ESTIMATES OF SOIL INGESTION BY WILDLIFE

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Abstract: Many wildlife species ingest soil while feeding, but ingestion rates are known for only a few species. Knowing ingestion rates may be important for studies of environmental contaminants. Wildlife may ingest soil deliberately, or incidentally, when they ingest soil-laden forage or animals that contain soil. We fed white-footed mice (*Peromyscus leucopus*) diets containing 0–15% soil to relate the dietary soil content to the acid-insoluble ash content of scat collected from the mice. The relation was described by an equation that required estimates of the percent acid-insoluble ash content of the diet, digestibility of the diet, and mineral content of soil. We collected scat from 28 wildlife species by capturing animals, searching appropriate habitats for scat, or removing material from the intestines of animals collected for other purposes. We measured the acid-insoluble ash content of the scat and estimated the soil content of the diets by using the soil-ingestion equation. Soil ingestion estimates should be considered only approximate because they depend on estimated rather than measured digestibility values and because animals collected from local populations at one time of the year may not represent the species as a whole. Sandpipers (*Calidris* spp.), which probe or peck for invertebrates in mud or shallow water, consumed sediments at a rate of 7–30% of their diets. Nine-banded armadillo (*Dasypus novemcinctus*, soil = 17% of diet), American woodcock (*Scolopax minor*, 10%), and raccoon (*Procyon lotor*, 9%) had high rates of soil ingestion, presumably because they ate soil organisms. Bison (*Bison bison*, 7%), black-tailed prairie dog (*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 turtle (*Terrapene carolina*, 4%), opossum (*Didelphis virginiana*, 5%), red fox (*Vulpes vulpes*, 3%), and wild turkey (*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. Soil-ingestion estimates may be required for risk assessments of wildlife inhabiting contaminated sites and for 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 with the concentrations in an animal's diet that the soil becomes an important means of exposure (Arthur and Alldredge 1979). Estimates of soil-ingestion rates are required for risk assessments that attempt to include all sources of exposure to environmental contaminants. Soil ingestion also may be important to animals 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 soil ingested by pronghorn (*Antilocapra americana*) (5.4% of diet) and black-tailed jackrabbit (*Lepus californicus*) (6.3% of diet) contained more than half the total vanadium, sodium, iron, and fluorine ingested.

Deliberate ingestion of soil by wildlife is well documented; the list of animals recorded visiting salt licks or ingesting soil includes >50 species (Cowan and Brink 1949, Hebert and Cowan 1971, Weeks and Kirkpatrick 1976, Kreulen and Jager 1984). Deliberate soil ingestion 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). The acid-insoluble residue of scat from a herd of bighorn sheep (*Ovis canadensis*) in Alberta was as high as 30% (Skipworth 1974). Box turtles have been observed ingesting soil, probably for nutrients other than sodium (Kramer 1973). Lizards, crocodilians, and tortoises also deliberately ingest soil (Sokol 1971). Ring-necked pheasant (*Phasianus colchicus*) (Kopischke 1966) and many other avian species 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 soil with food items. From

10 to 60% sand was reported in the alimentary tracts of 8 species of shorebirds (Reeder 1951). Woodcock feeding on earthworms ingest soil in the earthworm's gut and soil on the outside of the earthworm. Armadillo stomachs have been found to contain large amounts of soil, probably ingested with soil organisms (Chapman and Feldhamer 1982). Grazers ingest dried mud on grass and soil attached to roots.

In studies on grazing domestic animals (Fries et al. 1982*a*), soil-ingestion rates usually have been estimated from the soil content of the animals' scat. The soil in scat includes 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 (Healy 1968, Fries et al. 1982*a*), which is abundant in soil but found only at low concentrations in food items.

We examined the relation between dietary soil content and percent acid-insoluble ash content of scat of white-footed mice kept under laboratory conditions. We then estimated average soil-ingestion rates for a variety of species. Although sample sizes are inadequate to provide thorough data for each species, they identify those species ingesting substantial amounts of soil.

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METHODS

Acid-Insoluble Ash of Scat

The ratio of acid-insoluble ash to dry mass in most animal and plant tissues is generally a few percent. Mineral soil, in contrast, generally contains ≥90% acid-insoluble ash. This means that a soil content of a few percent in animal or plant tissues can be measured by ashing and weighing. We followed Stafford and McGrath (1986) for sample analysis.

