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SURVEY OF SOIL INGESTION BY WILDLIFE

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Abstract: Many species of wildlife ingest substantial amounts of soil while feeding, but the rates of ingestion of only a few species are known. Wildlife may ingest soil deliberately, such as at salt licks, or incidently, when they ingest soil-laden forage or earthworms that contain soil. White-footed mice (*Peromyscus leucopus*) were fed diets containing from 0 to 15% soil to relate the dietary soil content to the acid-insoluble ash content of scat collected from the mice. The relation was accurately described by an equation that required estimates of the percent acid-insoluble ash content of the diet, the digestibility of the diet, and the mineral content of the soil. Scat from 28 species of wildlife were collected through capturing, searching appropriate habitats for scat, or removing material from the intestines of animals collected for other purposes. The acid-insoluble ash content of the scat was measured and the soil content of the diets was estimated from the soil ingestion equation. Sandpipers, which probe or peck for invertebrates in mud or shallow water, consumed soil at a rate of 7.3 - 30% of their

diets. Armadillos (Dasypus novemcinctus, soil = 17% of diet), American woodcock (Scolopax minor, 10%) and raccoon (Procyon lotor, 9%) had high rates of ingestion of soil, presumably because they ate soil organisms. Bison (Bison bison, 7%), black-tailed prairie dogs (Cynomys ludovicianus, 8%) and Canada geese (Branta canadensis, 8%) consumed soil at the highest rates among the herbivores studied, and various browsers studied consumed little soil. Box turtles (Chrysemys picta, 4%) opossums (Didelphis virginianus, 5%), red fox (Vulpes vulpes, 3%), and wild turkeys (Meleagris gallopavo, 9%) consumed soil at intermediate rates. Ingested soil may be the principal means of exposure to some environmental contaminants or the principal source of certain minerals. The estimates of soil ingestion may be used in risk assessments of wildlife inhabiting contaminated sites and in computing budgets of those nutrients associated mainly with soil.

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Wildlife may ingest substantial amounts of soil while feeding. Concentrations of some elements and environmental contaminants in ingested soil may be so high in comparison to the concentrations in an animal's diet that the soil is an important means of exposure (Arthur and Alldredge 1979). Soil ingestion may also be important by supplying nutrients or by interfering with absorption of nutrients (Allen et al. 1986, Garcia-Bojalil et al. 1988). Arthur and Gates (1988) estimated that more than half the vanadium, sodium, iron, and fluorine ingested by pronghorn and black-tailed jack rabbits was from soil.

Deliberate ingestion of soil by wildlife is well known; the list of animals recorded visiting salt licks or ingesting soil includes over fifty species (Kreulen and Jager 1984). In North America these species include bighorn sheep (Ovis canadensis), mountain goats (Oreamnos americanus), moose (Alces alces), caribou (Rangifer arcticus) (Cowan and Brink 1949, Hebert and Cowan 1971), and white-tailed deer (Odocoileus virginianus) (Weeks and Kirkpatrick 1976). The behavior is seasonal, is especially common in ungulates in arid areas, and in general probably results from an increased need for sodium (Kreulen and Jager 1984). Box turtles have been observed ingesting soil, probably for nutrients in soil other than sodium (Kramer 1973). Lizards, crocodilians, and tortoises also deliberately ingest soil (Sokol 1971). Pheasants (Kopischke 1966) and many other species of birds consume grit, either to supplement their calcium or because it is abrasive.

Wildlife also ingest soil inadvertently. Sandpipers probing for invertebrates on a mud flat, for example, ingest some soil with food items. A woodcock feeding on an earthworm ingests soil in the earthworm's gut, as well as soil on the outside of the earthworm. Grazers ingest dried mud splashed up on grass blades by rain. Armadillo stomachs have been found to contain large amounts of soil, probably an unavoidable result their method of feeding on soil organisms (Chapman and Feldhamer 1982).

When an environmental contaminant is present at high concentrations in soil, but at low concentrations in an animal's food, evaluating the toxic risk to the animal requires estimating the amount of soil ingested. On farms contaminated with lead, as much as 87% of the lead ingested by

cattle may be from ingested soil (Russell et al. 1985). Soil ingestion by cattle has been concluded to be the main route of exposure of PCBs in sewage sludge applied to farms (Fries 1982) and of polybrominated biphenyls (PBBs) on contaminated farms in Michigan (Fries and Jacobs 1986). Soil ingestion was also considered the main route of exposure for sheep grazing on land experimentally treated with hexachlorobenzene, DDT, or PBBs (Fries and Marrow 1982). Several studies on cattle and sheep have shown that under lush vegetative conditions about 1 to 2% of their diet is soil, but when forage is sparse the value may be as high as 18% (Fries and Paustenbach 1990). Diets of range cattle in Idaho were estimated to contain about 6% soil in June and 11% soil in August (Mayland et al. 1977). Soil ingestion was suggested to be an important route of exposure to contaminants for swine, estimated as 3.3 to 8.0% of their diet in pastures (Fries et al. 1982a). Soil ingestion would presumably also be the main route of exposure for various species of wildlife, some of which would be expected to consume soil at rates comparable to those of domestic animals.

