than the short-tailed shrew's stomach and liver means, as well as the prairie vole's stomach mean (Fig. 7). Although the deermouse liver was not lower than the prairie vole's liver in the above analysis, both its liver and stomach lead means were significantly lower than the vole's in a more rigorous ANOVA analysis with only these two species in the model (Fig. 8).

The short-tailed shrew stomach and liver mean lead levels of 7.2 and 2.1 ppm were the highest of all the small mammals analyzed during this study (Fig. 7). Beetles occurred in 95% of the diets of the shrews analyzed. However, the highest mean lead concentration in ground beetles was only 5.6 ppm, lower than the

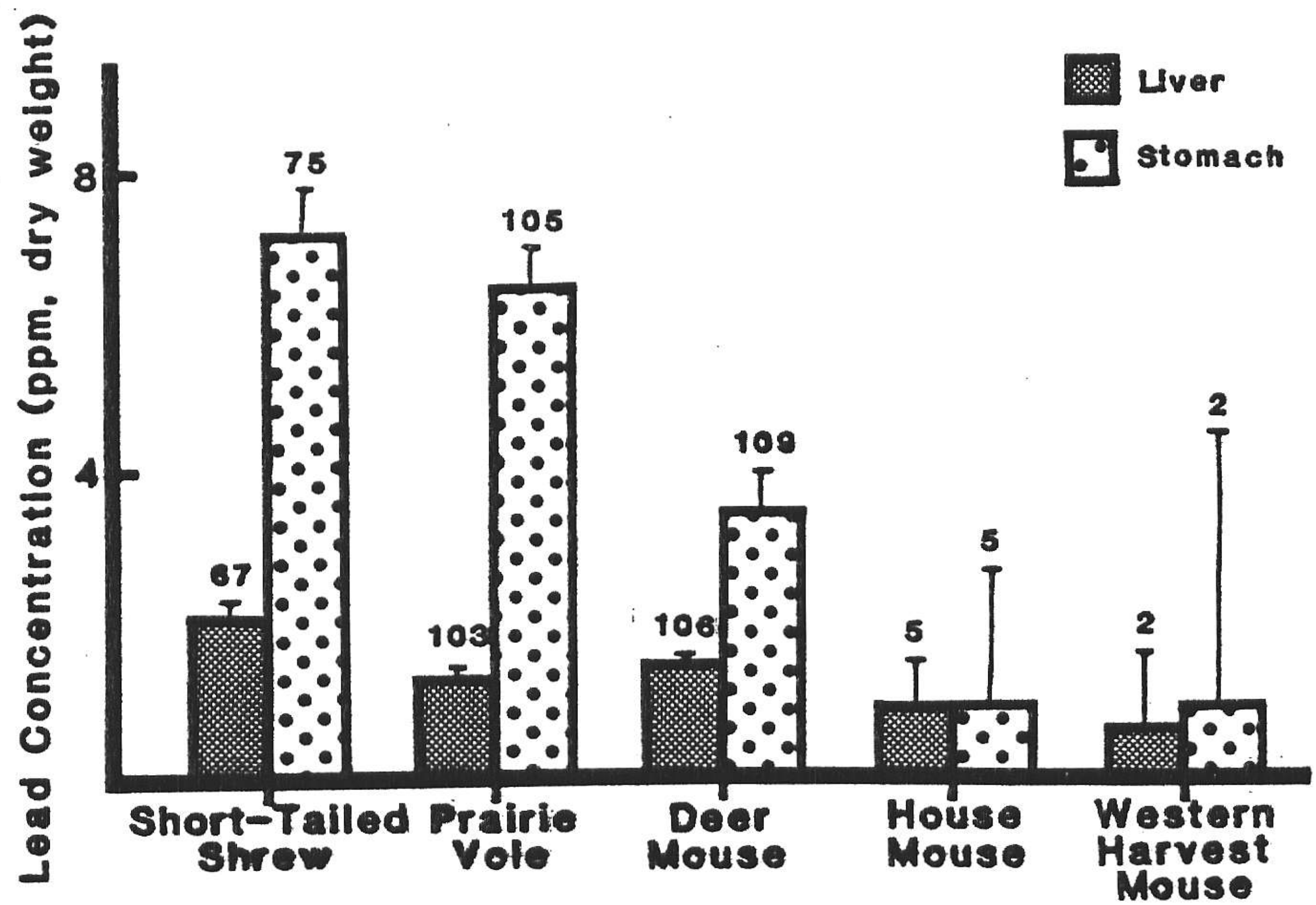
Fig.6. Lead concentration (ppm, dry weight) in the stomach of deermice and prairie voles collected during 4 sampling times. Mean lead concentration is represented by the height of each bar. One standard error is indicated by a T at one end of each bar. Sample size is indicated by the number above the standard error symbol.