We thawed and stirred each scat sample and transferred a 0.2–1.0 g subsample (dry mass) to a preweighed 30-mL porcelain crucible. The crucible was dried for approximately 12 hours at 100 C and then weighed. The sample was gradually heated in a muffle furnace to 450 C, ashed for 8 hours, cooled, and weighed. We added 5 mL of 6N HCl and took the sample to dryness in about 1 hour on a hot plate. We reextracted the sample into 5 ml hot 3% 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 2 hours, cooled, and weighed. We expressed results as acid-insoluble mass divided by dry mass.

We calculated method detection limits as the standard deviation measured in a series of spiked samples, multiplied by the Student's t value for $P = 0.01$ (U.S. Environ. Prot. Agency 1992). For a sample of 0.5 g (dry) the method detection limit was 0.75% (ash/dry mass) and for a sample of 0.2 g the method detection limit was 2.7% (ash/dry mass). Both values were equivalent to about 0.004 g. We checked analyses by running a sample of northern bobwhite (*Colinus virginianus*) scat spiked with 5% soil and a duplicate sample with each group of 30 samples.

Soil-Ingestion Equation

The purpose of the soil-ingestion equation was to estimate the fraction of soil in the diet from parameters we estimated and from the acid-insoluble ash content of the scat, which we measured. We defined x = fraction of soil in diet (dry mass); a = digestibility of food (dry mass); b = concentration of acid-insoluble ash in food (dry mass); and c = concentration of acid-insoluble ash in soil (dry mass). We then defined fraction of diet that was food = $1 - x$; fraction of diet that was digested = $a(1 - x)$; fraction of diet found in scat = $1 - a(1 - x)$; fraction of scat that was acid-insoluble ash from food = $b(1 - x)$; and fraction of scat that was acid-insoluble ash from soil = cx. We expressed the acid-insoluble ash in scat (y) as

$$y = (b[1 - x] + cx)/(1 - a[1 - x])$$

Solving for x yields

$$x = (b - y + ay)/(ay - c + b)$$

This equation was derived from basic assumptions about digestion. Before it was applied in the wildlife survey, however, we tested the equation on mice under controlled conditions to ensure that empirical data fit predicted values of the equation.

Laboratory Mouse Study

We maintained 25 white-footed mice individually in stainless steel hanging cages (18 × 13 × 10 cm), at 23 C, and in 14 hours light/day. A mash diet (Natl. Inst. Health 07 rat and mouse meal) was provided ad libitum in Wahmann critical measurement powder feeders, which minimize spillage. We placed paper beneath cages to collect scat. We prepared diets 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 treated diets for 4 days. We collected scat during the next 4 days and recorded food consumption. Then we fed mice control diets for 4 days, randomly assigned mice to a new treatment group, and repeated the process to obtain 10 values of percent acid-insoluble ash in scat for each diet.

The mash diet had a 2.2% acid-insoluble ash content. This is higher than would be expected in natural diets because the mash diet contained ground limestone, zinc oxide, and other inorganic supplements. The acid-insoluble ash content of the soil (c) was 92%. We estimated digestibility as 76% by comparing acid-insoluble ash content of the control diet with that of scat. These parameters were entered into the soil-ingestion equation so predicted acid-insoluble ash content of scat could be compared with observed values.

Wildlife Survey

We collected scat samples in various states (Table 1) from captured animals (eastern painted turtle [*Chrysemys picta*], box turtle, white-footed mouse, meadow vole [*Microtus pennsylvanicus*], armadillo, opossum, woodchuck [*Marmota monax*], raccoon, and sandpipers [*Micropalama himantopus*, *Calidris pusilla*, *C. minutilla*, *C. mauri*]), from various habitats (black-tailed prairie dog, white-tailed prairie dog [*Cynomys leucurus*], red fox, white-tailed deer [*Odocoileus virginianus*], mule deer [*O. hemionus*], bison, elk [*Cervus elaphus*], moose [*Alces alces*], and Canada geese), and from carcasses collected for other studies (feral hog [*Sus scrofa*], blue-winged teal [*Anas discors*], ring-necked duck [*Aythya collaris*], wood duck [*Aix sponsa*], mallard [*Anas platyrhynchos*], and American woodcock). We used only samples uncontaminated by soil and thought to be no older than 2 days. Samples were kept frozen until analysis.

Earthworms are eaten by many species of wildlife and contain much soil. We collected samples of 2 species (*Lumbricus rubellus*, *Eisenoides lonnbergi*) and measured acid-insoluble ash content.

Digestibility and Acid-Insoluble Ash Content of Soil and Diets

We did not have estimates of the ratio of acid-insoluble ash to dry mass of diets without soil for wildlife, but we used 2% for all animals, assuming that the true value was less for all diets. We estimated acid-insoluble ash content of soil as 90%, expecting the actual value generally to be >90%.