In studies on grazing domestic animals (Fries et al. 1982b), soil ingestion rates have usually been estimated from the soil content of the animals' scat. The soil in scat includes both soil deliberately ingested and soil incidentally ingested during feeding and grooming. Soil content of scat is generally estimated from acid-insoluble ash content (Skipworth 1974) or from concentrations in scat of an element such as titanium (Fries et al. 1982b), which is abundant is soil, but found only at low concentrations in food items.

Soil-ingestion rates of only a few wildlife species have been estimated. Arthur and Gates (1988) evaluated potential exposure of wildlife to radioactivity and to various potentially toxic soil-bound elements in sagebrush (Artemisia tridentata). Titanium in scat was used as a marker for soil to estimate that 5.4% of the diet (dry wt) of pronghorn (Antilocapra americana) and 6.3% of the diet (dry wt) of jackrabbits (Lepus californicus) was soil. In a similar study, the soil content of the diet (dry wt) of mule deer in Colorado was estimated as 0.6% to 2.1% soil (Arthur and Alldredge 1979). The acid-insoluble residue of scat from one herd of bighorn sheep in Alberta was estimated to be highest in June and July, when it was about 30%, and was about one-third that in a second herd (Skipworth 1974). From 10 to 60% sand was reported in the alimentary tracts of shorebirds (Reeder 1951), but unfortunately the brief report of these results contained no information about methods used or differences between species. Sediments have been noted in the stomachs of ruddy ducks (Oxyura jamaicensis) and northern shovelers (Anas clypeata) (Goodman and Fisher 1962). The proportion of soil in the stomach and caecal contents of 18 wild cotton rats (Sigmodon hispidus) was reported to be 3% (Garten 1980). Soil was also detected in the stomachs of a few white-footed mice (Peromyscus leucopus) and eastern chipmunks (Tamias striatus) sampled (Garten 1980).

In this paper we first examine the relation between dietary soil content and percent acid-insoluble ash content of scat of white-footed mice kept under laboratory conditions. Then we estimate average soil-ingestion rates for a wide variety of species. Although the sample sizes are inadequate to provide thorough data for each species, they are

adequate to identify those species ingesting substantial amounts of soil.

The work was supported in part by the Office of Policy, Planning and Evaluation of the U. S. Environmental Protection Agency (R. Miller, Project Officer). L. LeCaptain and J. Eisemann collected some of the samples and carried out some of the analyses. D. Jett provided expertise on the white-footed mouse portion of the study. G. Fries and O. H. Pattee reviewed the manuscript. Samples of scat were collected with the help of S. Gotte, P. Henry, K. Larson, G. Linder, T. Mills, G. Reid, R. Sanchez, S. Skagen, K. Stone, and M. Vander Haegen

METHODS

Acid-insoluble ash of scat

The ratio of acid-insoluble ash to dry weight in most animal and plant tissues is generally at most a few percent. Mineral soil, in contrast, generally contains at least 90% acid-insoluble ash. This means that soil at a concentration of a few percent in animal or plant tissues can be measured simply by ashing and weighing. We adopted the method of Stafford and McGrath (1981) to our samples.

Each scat sample collected was thawed and stirred, and a subsample of about 0.2 to 1.0 g (dry wt) was transferred to a preweighed 50 mL porcelain crucible. The crucible was dried overnight at 100°C and then weighed. The sample was gradually heated in a muffle furnace to 450°C, ashed for 8 h, cooled, and weighed. We added 5 mL of 6N HCl and took the sample to dryness in about 1 h on a hot plate. The sample was re-extracted into 5 ml hot 5% HCl and filtered through a slow, ashless filter paper (Whatman 42), which was returned to the crucible. The crucible was heated to 600°C in a muffle furnace for at least 2 h,

cooled, and weighed. Results were expressed as acid-insoluble weight divided by dry weight.

The method detection limits were calculated as the standard deviation measured for a series of spiked samples multiplied by the Student's t value for a probability of 0.01 (U.S. Environmental Protection Agency 1982). For a sample of 0.5 g (dry) the method detection limit was 0.75% (ash/dry wt), and for a sample of 0.2 g the method detection limit was 2.1% (ash/dry wt). Both values are equivalent to about 0.004 g. The quality of the analyses was checked by running a sample of northern bobwhite scat spiked with 3% soil and a duplicate sample with each group of ten samples.