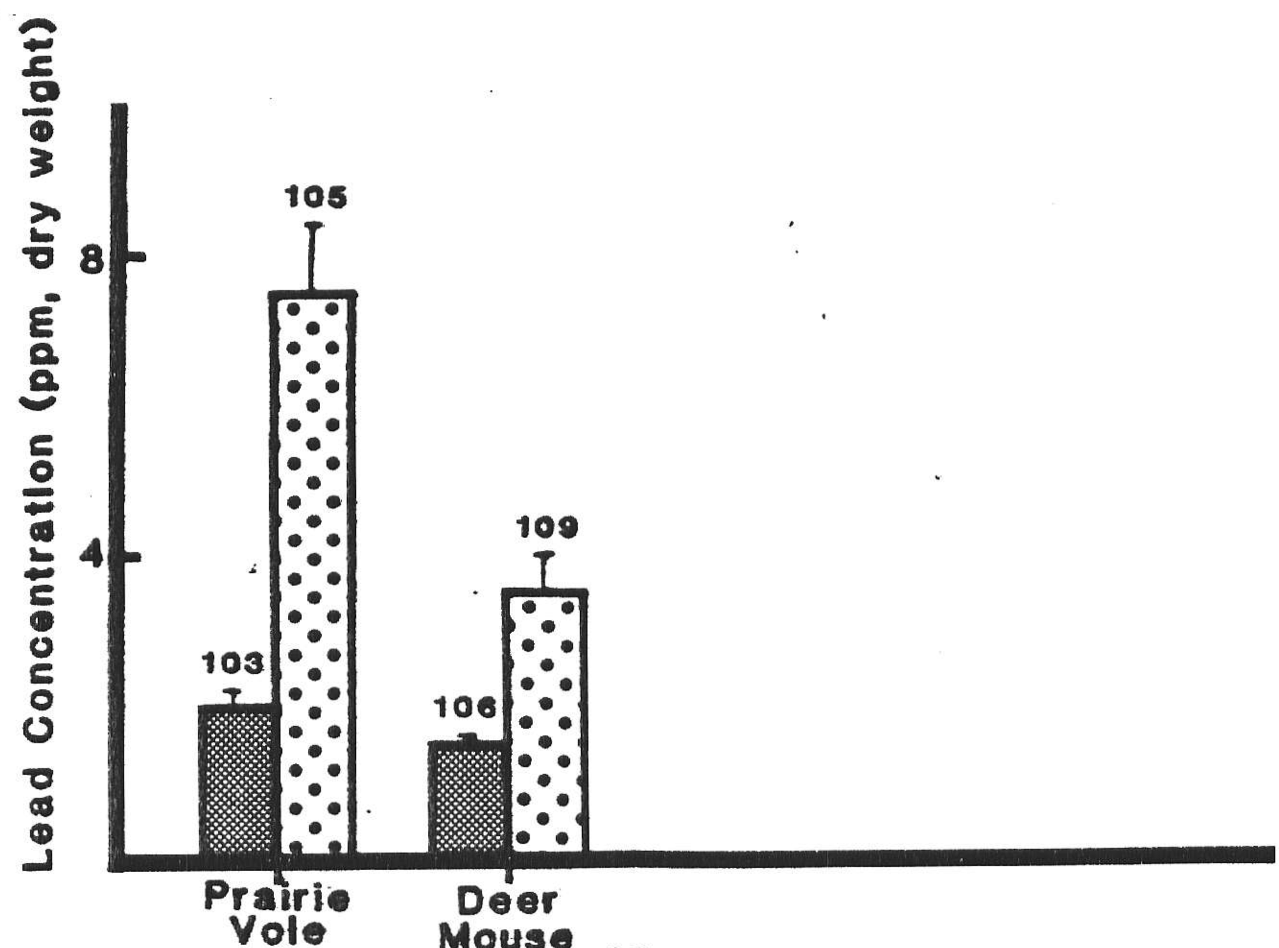
Stomach
Deermouse
Prairie Vole
Lead Concentration (ppm, dry weight)
12
8
4
22
30
36
32
23
26
23
17
Summer 1978
Fall 1978
Winter 1979
Summer 1979

Fig.7. Lead concentration (ppm, dry weight) in liver and stomach of 5 small mammals. Mean lead concentration is represented by the height of each bar. One standard error is indicated by a T at one end of each bar. Sample size is indicated by the number above the standard error symbol.

Fig.8. Lead concentration (ppm, dry weight) in liver and stomach of 2 small mammals. Mean lead concentration is represented by the height of each bar. One standard error is indicated by a T at one end of each bar. Sample size is indicated by the number above the standard error symbol.



Liver
Stomach
Lead Concentration (ppm, dry weight)
8
4
75
105
109
2
67
103
106
5
5
2
Short-Tailed Shrew
Prairie Vole
Deer Mouse
House Mouse
Western Harvest Mouse



Lead Concentration (ppm, dry weight)
8
4
105
109
103
106
Prairie Vole
Deer Mouse

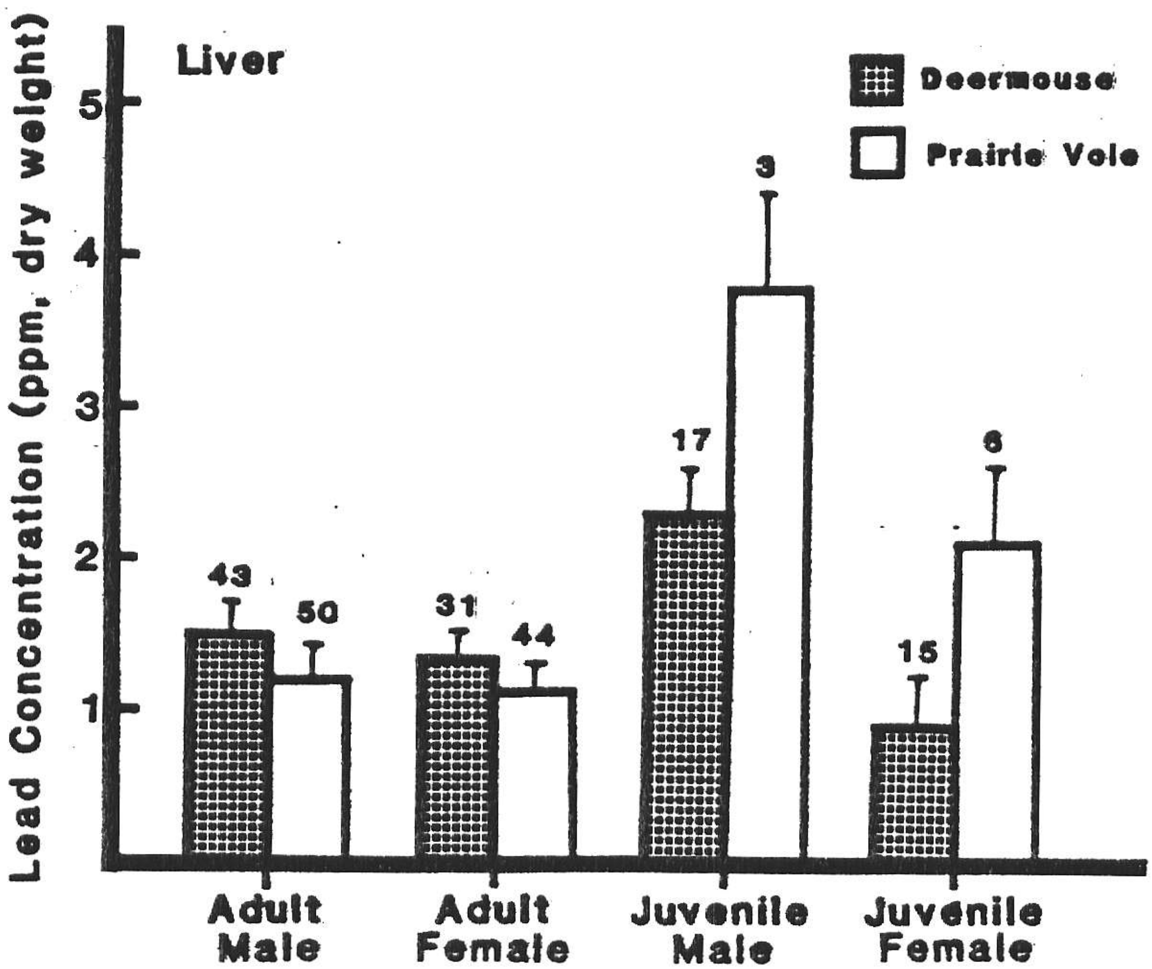
stomach lead mean. It can only be assumed that the higher lead levels in the shrews is the result of consumption of insects other than ground beetles and/or other dietary items. Pillbugs and ants were found in 20% and 29% of the shrews in this study. Pillbugs have been reported to have lead levels up to 682 ppm (Williamson and Evans, 1972), and ants as high as 45 ppm (Price et al., 1974).