We assumed digestibility of summer diets of deer and moose at 62%, from Arthur and Alldredge (1979), who found that on average mule deer ingested 1,390 g (Alldredge et al. 1974) and produced 527 g (Arthur 1977) of scat per day in summer. Other grazers were probably slightly less efficient. Forage digestibility for cattle on rangeland was estimated at 49% in June and 42% in August (Mayland et al. 1977). Bison are thought to be more efficient than cattle in digesting poor-quality forage (Meagher 1978), so we assumed digestibility was 50%. We used the same estimate for elk, which eat grasses and forbs in summer (Boyd 1978). We selected 55% for meadow vole, following Keys and Van Soest (1970), who showed experimental diets containing 50% orchardgrass (*Dactylis glomerata*) or brome grass (*Bromus* spp.) (and 50% milk and starch) had a digestibility of about 53%, and Batzli and Cole (1979), who estimated digestibility of monocotyledonous shoots as 54% and of dicotyledonous leaves and stems as 74%. The white-footed mouse and other omnivorous mammals have higher digestibilities than do small grazing herbivores, such as voles (Grodzinski and Wunder 1975). Consequently, we assumed digestibilities of 65% for white-footed mouse, woodchuck, and prairie dogs. Feral hogs are omnivorous, eating primarily mast, herbs, and fruit, but also roots, mushrooms, and invertebrates (Chapman and Feldhamer 1982). We assumed digestibility to be 50% according to 3 observations: (1) total digestible nutrients

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

Species and state	No. samples[a] analyzed (animals sampled)	Acid-insoluble ash of scat (%)			Assumed[b] digestibility (%)	Estimated[c] soil in diet (%)
		$\bar{x}$	SE	Range		
Box turtle, Md.	8	18	6.5	3.6–49	70	4.5
Eastern painted turtle, Md.	9	21	2.9	11–41	70	5.9
White-footed mouse, Md.	9 (4)	8.5	0.71	5.7–11	65	2.0
Meadow vole, Md.	7 (2)	8.9	1.2	4.2–14	55	2.4
Black-tailed prairie dog, Kans.	12	22	4.2	10–63	65	7.7
White-tailed prairie dog, Colo.	5	12	3.7	7.7–27	65	2.7
Nine-banded armadillo, La.	5	41	0.62	23–60	70	17
Opossum, Md., S.C.	16	28	3.6	3.7–51	70	9.4
Feral hog, S.C.	15	7.9	1.2	1.9–22	50	2.3
Woodchuck, Md.	6	9.2	2.0	6.5–19	65	2.0
Raccoon, Md.	4	28	8.9	13–50	70	9.4
Red fox, Md.	7	14	2.6	4.8–25	70	2.8
White-tailed deer, Md.	16	2.7	0.39	0.39–6.5	62	2.0
Mule deer, Wyo.	5	6.5	1.0	0.38–9.0	62	<2.0
Elk, Wyo.	4	7.1	1.1	4.6–10	50	2.0
Moose, Wyo.	3	5.4	0.12	5.2–5.6	62	2.0
Bison, Wyo.	4	15	0.91	13–17	50	6.8
Blue-winged teal, Minn.	12	2.3	0.36	0.72–5.1	60	2.0
Ring-necked duck, Minn.	6	0.72	0.11	0.50–1.2	60	2.0
Wood duck, Minn.	7	24	13	0–75	60	11
Mallard, Minn.	88	6.9	1.1	0.36–47	30	3.3
Canada goose, Md.	23	12	1.5	3.9–38	25	8.2
Stilt sandpiper, Kans.	1 (3)	40			70	17
Semipalmated sandpiper, Kans.	1 (6)	56			70	30
Least sandpiper, Kans.	1 (6)	24			70	7.3
Western sandpiper, Kans.	1 (7)	42			70	18
American woodcock, Me.	7	22	5.5	6.3–40	55	10.4
Wild turkey, S.D.	12	16	2.5	8.4–39	40	9.3

[a] When a sample analyzed was a composite, the no. of animals composite is given in parentheses.
[b] Diets and digestibilities were estimated from other published studies.
[c] The fraction of soil in the diet (x) was estimated from the soil ingestion equation $x = (b - y + ay)/(ay - c + b)$, where y = the acid-insoluble ash in scat, a = digestibility of food (dry mass), b = concentration of acid-insoluble ash in food (dry mass), c = concentration of acid-insoluble ash in soil (dry mass).

of a dried alfalfa diet (crude protein = 20%) fed to swine was 50% (Church and Pond 1974), (2) digestibilities of 13 shrubs and forbs in collared peccary (*Tayassu tajacu*) were estimated from 37 to 79% (Strey and Brown 1989), and (3) digestibility of acorns in northern bobwhite was estimated at 49% (Karasov 1990).