Relation between soil-ingestion rate and acid-insoluble ash of scat

The purpose of the soil ingestion equation is to estimate the fraction of soil in the diet, called "x," from parameters we estimate and from the acid-insoluble ash content of the scat, which we measure. The amount of acid-insoluble ash in the scat should be the same as that in the diet, but the ratio of acid-insoluble ash in the scat to its dry weight is greater than the corresponding ratio in the diet, because the dry matter is reduced as the diet is digested. The dry matter content of the diet excluding soil is $1 - x$. If "a" is the digestibility of the diet without soil, then $a(1-x)$ is the portion digested, and $1 - a(1-x)$ is the portion of the diet that is not digested and becomes scat. So if we divide the acid-insoluble ash content of the diet by $1 - a(1-x)$ we have the acid-insoluble ash content of the scat. The acid-insoluble ash content of the diet has two sources, the soil and nonsoil portion of the diet. If "b" is the ratio of acid-insoluble ash to dry weight of the

diet, then $b(1-x)$ is the portion of ash from the nonsoil portion of the diet. This is added to the portion from the soil, which is x times the ash content of the soil (c). We measure the acid-insoluble ash content of the scat divided by the dry weight of the scat, and call this ratio "y." This equals the sum of the two sources of ash, divided by the factor to take digestion into account, or $y = [b(1-x) + cx] / [1 - a(1-x)]$. This can be rearranged to yield $x = (b - y + ay)/(ay - c + b)$.

This equation was derived from a few basic assumptions about digestion. However, before it was applied to wildlife, the equation was tested on mice under controlled conditions, to ensure that the observed data fit the theortical equation reasonably well.

Laboratory mouse study

Twenty-five white-footed mice from a colony at the Patuxent Wildlife Research Center, Laurel, Maryland, were maintained individually in stainless steel hanging cages (18 x 13 x 10 cm), at about 23°C, and in 14 h light per day. A mash diet (National Institutes of Health 07 rat and mouse meal) was provided *ad libitum* in Wahmann "critical measurement powder feeders," which minimize spillage. Paper was placed beneath the cages for collecting scat. Diets were prepared containing 0, 2, 5, 10, or 15% Beltsville fine sandy loam, which had been dried and sieved (2-mm mesh). Five mice were assigned randomly to each treatment and were fed the treated diets for 4 days. Scat were collected during the next 4 days and food consumption was recorded. Then the mice were fed control diets for 4 days, the mice were randomly assigned to a new treatment group, and the process was repeated, to provide 10 values of percent acid-insoluble ash for each diet.

The mash diet was found to have a 2.2% acid-insoluble content. This is higher than would be expected in natural diets because the mash diet contains ground limestone, zinc oxide and other inorganic supplements. The mineral fraction of the soil (c) was found to be 92%. Digestibility was estimated as 76% by comparing the acid-insoulble ash content of the control diet to that of the scat. These parameters were put into the soil ingestion equation so that the predicted acid-soluble ash content of scat could be compared to the observed values. Although the soil ingestion equation intuitively makes sense, this experiment tests how well it works in practice.

Wildlife survey

Samples of scat were collected in various states (Table 1) from captured animals (turtles, mice, voles, armadillos, opossums, woodchucks, raccoon, and sandpipers), from habitats (prairie dogs, foxes, deer, bison, elk, moose, and geese), and from carcasses collected for other studies (wild pigs, waterfowl, and woodcock). Only relatively fresh samples uncontaminated by soil were used.

Earthworms are eaten by many species of wildlife and are known to contain much soil. Samples of two species (*Lumbricus rubellus*, *Eisenoides lonnbergi*) were collected and the acid-insoluble ash content measured.

Estimates of digestibility and acid-insoluble ash content of soil and diets

We did not have estimates of the ash (acid insoluble) to dry weight ratio of the diets without soil for wildlife, but used 2% for all animals, expecting that the true value was less for all of the diets. We

estimated the acid-insoluble ash content of soil as 90%, expecting the real value to be greater than 90%.

We estimated the digestibility of the summer diets of deer and moose at 62%, from the work of Arthur and Alldredge (1979), who estimated that on average in summer mule deer ingest 1,390 g and produce 527 g of scat per day. Other grazers are probably slightly less efficient. The digestibility of forage for cattle on rangeland was estimated at 49% in June and 42% in August (Mayland et al. 1977). Bison are thought to be slightly more efficient than cattle in digesting poor-quality forage (Meagher 1978), so we estimated digestibility for bison at 50%. We used the same estimate for elk, which eat mainly grasses and forbs in summer (Boyd 1978), and for feral hogs. We selected 55% as a value for meadow voles based on two studies; Keys and Van Soest (1970) estimated that experimental diets containing 50% orchardgrass or brome grass (and 50% milk and starch) had a digestibility of about 53%, and Batzli and Cole (1979) estimated the digestibility of monocotyledonous shoots as 54%, and of dicotyledonous leaves and stems as 74%. We lack information for white-footed mice but suggest a value of 65%, since they eat more dicotyledonous and invertebrate material than do voles, and these materials are more digestible than the grasses eaten by voles. We used the same estimate for woodchucks and prairie dogs. Feral hogs are mainly herbivorous, eating primarily mast, herbs, and fruit, but also roots, mushrooms, and invertebrates (Chapman and Feldman 1982). The total digestible nutrients of a dried alfalfa diet (crude protein = 20%) fed to swine was estimated as 50% (Church and Pond 1974). Acorns are a principal food of feral hogs, and when they were fed to bobwhite the