The deermouse may have the lowest lead levels of the 3 target species primarily because of its diet. The deermouse stomach concentration of lead is significantly lower than the shrew and the vole in all ANOVA analyses (Fig. 7). The deermouse is heavily dependent upon plants (seeds) during the late autumn and winter (Flake, 1973). Seeds have comparatively small amounts of lead, as do all parts of plants that are not in direct contact with the atmosphere (Page et al., 1971). The deermouse diet contained 50.7% animal matter. Of the deermouse intestinal tracts analyzed 95% contained beetles, 40% contained butterflies, and 20% contained grasshoppers. Grasshoppers have been reported to have low lead levels, 3.84 and 3.35 ppm next to highways with 21,040 and 1,085 vpd respectively. The deermice may also have consumed ground beetles which have low lead concentrations, e.g., from 1.9 to 5.6 ppm in the study.

Age and sex were variables for which both prairie voles and deermice were analyzed. Juvenile male deermice and prairie voles had significantly higher lead concentrations in their livers than all other age-sex groups (e.g. juvenile females, adult males and adult females), (Fig. 9).

The stomach lead levels of juvenile male deermice and prairie

Fig.9. Lead concentration (ppm, dry weight) in liver of adult male, adult female, juvenile male, and juvenile female deermice and prairie voles. Mean lead concentration is represented by the height of each bar. One standard error is indicated by a T at one end of each bar. Sample size is indicated by the number above the standard error symbol.


Liver
Deermouse
Prairie Vole
Lead Concentration (ppm, dry weight)
5
4
3
2
1
43
50
31
44
17
3
15
6
Adult Male
Adult Female
Juvenile Male
Juvenile Female

voles, though not significantly so, were higher than all other age-sex classes within their species, 4.2±1.0 and 10.8±2.9 ppm, respectively (Fig. 10). This would support the hypothesis that the juvenile males were selecting for food with higher lead contamination than was being consumed by other classes. The alternative hypothesis, that the juvenile males elevated stomach lead concentrations resulted from greater consumption of what the female and adults ate, is negated by the fact that the lead levels are in ppm, and therefore normalized for weight. The higher intake of dietary lead by juvenile males would result in elevated liver concentrations as occur in this study. The reason for livers of males containing significantly more lead than those of females is unknown. The observation of higher lead levels in young prairie vole livers compared to adults is consistent with the literature in that young growing mammals accumulate lead at very high rates.

Only sex was statistically analyzable for short-tailed shrews. Age was not analyzable due to small sample size representing the juvenile shrew population. No difference was found between male and female lead levels. Both sexes had mean liver values of 2.2 ppm. The mean stomach lead level for males was 5.2 ppm and for females, 5.4 ppm (Fig. 11).

The problem of lead poisoning is one of a chronic condition and not an acute condition. The maximum life span of the prairie vole, the short-tailed shrew, and deermouse is from 16 to 24 months in the wild (Swartz and Swartz, 1959). During such a short life span animals living along roadsides are unlikely to build up

Fig.10. Lead concentration (ppm, dry weight) in stomach of age*sex groupings of deermice and prairie voles. Mean lead concentration is represented by the height of each bar. One standard error is indicated by a T at one end of each bar. Sample size is indicated by the number above the standard error symbol.