We assumed an average digestibility of 40% for turkey, according to estimates of 22–56% for 6 kinds of plants eaten (Karasov 1990). We assumed a digestibility of 25% for Canada geese, following results of a study of feeding on cordgrass (*Spartina alterniflora*) (Karasov 1990). A digestibility of 30% was assumed for mallards, from an apparent energy coefficient for alfalfa of 32% and values for 5 aquatic plants from 15 to 30% (Karasov 1990). Blue-winged teal, ring-necked duck, and wood duck eat vegetable material and invertebrates (Johnsgard 1975), and we assumed the digestibility was 60%, a rough estimate, from a wide range of digestibilities reported for ducks eating vegetable material (Karasov 1990). The apparent metabolizable energy coefficient for woodcock feeding on earthworms is 59% (Vander Haegen 1992), and because coefficients for birds calculated from dry matter tend to be slightly lower than those calculated from calories (Karasov 1990), we assumed digestibility was 55%.

Digestion of aquatic invertebrates rarely has been studied, but in a study of the African black oystercatcher (*Haematopus moquini*) the apparent metabolizable energy coefficient was estimated to be 0.72 for polychaetes (*Pseudonereis variegata*) and rock mussels (*Choromytilus meridionalis*) and 0.73 for limpets (*Patella granularis*) (Karasov 1990). Consequently, we assumed digestibility of sandpiper diets was 0.70.

We lacked data on red fox, opossum, raccoon, box turtle, and eastern painted turtle, which are omnivorous (Llewellyn and Uhler 1952, Ernst and Barbour 1972), and on armadillo, which eat diets of wildlife.

%) Range	Assumed[b] digesti-bility (%)	Estimated[c] soil in diet (%)
.6–49	70	4.5
11–41	70	5.9
7–11	65	< 2.0
2–14	55	2.4
10–63	65	7.7
7–27	65	2.7
23–60	70	17
.7–51	70	9.4
9–22	50	2.3
5–19	65	<2.0
3–50	70	9.4
8–25	70	2.8
39–6.5	62	<2.0
38–9.0	62	<2.0
6–10	50	<2.0
2–5.6	62	<2.0
3–17	50	6.8
2–5.1	60	<2.0
0–1.2	60	< 2.0
0–75	60	11
6–47	30	3.3
9–38	25	8.2
	70	17
	70	30
	70	7.3
	70	18
3–40	55	10.4
4–39	40	9.3

ay = c + b), where y = the acid-insoluble
s), c = concentration of acid insoluble ash

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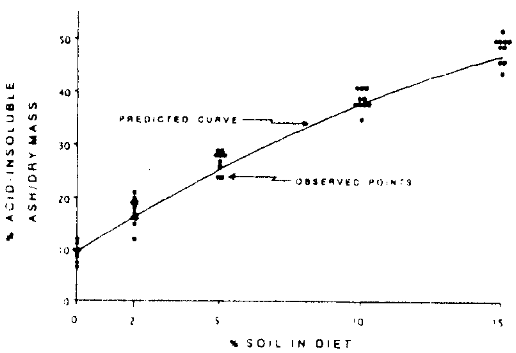

Fig. 1. Relation between the ratio of acid-insoluble ash to dry mass of scat and the soil content of the diet of white-footed mice under laboratory conditions. The points are observed values and the line shows the curve predicted by the soil-ingestion equation ($y = [b(1 - x) + cx]/[1 - a(1 - x)]$, where y = the acid-insoluble ash in scat; x = fraction of soil in diet [dry mass]; a = digestibility of food [dry mass]; b = concentration of acid-insoluble ash in food [dry mass]; and c = concentration of acid-insoluble ash in soil [dry mass]). The agreement between the points and line shows that the equation is useful in practice.

mainly soil invertebrates (Chapman and Feldhamer 1982). We expected digestibilities to be <90%, which was the approximate value suggested for carnivores (Robbins 1983), and above the values of herbivores. Grodzinski and Wunder (1975) reviewed literature on energy use of laboratory and natural foods for omnivores and suggested an average digestibility of 77%. Natural foods would presumably have lower values than laboratory foods. We assumed 70% as a rough estimate for these species. Because estimates of digestibilities were only approximate, estimates of soil ingestion also were only approximate, as will be described later.

RESULTS

Mouse Study in the Laboratory

Mice accepted foods containing soil. Mean 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, acid-insoluble ash content of scat varied with soil content of the diet (Fig. 1). Values were clustered about the mean of each treatment level, and data were closely approximated by the theoretical soil-ingestion curve.