assimilation coefficient was estimated as 49% (Karasov 1990). We estimated an average digestibility of 50% for feral hogs. We estimated an average digestibility of 40% for turkeys, based on estimates of 22% to 56% for six kinds of plants eaten (Karasov 1990). A digestibility of only 25% was estimated for Canada geese, based on a study in which they were fed Spartina alterniflora (Karasov 1990). We estimated a digestibility of 0.30 for mallards, based on an apparent energy coefficient for alfalfa of 0.32, and values for five aquatic plants from 0.15 to 0.30 (Karasov 1990). Blue-winged teal, ring-necked ducks, and wood ducks eat primarily vegetable material (Johnsgard 1975), and we estimated the digestibility at 60%, a rough estimate, based on a wide range of digestibilities reported for ducks eating vegetable material (Karasov 1990). We lack estimates for fox, opossums, and raccoons, but from previous work where these animals were collected, we know that they eat a mixture of animal and plant material (Llewellyn and Uhler 1952). Grodziński and Wunder (1975) reviewed the literature on energy utilization of both laboratory and natural foods for omnivores and suggested an average digestibility of 77%. We have reduced our estimate to 70% because estimates based on dry wt should be somewhat lower than those based on calories (Karasov 1990). We also used this value for armadillos, which eat mainly soil invertebrates (Chapman and Feldhamer 1982), and for box turtles and eastern painted turtles, which are omnivorous (Ernst and Barbour 1972). The apparent metabolizable energy coefficient for woodcock feeding on earthworms is 59% (Vander Haegen 1992), and thus we estimated the digestibility at 55%. Digestion of aquatic invertebrates has rarely been studied, but in a study of African

black oystercatchers the apparent metabolizable energy coefficient was estimated to be 0.72 for polychaetes and rock mussels, and 0.73 for limpets (Karasov 1990); we estimated the digestibility of sandpiper diets to be 0.70.

RESULTS

Mouse study in the laboratory

The mice readily accepted the diets containing soil. Average daily food consumption per mouse, expressed on a soil-free basis, was 3.5 g at 0% soil, 3.5 g at 2% soil, 3.5 g at 5% soil, 3.9 g at 10% soil, and 3.8 g at 15% soil. As expected, the acid-insoluble ash content of the scat varied closely with the soil content of the diet (Fig. 1). The values were clustered about the mean of each treatment level. The data were closely approximated by the theoretical soil ingestion curve, which justifies its use in the survey.

Survey of wildlife

Substantial amounts of soil are ingested by many species of wildlife (Table 1). The highest estimates of soil ingestion (7 - 30%) were recorded for the four species of sandpipers, which probe or peck for invertebrates in mud or shallow water (Johnsgard 1981). Armadillos (17%), woodcock (9%) and raccoons (9%) had the next highest estimates, and they also presumably ingest soil as they eat soil organisms. Bison (7%), prairie dogs (8%) and Canada geese (8%) consumed soil at the greatest rates among the herbivores, and the browsers consumed little soil. The values of acid-insoluble ash in the feces of ducks were very skewed. Samples from most of the mallards contained little or no

sediment (average = 3.3%), but the 10% of the mallards with the highest amounts consumed an estimated 26% sediment in their diet.

The acid-insoluble ash contents of the earthworms sampled were 13% (Lumbricus rubellus) and 24% (Eisenoides lonnbergi).

DISCUSSION

The strengths and weaknesses of the method

The estimates of soil ingestion rates in Table 1 should be considered only approximate; the soil ingestion equation introduces some error and several of the estimates in Table 1 are based on small sample sizes. Soil ingestion rates would be expected to depend on many variables, and so determining a value representative of a species would require more extensive sampling, at various sites and seasons.

The errors associated with the estimates of the parameters in the soil ingestion equation may be important in particular instances. The estimated mineral content of the soil is probably not an important source of error unless the soil ingested has an unusually high organic matter content. Using an estimate of 90% is reasonable. In a typical example, in which the soil ingestion rate was estimated as 3.2%, increasing the estimate of the mineral content of the soil to 100% would change our estimate of soil ingestion to 3.6%. The estimated ash content of the diet is important for diets with soil contents close to the method detection limit of 2%, but makes little difference for most of the species in Table 1. However, the estimated digestibility is potentially a serious source of error. If the digestibility of bison diets were 40% rather than the estimated 50%, then we would have underestimated by 20% the consumption of soil by bison. However, when the estimated

digestibility is high and also inaccurate, the error can be very serious. If, for example, the digestibility of an opossum diet were really 80% rather than the estimated 70%, then soil consumption would actually be little more than half what we estimated.