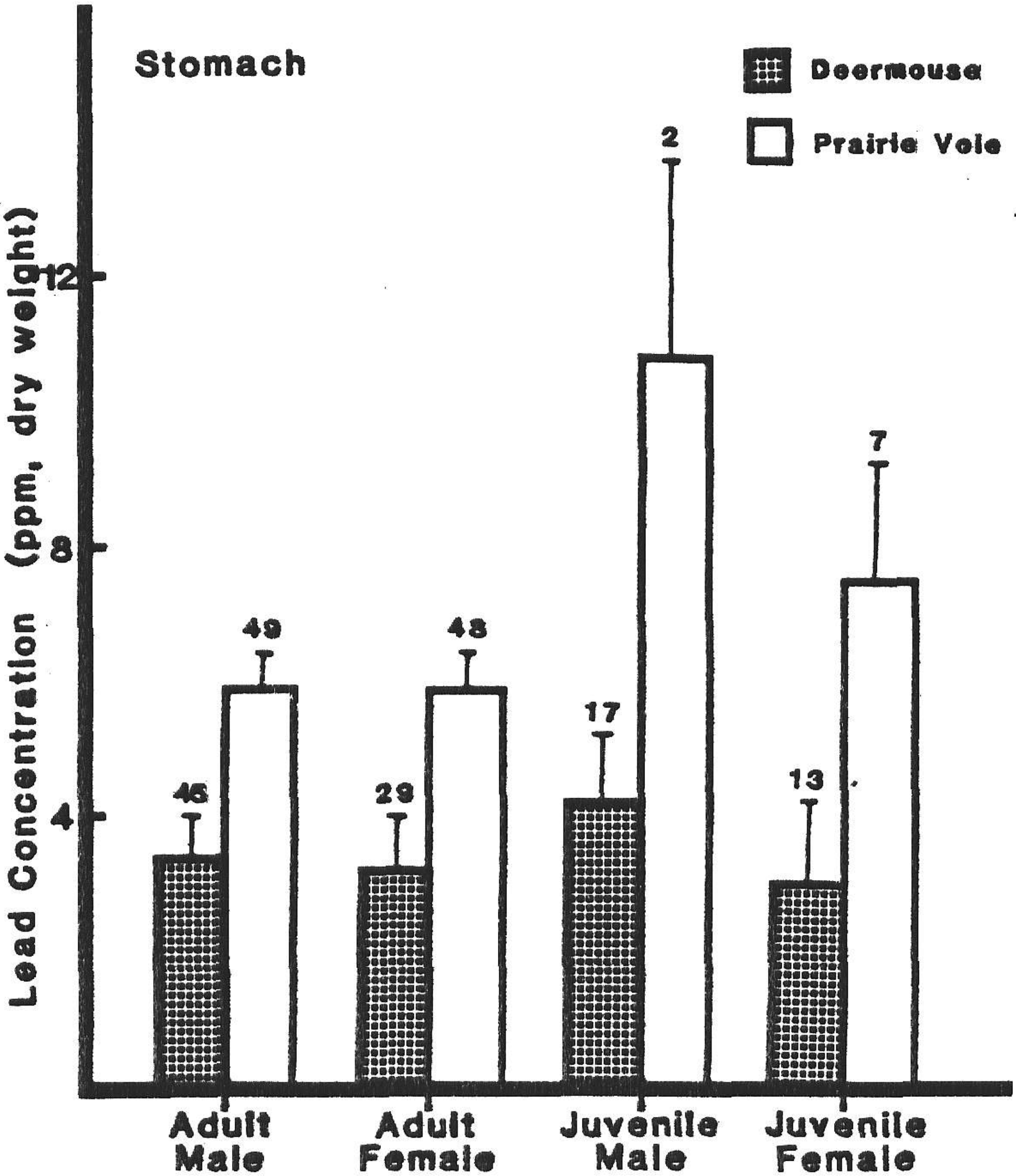
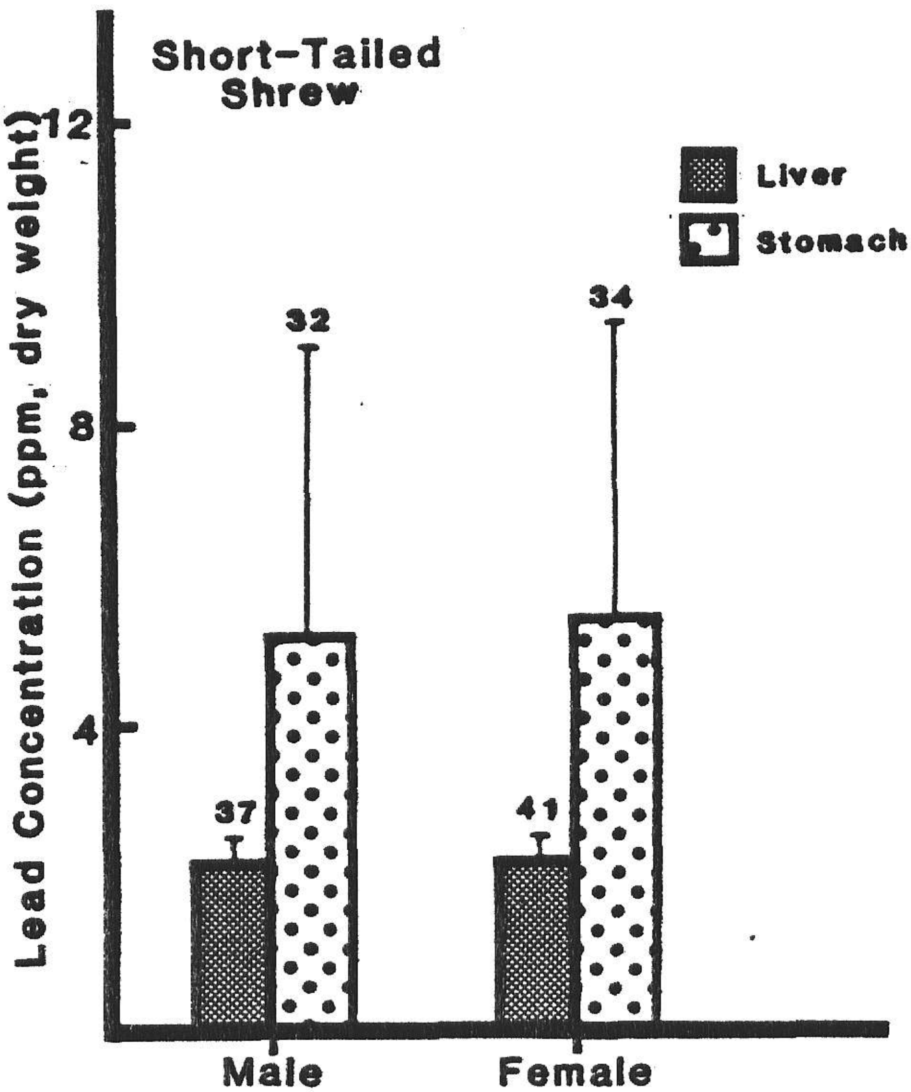

Stomach
Deermouse
Prairie Vole
Lead Concentration (ppm, dry weight)
12
8
4
45
49
29
48
17
2
13
7
Adult Male
Adult Female
Juvenile Male
Juvenile Female

Fig.11. Lead concentration (ppm, dry weight) in the liver and stomach of male and female short-tailed shrews. Mean lead concentration is represented by the height of each bar. One standard error is indicated by a T at one end of each bar. Sample size is indicated by the number above the standard error symbol.