The methods used in this study are appropriate for measuring relatively high concentrations of soil in scat, and they are easier to use than methods requiring analysis of titanium or other elements. The titanium method is more accurate for estimating low concentrations of soil, but requires estimating the titanium content of the soil ingested. The detection limit of the insoluble-ash method (2.1% ash/dry wt for a 0.2 g sample) was adequate for our purposes, but we could not obtain adequate weights of scat for some species. We had to combine samples from several sandpipers, and we failed to obtain samples of adequate weight from shrew carcasses. We considered digesta from large intestines the same as feces, but this was a simplification for birds, in which the addition of uric acid increases the amount of dry weight produced, but presumably not increase the acid-insoluble ash.

Advantages of analyzing scat in contaminant studies

Analyzing scat is a sensible means of estimating exposure of wildlife to soil and to some contaminants. Although scat have been analyzed for soil content in several studies evaluating hazards to domestic animals from environmental contaminants, they have rarely been analyzed in wildlife contaminant studies (Arthur and Alldredge 1979, Arthur and Gates, 1988). Scat may also be analyzed for environmental contaminants to estimate exposure. Clark et al. (1982) related pesticide burdens in bats to bat guano collected from colonies and Mason et al.

(1992) analyzed scat from otters for PCBs to identify contaminated areas. The analysis of scat to estimate exposure of wildlife to contaminants is best suited to contaminants that are poorly absorbed from the gut, so that absorption and excretion can be ignored. Because food moves through a gut in a matter of hours for most species, the contaminants in scat may be assumed to be from recent exposure. The mean retention time through the gut for birds depends on the size of the animal, but generally is less than four hours (Karasov 1990). One of the advantages of using scat to estimate exposure is that collections can be made without harming the animal and, in many instances, without catching the animal.

Source of soil measured in the diet

Soil from salt licks probably contributed little to the soil ingestion rates in Table 1. In some situations, however, salt licks might be an important source of contamination. Weeks (1978) observed white-tailed deer ingesting soil from a site where unknown chemicals had been dumped, as well as from natural salt licks. The scat from these deer contained an average of 29.4% inorganic matter. Fox squirrels and woodchucks have been observed licking road surfaces, presumably for sodium (Weeks and Kirkpatrick 1978), and this behavior would expose them to soil and contaminants.

Much of the soil that grazers consume is probably from soil adhering to plant material ingested. Cherney et al. (1983) found that during peak periods of soil ingestion beef cattle rumen contained 9.5% soil and forage contained 7.0% soil. Bison, consuming soil at a rate of 6.8% (Table 1) are probably comparable to cattle on poorly vegetated range land. Soil ingestion increases as forage becomes less available

(Fries and Paustenbach 1990). Herbivores in general, however, do not ingest much soil as they eat. Elk, moose, white-tailed deer, mule deer, and woodchuck all had low rates of soil ingestion, although they all have been reported to frequent salt licks (Kreulen and Jager 1984). It makes sense that the species deliberately ingesting soil at salt licks would be those that do not ingest much soil with their food. Burrowing is not necessarily associated with a high rate of soil ingestion, as illustrated by the example of the woodchuck. We had expected feral hogs to ingest large quantities of soil, because they ingest roots and tubers. However, the feral hogs sampled ingested less soil (2.3%) than has been reported (3.3 to 8.0%) for domestic swine on grass pasture (Fries et al. 1982a).

In this study, the acid-insoluble ash content of the 2 species of earthworms sampled were 13% and 24%. Stafford and McGrath (1986) kept earthworms on various soils, some of which were contaminated and possibly unpalatable to earthworms, and they found acid-insoluble ash contents of 5 to 41%. Various earthworm species in dredged material contained an average of about 30% soil (Beyer et al., 1993). Hendrikson (1991) found that the soil content of two species of Lumbricus was about 20% of the ash-free dry weight. The soil within an earthworm's gut contains higher amounts of most elements than are in its tissues (Beyer et al., 1993) and this soil would be the main source of exposure for predators of earthworms. Aquatic organisms may contain considerable amounts of sediment; the burrowing mayfly is estimated to contain 12% sediment (Hare et al. 1989). Whole tadpoles have been found to contain high concentrations of lead (Birdsall et al. 1986), even though lead would not be expected to concentrate in their tissues, and it seems likely that

most of this lead is in the gut, adsorbed to sediment. Researchers studying earthworms or tadpoles are generally interested in the amounts of contaminants in the organisms themselves, rather than in their digesta, and so this means of exposure of predators has been largely ignored in wildlife toxicology. Once the rates of soil ingestion become better known, the bioavailability of soil-bound environmental contaminants becomes important when evaluating hazards to wildlife.

LITERATURE CITED

Allen, V. G., F. P. Horn, and J. P. Fontenot. 1986. Influence of ingestion of aluminum, citric acid and soil on mineral metabolism of lactating beef cows. J. Anim. Sci. 62:1396-1403.