Short-Tailed Shrew
Lead Concentration (ppm, dry weight)
12
8
4
Liver
Stomach
32
34
37
41
Male
Female

toxic levels of lead. Predators (shrews) of lead-contaminated invertebrates (insects) are subjected to high dietary lead intake. Robel et al.(1981) and Price et al. (1974) have shown evidence of biomagnification in dung beetles and predatory insects, respectively. The level of lead exposure required to produce recognizable symptoms (renal inclusions) in an experimental population of deermice was about five times greater (0.5% lead acetate for 26 weeks) than that experienced by a wild population at a traffic volume of 19,800 vpd. Liver tissue of this wild population (which would not be expected to have symptoms of lead poisoning) contained 3.3±1.8 ppm of lead compared to 1.5 ± 0.1 ppm in the deermice in my study. It has been estimated that a traffic volume of 100,000 vpd would be required to produce lead poisoning symptoms in a wild population, with severe poisoning not expected at traffic volumes less than 200,000 vpd (Mierau and Favara, 1975). Predators consuming lead contaminated vertebrate prey have not exhibited biomagnification possibly due to the tendency for the highest lead levels to be found in hard tissue e.g. bone (Mierau and Favara, 1975; Goyer et al., 1970) which many predators cannot digest. Holtzman (1968) observed lower lead levels in wolves than in their prey, caribou, which had consumed concentrated lead in their primary food (lichens). Pasture herbage reached 30 to 40 ppm in late winter without a known source of nearby aerial lead contamination (Mitchell and Reith, 1966). These authors felt consideration of possible health hazards to winter grazing livestock was justified. However, Marten and Hammond (1966) suggested at least 150 ppm lead in the total-ration dry matter was needed to approach levels observed to be toxic to cattle and horses. Long-lived mammals such as humans could, however, suffer chronic lead poisoning by long-term intake of low lead levels such as occur along highways in this study. Sublethal effects of lead poisoning are produced in man by a sustained daily lead intake above 1 mg (16 μg/kg/day)(Chisholm, 1971). Mean lead levels of 17.3 to 36.5 ppm in the vegetation on the study sites are high enough to indicate the possible occurrence of chronic lead poisoning.

SUMMARY

1. The lead concentrations in vegetation and soil sampled were above background levels.

2. The highest lead concentrations in soil, vegetation, insects, and small mammal tissues occurred along the highest traffic volume study site.

3. The highest lead levels were in winter samples of vegetation, of prairie vole stomachs, and of deermouse stomachs. The latter, however, was not significantly higher.

4. Lead contamination in stomach contents of prairie voles and deermice followed a seasonal variation similar to that of vegetation.

5. Prairie voles and deermice which consume approximately 95-100% and 50%, respectively, of plant material, have lower stomach lead levels than randomly sampled vegetation probably due to the animals selecting low plant material closest to their height e.g., young or small plants that are screened by the upper canopy from aerial lead fallout.

6. Food habits of the short-tailed shrew, prairie vole, and deermouse in Kansas support the classification of these small mammals as insectivore, herbivore and omnivore, respectively.

7. There is a trend for short-tailed shrew (insectivores) to have the highest lead levels, the prairie vole (herbivores) to have intermediate levels, and the deermice (omnivores) to have the lowest levels in stomachs and livers.

8. Juvenile male prairie voles and deermice have higher lead levels for liver and stomach than all other sex-age classifications.

9. Vegetation lead levels for the combined data of 3 sites decreases with increasing distance (9-15 m) from a traffic lead source.

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Appendix Table 1. Kansas Department of Transportation Mowing Policy*

MOWING POLICY

1. The following standards have been developed for use as a guideline for mowing our roadways on a statewide basis. The number of mowings required will vary across the state to accomplish the following requirements.

   a. All mowing should be accomplished between May 1 and October 1.

   b. The shoulders should be mowed one mower width wide, or sufficient width to delineate the shoulder, as often as necessary to maintain a neat appearance.

   c. All medians and junctions should be mowed as often as necessary to maintain a neat appearance and insure proper sight distance.

   d. Divided highways having medians 100 feet wide or wider should be treated as two roadways and the shoulder of the median will be all that is mowed yearly.

   e. The entire right of way should be mowed out once every three years if undesirable plants are present.

   f. All areas of the right of way containing excessive amounts of weeds and brush should be mowed as often as necessary to maintain control.

   g. All right of way in urban areas or adjacent to cemeteries, roadside facilities, houses, etc. should be mowed as often as necessary to maintain a neat appearance.

Appendix Table 1.Cont.

2. The following mowing procedures are to be used by the mower operator in adjusting the mower and in deciding what areas not to be mowed.

   a. The height of mowing will be between 5 inches (13 cm) and 11 inches (28 cm).

   b. Slopes are not to be mowed if there is a chance of damaging the slope or endangering the operator.

   c. The Engineer will designate any special wildlife areas not to be mowed.

3. Haying of Right of Way

   a. In certain locations, adjacent landowner can be permitted to harvest hay along the right-of-way.

   b. A permit will be required for haying right of way as per Section 6, II, B, 1. of the Maintenance Manual.

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*Mowing policy was an enclosure in a letter (sent April 7, 1981) from V.L. Craig, Engineer of Planning and Development for the Kansas Transportation Department.

Appendix.Table 2. Scientific and common names of the uncommon plants (plants representing less than 2% of the canopy-coverage) on roadside sites studied in Kansas.

Scientific Name*	Common Name*
Achillea millefoluim	Common yarrow
Agropyron smithii	Western wheatgrass
Amaranthus sp.	Amaranth
Ambrosia psilostachya	Western ragweed
Amorpha canescens	Leadplant amorpha
Apocymum cannabinum	Indianhemp dogbane
Asclepias syriaca	Common milkweed
Asclepias verticillata	Eastern whorled milkweed
Aster oblongifolius	Aromatic aster
Aster sericeus	Silky aster
Baptisia australis	White wildindigo
Bouteloua curtipendula	Sideoats grama
Bromus japonicus	Japanese brome
Buchloe dactyloides	Common buffalograss
Carex sp.	Sedge
Celtis sp.	Hackberry
Cercis canadensis	Eastern redbud
Cirsium undulatum	Wavyleaf thistle
Convolvulus arvensis	Field bindweed
Croton monanthogynus	Prairietea croton
Cynanchum sp.	Swallowwort
Desmanthus illinoensis	Illinois bundleflower
Desmodium sp.	Tickclover
Echinacea augustifolia	Blacksamson echinacea
Elymus canadensis	Canada wildrye
Erigeron sp.	Fleabane
Eupatorium sp.	Joepieweed
Euphorbia marginata	Snowonthemountain spurge
Euphorbia palmeri	Palmer spurge
Gaura sp.	Muskwood
Gleditsia triacanthos	Common honeylocust
Grindelia squarrosa	Curlycup gumweed
Gutierrezia sp.	Snakeweed
Helianthus annuus	Common sunflower
Hymenopappus sp.	Hymenopappus
Kuhnia eupatorioides	False prairie boneset
Lepidium sp.	Common pepperweed
Lespedeza capitata	Roundhead lespedeza
Liatris punctata	Dotted gayfeather
Linum sp.	Flax

Appendix.Table 2. (continued).

Scientific Name*	Common Name*
Medicago sativa	Alfalfa medic
Oenothera sp.	Primrose
Opuntia sp.	Pricklypear
Panicum scribnerianum	Scribner panic
Petalostemon purpureum	Purple prairieclover
Physalis virginiana	Virginia groundcherry
Plantago pusilla	Slender plantain
Polygonum ramosissimum	Bushy knotweed
Psoralea tenuiflora	Slimflower scurfpea
Ratibida columnifera	Upright prairieconeflower
Rhus radicans	Poison ivy
Rosa sp.	Rose
Rudbeckia sp.	Coneflower
Ruellia humilis	Fringeleaf ruellia
Rumex crispus	Curly dock
Salvia azurea	Pitcher sage
Sisyrinchium campestre	Prairie blue-eyed grass
Silphium laciniatum	Compassplant rosinweed
Solidago sp.	Goldenrod
Sorghastrum nutans	Yellow indiangrass
Sporobolus vaginiflorus	Poverty dropseed
Symphoricarpos orbiculatus	Indiancurrant coralberry
Verbena stricta	Wooly verbena
Vernonia baldwini	Baldwin ironweed

*Scientific and common names are according to Barkley (1968).

Plant identification was tentative, many of the plant specimens were not in flower when classified.

Appendix.Table 3. Mean lead concentrations (ppm, dry weight), and standard errors (S.E.) for soil collected 0 to 3 cm depth 12 m from Kansas roads with different traffic volumes (vehicles per day) and different sampling times. Ranges of lead concentrations are in parentheses.

	Soil Lead Concentration (Mean ± S.E.)			
Site/ Traffic Volume	Summer 1978	Fall 1978	Winter 1979	Summer 1979
Alta Vista	36.4±4.1	43.3±4.1	46.0±4.1	48.6±4.1
1,050	(27.8-47.4)	(29.1-53.8)	(32.3-58.7)	(36.6-59.2)
Konza	61.7±4.1	60.4±4.1	63.8±4.1	67.3±4.1
7,255	(44.0-80.1)	(49.9-68.7)	(51.9-0.4)	(57.6-80.4)
Paxico	66.5±4.1	71.4±4.1	62.8±4.1	63.9±4.1
10,181	(53,2-83.3)	(52.1-88.0)	(56.2-73.8)	(43.8-75.1)

N=6 for each mean.
Seasons are defined as: summer (June - July), fall (Oct - Nov), and winter (Feb - Mar).

Appendix.Table 4. Age comparison of the mean lead concentrations (ppm, dry weight) in organs of prairie voles and deermice from Kansas roadsides.

Species	Juvenile	Adult
	Lead Concentration in Liver	
	Mean ± S.E. (N) Range	Mean ± S.E. (N) Range
Prairie vole	2.9[a] ± 0.4 (9) 0.6 - 8.3	1.1[a] ± 0.1 (93) 0.0 - 4.2
Deermouse	1.6[b] ± 0.2 (31) 0.0 - 8.3	1.4[a] ± 0.1 (76) 0.0 - 4.4
	Lead Concentration in Stomach with Contents*	
	Mean ± S.E. (N) Range	Mean ± S.E. (N) Range
Prairie vole	9.1 ± 1.7 (9) 1.0 - 12.5	5.9 ± 0.4 (97) 0.0 - 35.5
Deermouse	3.6 ± 0.9 (30) 0.3 - 9.0	3.3 ± 0.5 (75) 0.0 - 19.0

* Age comparison of the mean lead concentrations for stomach was not significant.
Means with common superscripts within a column are not significantly different ($p=0.05$).
N = sample size

Appendix.Table 5. Sex comparison of the mean lead concentrations (ppm, dry weight) in organs of prairie voles and deermice from Kansas roadsides.

Species	Male	Female
	Lead Concentration in Liver	
	Mean ± S.E. (N) Range	Mean ± S.E. (N) Range
Prairie vole	2.5[a] ± 0.3 (53) 0.0 - 8.3	1.6[a] ± 0.3 (50) 0.0 - 6.2
Deermouse	1.9[a] ± 0.2 (60) 0.0 - 8.3	1.1[a] ± 0.2 (46) 0.0 - 3.1
	Lead Concentration in Stomach with Contents*	
	Mean ± S.E. (N) Range	Mean ± S.E. (N) Range
Prairie vole	8.4 ± 1.5 (51) 0.9 - 19.0	6.7 ± 0.9 (54) 0.0 - 35.5
Deermouse	3.8 ± 0.6 (62) 0.0 - 19.0	3.1 ± 0.7 (42) 0.3 - 11.7

* Sex comparison of the mean lead concentrations for stomach was not significant.
Means with common superscripts within a column are not significantly different (p=0.05).
N = sample size

Appendix.Table 6. Season-site comparison of the mean lead concentrations (ppm, dry weight) in liver of prairie voles and deermice from 3 Kansas roadsides.