Arthur, W. J., III, and A. W. Alldredge. 1979. Soil ingestion by mule deer in northcentral Colorado. J. Range Manage. 32:67-70.

Arthur, W. J., III, and R. J. Gates. 1988. Trace element intake via soil ingestion in pronghorns and in black-tailed jackrabbits. J. Range Manage. 41:162-166.

Batzli, G. O., and F. R. Cole. 1979. Nutritional ecology of microtine rodents: digestibility of forage. J. Mammal. 60:740-750.

Beyer, W. N., C. Stafford, and D. Best. 1993. Survey and evaluation of contaminants in earthworms from confined disposal facilities for dredged material in the Great Lakes. Environ. Monit. Assess. 24:151-165.

Birdsall, C. W., C. E. Grue, and A. Anderson. 1986. Lead concentrations in bullfrog *Rana catesbeiana* and green frog *R. clamitans* tadpoles inhabiting highway drainages. Environ. Pollut. (Ser. A) 40:233-247.

Boyd, R. J. 1978. American elk. Pages 11-29 in J. L. Schmidt and D. L. Gilbert, eds. Big game of North America: ecology and management. Stackpole Books, Harrisburg, Pa.

Chapman, J. A., and G. A. Feldhamer. 1982. Wild mammals of North America. The Johns Hopkins University, Baltimore, Md. 1,147pp.

Cherney, J. H., D. L. Robinson, L. C. Kappel, F. G. Hembry, and R. H. Ingraham. 1983. Soil contamination and elemental concentrations of forages in relation to grass tetany. Agron. J. 75:447-451.

Church, D. C. and W. G. Pond. 1974. Basic Animal Nutrition and Feeding. Albany Printing Co., Albany, Oregon. 300 pp.

Clark, D. R., Jr., R. K. LaVal, and M. D. Tuttle. 1982. Estimating pesticide burdens from guano analyses. Bull. Environ. Contam. Toxicol. 29:214-220.

Cowan, I. M., and V. C. Brink. 1949. Natural game licks in the rocky mountain national parks of Canada. J. Mammal. 30:379-387.

Ernst, C. H., and R. W. Barbour. 1972. Turtles of the United States. The University Press of Kentucky, Lexington. 347pp.

Fries, G. F. 1982. Potential polychlorinated biphenyl residues in animal products from application of contaminated sewage sludge to land. J. Environ. Qual. 11:14-20.

_____, and L. W. Jacobs. 1986. Evaluation of residual polybrominated biphenyl contamination present on Michigan farms in 1978. Mich. State Univ. Agric. Exp. Sta. Res. Rep. 477. 15pp.

_____, and G. S. Marrow. 1982. Residues in the fat of ewes grazing on soil contaminated with halogenated hydrocarbons. J. Anim. Sci. 55:1118-1124.

_____, _____, and P. A. Snow. 1982a. Soil ingestion by swine as a route of contaminant exposure. Environ. Chem. 1:201-204.

_____, _____, and _____. 1982b. Soil ingestion by dairy cattle. J. Dairy Sci. 65:611-618.

_____, and D. J. Paustenbach. 1990. Evaluation of potential transmission of 2,3,7,8-tetrachlorodibenzo-p-dioxin-contaminated incinerator emissions to humans via foods. J. Toxicol. Environ. Health 29:1-43.

Garcia-Bojalil, C. M., C. B. Ammerman, P. R. Henry, R. C. Littell, and W. G. Blue. 1988. Effects of dietary phosphorus, soil ingestion and dietary intake level on performance, phosphorus utilization and serum and alimentary tract mineral concentrations in lambs. J. Anim. Sci. 66:1508-1519.

Garten, C. T. 1980. Ingestion of soil by hispid cotton rats, white-footed mice, and eastern chipmunks. J. Mammal. 61:136-137.

Goodman, D. C., and H. I. Fisher. 1962. Functional anatomy of the feeding apparatus in waterfowl (Aves: Anatidae). Southern Illinois University Press, Carbondale, 193pp.

Grodziński, W. and B. A. Wunder. 1975. Ecological energetics of small mammals. Pages 173-204 in F. B. Golley, K. Petrusewicz, and L. Ryszkowski, eds. Small mammals: their productivity and population dynamics. Cambridge Univ. Press, New York, N.Y.

Hare, L., P. G. C. Campbell, A. Tessier, and N. Belzile. 1989. Gut sediments in a burrowing mayfly (Ephemeroptera, *Hexagenia limbata*): their contribution to animal trace element burdens, their removal,

and the efficiency of a correction for their presence. Can. J. Fish. Aquat. Sci. 46:451-456.

Hebert, D., and I. M. Cowan. 1971. Natural salt licks as a part of the ecology of the mountain goat. Can. J. Zool. 49:605-610.