	Alta Vista	Konza	Paxico
	Lead Concentrations in Liver Mean±S.E. Range (Sample Size)		
	Prairie Vole		
Summer 1978	$2.3^{ab}\pm0.6$ 1.1-1.9 (3)	$1.4^{a}\pm0.3$ 0.3-4.2 (13)	$2.1^{a}\pm0.4$ 0.0-3.0 (9)
Fall 1978	$2.4^{ab}\pm0.3$ 0.2-8.3 (10)	$1.6^{a}\pm0.4$ 0.4-1.8 (10)	$2.0^{a}\pm0.4$ 0.3-2.1 (14)
Winter 1979	$2.8^{a}\pm0.4$ 1.7-4.2 (11)	$1.9^{a}\pm0.4$ 0.0-1.8 (8)	$2.2^{a}\pm0.4$ 0.8-1.9 (8)
Summer 1979	$1.2^{b}\pm0.6$ 0.3-0.4 (3)	$1.7^{a}\pm0.4$ 0.5-2.0 (7)	$2.7^{a}\pm0.4$ 0.6-2.6 (7)
	Deermouse		
Summer 1978	$3.3^{a}\pm0.3$ 0.6-8.3 (10)	$1.1^{a}\pm0.4$ 1.0-1.6 (8)	$1.3^{a}\pm0.5$ 0.6-1.8 (5)
Fall 1978	$1.5^{b}\pm0.4$ 0.4-6.1 (8)	$1.3^{a}\pm0.3$ 0.0-3.6 (14)	$1.7^{a}\pm0.3$ 0.0-2.8 (13)
Winter 1979	$1.8^{b}\pm0.5$ 0.6-2.2 (4)	$1.3^{a}\pm0.3$ 0.5-3.0 (14)	$1.1^{a}\pm0.4$ 0.2-1.9 (6)
Summer 1979	$0.8^{b}\pm0.5$ 0.0-1.9 (6)	$0.9^{a}\pm0.3$ 0.2-2.2 (12)	$1.6^{a}\pm0.4$ 0.7-3.1 (6)

Means with common superscripts within a column are not significantly different (p=0.05).

Appendix.Table 7.Site-season comparison of the mean lead concentrations (ppm, dry weight) in liver of prairie voles and deermice from 3 Kansas roadsides.

	Summer 1978	Fall 1978	Winter 1979	Summer 1979
	Lead Concentrations in Liver Mean±S.E. Range (Sample size)			
	Prairie Vole			
Alta Vista	2.3±0.6[a] 1.1-1.9 (3)	2.4±0.3[a] 0.2-8.3 (10)	2.8±0.4[a] 0.7-4.2 (11)	1.2±0.6[a] 0.3-0.4 (3)
Konza	1.4±0.3[a] 0.3-4.2 (13)	1.6±0.4[a] 0.4-1.8 (10)	1.9±0.4[a] 0.0-1.8 (8)	1.7±0.4[a] 0.5-2.0 (7)
Paxico	2.1±0.4[a] 0.0-3.0 (9)	2.0±0.4[a] 0.3-2.1 (14)	2.2±0.4[a] 0.8-1.9 (8)	2.7±0.4[a] 0.6-2.6 (7)
	Deermouse			
Alta Vista	3.3±0.3[b] 0.6-8.3 (10)	1.5±0.4[b] 0.4-6.1 (8)	1.8±0.5[a] 0.6-2.2 (4)	0.8±0.5[a] 0.0-1.9 (6)
Konza	1.1±0.4[a] 1.0-1.6 (8)	1.3±0.3[b] 0.0-3.6 (14)	1.3±0.3[a] 0.5-3.0 (14)	0.9±0.3[a] 0.2-2.2 (12)
Paxico	1.3±0.5[a] 0.6-1.8 (5)	1.7±0.3[b] 0.0-2.8 (13)	1.1±0.4[a] 0.2-1.9 (6)	1.6±0.4[a] 0.7-3.1 (6)

Means with common superscripts within a column are not significantly different (p=0.05).
Seasons are defined as follows: summer (June - July); fall (Oct - Nov); and winter (Feb - Mar).

Appendix.Table 8. Season-site comparison of the mean lead concentrations (ppm, dry weight) in stomach (including contents) of prairie voles and deermice from 3 Kansas roadsides.

	Alta Vista	Konza	Paxico
	Lead Concentrations in Stomach with Contents* Mean±S.E. Range (Sample Size)		
	Prairie Vole		
Summer 1978	3.5±2.4 1.1-1.9 (3)	4.5±1.2 0.3-4.2 (14)	8.1±1.4 0.0-3.0 (13)
Fall 1978	6.2±1.5 0.2-8.3 (9)	7.5±1.6 0.4-1.8 (9)	10.2±1.4 0.3-2.1 (14)
Winter 1979	9.4±1.5 1.7-4.2 (11)	7.9±1.6 0.0-1.8 (8)	14.4±1.7 0.8-1.9 (7)
Summer 1979	4.0±2.4 0.3-0.4 (3)	3.1±1.6 0.5-2.0 (7)	11.5±1.7 0.6-2.6 (7)
	Deermouse		
Summer 1978	2.4±1.2 0.6-8.3 (10)	3.0±1.5 1.0-1.6 (7)	2.6±1.8 0.6-1.8 (5)
Fall 1978	2.7±1.4 0.4-6.1 (8)	1.5±1.0 0.0-3.6 (14)	7.1±1.1 0.0-2.8 (14)
Winter 1979	6.2±1.8 0.6-2.2 (5)	2.7±1.3 0.5-3.0 (12)	5.3±1.7 0.2-1.9 (6)
Summer 1979	1.3±1.7 0.0-1.9 (6)	4.8±1.2 0.2-2.2 (11)	2.2±1.7 0.7-3.1 (6)

*Season-site comparison of mean lead concentrations for stomach was not significant.

Appendix.Table 9. Site-season comparison of the mean lead concentrations (ppm, dry weight) in stomach (including contents of prairie voles and deermice from 3 Kansas roadsides.