Hendriksen, N. B. 1991. Gut load and food-retention time in the earthworms Lumbricus festivus and L. castaneus: a field study. Biol. Fertil. Soils 11:170-173.

Johnsgard, P. A. 1975. Waterfowl of North America. Indiana University Press, Bloomington, 575pp.

_____. 1981. The plovers, sandpipers, and snipes of the world. Univ. of Nebraska Press, Lincoln. 493pp.

Karasov, W. H. 1990. Digestion in birds: chemical and physiological determinants and ecological implications. Stud. Avian Biol. 13:391-415.

Keys, J. E., Jr., and P. J. Van Soest. 1970. Digestibility of forages by the meadow vole (*Microtus pennsylvanicus*). J. Dairy Sci. 53:1502-1508.

Kopischke, E. D. 1966. Selection of calcium- and magnesium-bearing grit by pheasants in Minnesota. J. Wildl. Manage. 30:276-279.

Kramer, D. C. 1973. Geophagy in *Terrepene ornata ornata* Agassiz. J. Herpetol. 7:138-139.

Kreulen, D. A., and T. Jager. 1984. The significance of soil ingestion in the utilization of arid rangelands by large herbivores, with special reference to natural licks on the Kalahari pans. Pages 204-221 in F. M. C. Gilchrist and R. I. Mackie, eds. International symposium on herbivore nutrition in the subtropics and tropics

(1983: Pretoria, South Africa). Science Press, Chraignall, South Africa.

Llewellyn, L. M., and F. M. Uhler. 1952. The food of fur animals of the Patuxent Research Refuge, Maryland. Am. Midl. Nat. 48:193-203.

Mason, C. F., S. M. Macdonald, H. C. Bland, and J. Ratford. 1992. Organochlorine pesticide and PCB contents in otter (Lutra lutra) scats from western Scotland. Water, Air, and Soil Pollut. 64:617-626.

Mayland, H. F., G. E. Shewmaker, and R. C. Bull. 1977. Soil ingestion by cattle grazing crested wheatgrass. J. Range Manage. 30:264-265.

Meagher, M. M. 1978. Bison. Pages 123-133 in J. L. Schmidt and D. L. Gilbert, eds. Big game of North America: ecology and management. Stackpole Books, Harrisburg, PA.

Reeder, W. G. 1951. Stomach analysis of a group of shorebirds. Condor 53:43-45.

Russell, K., J. Brebner, I. Thornton, and N. F. Suttle. 1985. The influence of soil ingestion on the intake of potentially toxic metals and absorption of essential trace elements by grazing livestock. Pages 847-849 in Proc. 5th inter. symposium on trace elements in man and animals (1984). Grampian, Aberdeen, Scotland.

Skipworth, J. P. 1974. Ingestion of grit by bighorn sheep. J. Wildl. Manage. 38:880-883.

Sokal, O. M. 1971. Lithophagy and geophagy in reptiles. J. Herpetol. 5:69-71.

Stafford, E. A., and S. P. McGrath. 1986. The use of acid insoluble residue to correct for the presence of soil-derived metals in the

gut of earthworms used as bio-indicator organisms. Environ. Pollut. Ser. A 42:233-246.

U.S. Environmental Protection Agency. 1982. Definition and procedure for the determination of the method detection limit. 40 CFR Part 136, Appendix B.

Vander Haegen, W. M. 1992. Bioenergetics of American woodcock during the breeding season on Moosehorn National Wildlife Refuge, Maine. Ph.D. Thesis, University of Maine, Orono. 103pp.

Weeks, H. P., Jr., 1978. Characteristics of mineral licks and behavior of visiting white-tailed deer in southern Indiana. Am. Midl. Nat. 100:384-395.

_____, and C. M. Kirkpatrick. 1976. Adaptations of white-tailed deer to naturally occurring sodium deficiencies. J. Wildl. Manage. 40:610-625.

_____, and _____. 1978. Salt preferences and sodium drive phenology in fox squirrels and woodchucks. J. Mamm. 59:531-542.

Table 1. Acid-insoluble ash of scat, estimated digestibility of diets, and estimated soil in diets of wildlife.

Species and state	Samples analyzed (animals/sample)	Acid-insoluble ash of feces (%) Mean	Range	Estimated digestibility(%)	Estimated soil in diet(%)
Box turtle *Terrapene carolina*, MD	8(1)	18	3.6-49	70	4.5
Eastern painted turtle *Chrysemys picta*, MD	9(1)	21	11-41	70	5.9
White-footed mouse *Peromyscus leucopus*, MD	9(4)	8.5	5.7-11	65	<2
Meadow vole *Microtus pennsylvanicus*, MD	7(2)	8.9	4.2-14	55	2.4
Black-tailed prairie dog *Cynomys ludovicianus*, KS	12(1)	22	10-63	65	7.7
White-tailed prairie dog *Cynomys leucurus*, CO	5(1)	12	7.7-27	65	2.7
Nine-banded armadillo *Dasypus novemcinctus*, LA	5(1)	41	23-60	70	17
Opossum *Didelphis virginianus*, MD, SC	6(1)	20	11-36	70	5.4
Woodchuck *Marmota marmota*, MD	6(1)	9.2	6.5-19	65	<2
Raccoon *Procyon lotor*, MD	4(1)	28	13-50	70	9.4
Red fox *Vulpes vulpes*, MD	7(1)	14	4.8-25	70	2.8
White-tailed deer *Odocoileus virginianus*, MD	16(1)	2.7	0.39-6.5	62	<2
Mule deer *Odocoileus hemionus*, WY	5(1)	6.5	0.38-9.0	62	<2
Elk *Cervus elaphus*, WY	4(1)	7.1	4.6-10	50	<2
Moose *Alces alces*, WY	3(1)	5.4	5.2-5.6	62	<2