	Summer 1978	Fall 1978	Winter 1979	Summer 1979
	Lead Concentrations in Stomach with Contents Mean±S.E. Range (Sample Size)			
	Prairie Vole			
Alta Vista	3.5±2.4[a] 0.7-2.5 (3)	6.2±1.5[a] 0.0-8.8 (9)	9.4±1.5[a] 1.3-15.2 (11)	4.0±2.4[a] 1.3-4.2 (3)
Konza	4.5±1.2[a] 1.0-10.2 (14)	7.5±1.6[ab] 4.4-8.2 (9)	7.9±1.6[a] 2.5-10.5 (8)	3.1±1.6[a] 0.9-4.0 (7)
Paxico	8.1±1.4[b] 1.1-12.5 (13)	10.2±1.4[b] 3.1-19.0 (14)	14.4±1.7[b] 3.7-17.8 (7)	11.5±1.7[b] 2.4-35.5 (7)
	Deermouse			
Alta Vista	2.4±1.2[a] 0.6-10.3 (10)	2.7±1.4[a] 0.9-10.1 (8)	6.2±1.8[ab] 1.7-9.3 (5)	1.3±1.7[a] 0.0-4.0 (6)
Konza	3.0±1.5[a] 0.8-9.0 (7)	1.5±1.0[a] 0.3-3.8 (14)	2.7±1.3[a] 0.5-7.8 (12)	4.8±1.2[a] 0.6-18.0 (11)
Paxico	2.6±1.8[a] 1.6-5.0 (5)	7.1±1.1[b] 1.0-19.0 (14)	5.3±1.7[b] 2.0-11.7 (6)	2.2±1.7[a] 1.1-3.1 (6)

Means with common superscripts within a column are not significantly different (p=0.05).
Seasons are defined as follows: summer (June - July); fall (Oct - Nov); and winter (Feb - Mar).

Appendix.Table 10. Mean lead concentrations (ppm, dry weight), standard errors (S.E.), ranges, and sample sizes for liver tissue from short-tailed shrews collected from Kansas roads with different traffic volumes (vehicles per day) and different trapping seasons.

	Short-Tailed Shrew			
	Lead Concentration in Liver (Mean ± S.E.)			
Site/Traffic Volume	Summer 1978	Fall 1978	Winter 1979	Summer 1979
Alta Vista/1,050	3.2±0.7 [a]	1.1±0.5 [a]	2.4±1.0 [a]	1.8±0.6 [a]
Range	1.1-7.7	0.4-2.6	1.2-4.6	0.8-3.4
N	6	10	3	9
Konza/7,255	1.6±0.5 [b]	1.3±0.5 [a]	2.8±1.2 [a]	1.8±0.7 [a]
Range	0.0-3.2	0.7-2.1	2.4-3.2	0.4-3.6
N	13	10	2	6
Paxico/10,181	5.1±0.6 [c]	2.0±0.6 [a]		1.0±1.2 [a]
Range	0.7-10.5	0.9-3.1		0.3-1.6
N	10	8		2

Seasons are defined as: summer (Jun - Jul); fall (Oct - Nov); and winter (Feb - Mar).
Means with common superscripts within a column are not significantly different ($p = 0.05$); values joined by underlining are not significantly different.

Appendix.Table 11.Mean lead concentrations (ppm, dry weight), standard errors (S.E), ranges, and sample sizes for stomachs and their contents from short-tailed shrews collected from Kansas roads with different traffic volumes (vehicles per day) and different trapping seasons.

	Short-Tailed Shrews: Lead Concentration in Stomach with Contents (Mean ± S.E.)			
Site/Traffic Volume	Summer 1978	Fall 1978	Winter 1979	Summer 1979
Alta Vista/1,050	7.0[a] ± 5.0	1.2[a] ± 4.3	14.9	8.1[a] ± 4.4
Range	1.7 - 20.7	0.0 - 5.8	-----	0.8 - 25.0
N	6	10	1	9
Konza/7,255	7.1[a] ± 4.3	1.6[a] ± 4.3	3.7	0.0[a] ± 4.6
Range	1.6 - 20.1	0.0 - 9.	-----	0.0 - 6.1
N	10	10	1	6
Paxico/10,181	10.1[a] ± 3.7	6.0[a] ± 4.5	-----	0.0[a] ± 6.1
Range	2.6 - 37.4	0.0 - 19.8	-----	1.0 - 2.4
N	8	7	0	2

Seasons are defined as: summer (Jun - Jul); fall (Oct - Nov); and winter (Feb - Mar).
----- Indicates lack of data for analysis.
Means with common superscripts within a column are not significantly different (p=0.05); values joined by underlining are not significantly different.

LEAD IN SOIL, PLANTS, INSECTS, AND SMALL MAMMALS ALONG THREE KANSAS HIGHWAYS

by

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Soil, plants, insects, and small mammals were collected seasonally along 3 Kansas roadsides with traffic volumes of 1,050, 7,255 and 10,181 vehicles per day (vpd). Lead concentrations as high as 88.0 ppm were measured in soil, 99.9 ppm in plants, 16.3 ppm in ground beetles (Carabidae), 10.5 ppm in livers of small mammals, and 37.4 ppm in stomachs of small mammals. The greatest lead concentrations were associated with the highest traffic volume site.

The soil lead levels increased did not change significantly from the summer of 1978 to the summer of 1979. Significant seasonal variations in lead levels were evident in vegetation and prairie vole stomachs and to a lesser extent, in deermouse stomachs.

Only for vegetation did mean lead levels increase with increasing traffic volume on all 3 sites. Climatic, site physical characteristics, and animal behavior differences were all factors which were thought to cause the lead levels in animals, insects, and soil to deviate from ranking according to traffic volume. Vegetation lead contamination did decrease with increasing distance, 9-15 m from the highway, although insect contamination did not.

Food habit results supported the classification of the short-tailed shrew (Blarina brevicauda) as an insectivore, the prairie vole (Microtus ochrogaster) as an herbivore, and the deermouse (Peromyscus maniculatus) as an omnivore in Kansas. There was a trend for the insectivore to have the highest lead levels, the herbivore intermediate levels, and the deermouse the lowest lead concentrations. Juvenile male prairie voles had a higher lead level than adults of both sexes and juvenile females. Results of analyses of stomach contents suggest that juvenile males were consuming food with a higher lead content than the other groups and that this dietary trend significantly elevated the lead content of their livers.

Analysis of samples from the 3 roadside areas did not reflect lead contamination high enough to cause acute toxicity to wildlife or livestock feeding on these areas. However, caution is recommended to human consumers of roadside vegetation and/or animals. As a result of our relatively long lives we could be susceptible to chronic lead poisoning from long-term intake of low lead levels such as occur along high volume highways.