Bison Bison bison, WY	4(1)	15	13-17	50	6.8
Blue-winged teal Anas discors, MN	12(1)	2.3	0.72-5.1	60	<2
Ring-necked duck Aythya collaris, MN	6(1)	0.72	0.50-1.2	60	<2
Wood duck Aix sponsa, MN	7(1)	24	0-75	60	11
Mallard Anas platyrhynchos, MN	88(1)	6.9	0.36-47	60	<2
Canada goose Branta canadensis, MD	23(1)	12	3.9-38	25	8.2
Stilt sandpiper Calidris himantopus, KS	1(3)	40	none	70	17
Semipalmated sandpiper Calidris pusilla, KS	1(6)	56	none	70	30
Least sandpiper Calidris minutilla, KS	1(6)	24	none	70	7.3
Western sandpiper Calidris mauri, KS	1(7)	42	none	70	18
American woodcock Scolopax minor, ME	7(1)	22	6.3-40	55	10.4
Wild turkey Meleagris gallopavo, SD	12(1)	16	8.4-39	40	9.3

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Figure 1. Relation between the (1) ratio of acid-insoluble ash to dry weight of scat and the (2) soil content of the diet of white-footed mice under laboratory conditions. The line shows the curve predicted by the soil ingestion equation, and the points are observed values.

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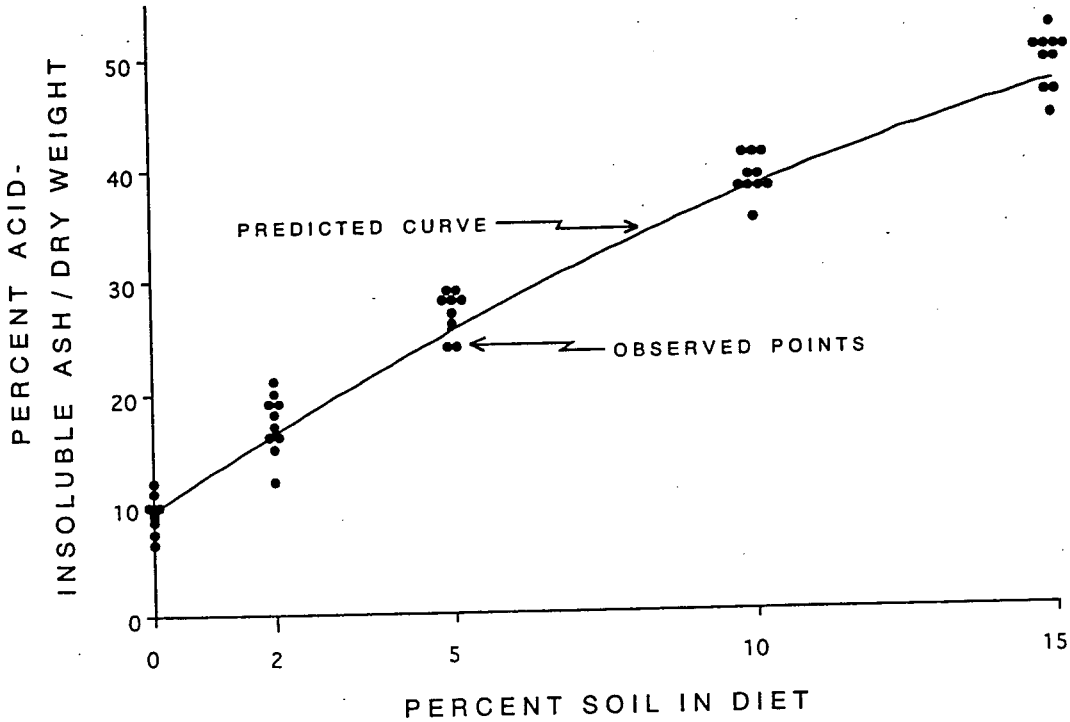
PERCENT ACID-
INSOLUBLE ASH / DRY WEIGHT
50
40
30
20
10
0
PREDICTED CURVE
OBSERVED POINTS
0
2
5
10
15
PERCENT SOIL IN DIET