Survey of Wildlife

Substantial amounts of soil were ingested by several wildlife species (Table 1). Highest estimates of soil ingestion (7–30%) were recorded for the 4 species of sandpipers, which probe or peck for invertebrates in mud or shallow water (Johnsgard 1981). Armadillo (17%), woodcock (9%), and raccoon (9%) had the next highest estimates; they presumably ingest soil as they eat soil organisms. Bison (7%), prairie dogs (8%), and Canada geese (8%) consumed a high percentage of soil and browsers consumed little soil. Values of acid-insoluble ash in scat of ducks were very skewed. Samples from most mallards contained little or no sediment ($\bar{x}$ = 3.3%), but 10% of the mallards (out of 88) with the highest sediment content consumed an estimated 26% sediment in their diet. The mean for 5 wood ducks was below the method detection limit, but samples from 2 wood ducks contained >70% acid-insoluble ash.

Percent recovery from spiked samples was 98%. Relative percent difference of the duplicate samples was 20%. Acid-insoluble ash contents of earthworms sampled were 13 (*Lumbricus rubellus*) and 24% (*Eisenoides lonnbergi*).

DISCUSSION

Strengths and Weaknesses of the Method

Our estimates of soil-ingestion rates should be considered approximate (Table 1). The analytical technique and small sample sizes for some species introduced error. Using the soil-ingestion equation to estimate dietary soil ingestion introduced additional uncertainty. We know that soil-ingestion rates would be expected to depend on ecological variables and that determining a value representative of a species would require more extensive sampling at various sites and seasons. Waterfowl results were most variable.

Errors in estimating some parameters in the soil-ingestion equation may reduce accuracy of soil-ingestion estimates. Estimated mineral content of soil is probably not an important source of error unless soil ingested has an unusually high organic matter content. Using an estimate of 90% throughout the study seems 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%. Estimated acid-insoluble ash content of the diet is important for diets with soil contents close to the method detection limit of 2%, but it makes little difference for most species (Table 1). However, some grass species contain >2% acid-insoluble ash (Mayland et al. 1975). The lowest soil-ingestion rates were recorded as <2%

rather than as precise values (Table 1). The estimated digestibility is probably the most serious source of error in soil-ingestion estimates. If digestibility of bison diets was 40% rather than the assumed 50%, then we would have underestimated soil consumption by 20%. However, when estimated digestibility is high and also inaccurate, error can be large. If, for example, digestibility of an opossum diet were 80 rather than 70%, then soil consumption would actually be little more than half what we estimated. Consequently, the mean soil-ingestion estimates are less accurate than mean acid-insoluble ash measurements of scat (Table 1).

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 can detect low concentrations of soil, but it requires estimating titanium content of the soil ingested. The method-detection limit of the insoluble-ash method (2.1% ash dry mass for a 0.2 g sample) was adequate for our purposes, but we could not obtain an adequate mass of scat for some species. We had to combine samples from several sandpipers, and we failed to obtain samples of adequate mass from northern short-tailed shrew (*Blarina brevicauda*) carcasses. We considered digesta from large intestines the same as scat, but this was a simplification for birds, in which the addition of uric acid increases the amount of dry mass produced but presumably does not increase acid-insoluble ash.

Relation of Soil Ingestion to Feeding Habits

Soil from salt licks probably contributed little to our soil-ingestion rates. 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. Feces from these deer contained an average of 29.4% inorganic matter. Eastern fox squirrels (*Sciurus niger*) 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 ingested plant material. Cherney et al. (1983) found that during peak periods of soil ingestion, cattle rumen contained 9.5% soil and forage contained 7.0% soil. Bison, consuming soil at a rate of [illegible], were probably comparable with cattle on poorly vegetated rangeland. Soil ingestion increases as forage becomes less available (Fries and Paustenbach 1990). Several studies on cattle and sheep have shown that under lush vegetational conditions 1–2% of their diet is soil, but when forage is sparse the value may be as high as 18% (Fries and Paustenbach 1990). Most herbivores studied did not ingest much soil, however (Table 1). 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). Animals deliberately ingesting soil at salt licks may not otherwise ingest much soil incidental to their feeding. Burrowing is not necessarily associated with a high rate of soil ingestion, as illustrated by woodchuck results. We had expected feral hogs to ingest large quantities of soil because they ingest roots and tubers. However, feral hogs sampled ingested less soil ([illegible]) than has been reported (3.3–8.0%) for domestic swine (Fries et al. 1982*b*).

Wildlife preying on soil invertebrates or aquatic organisms associated with sediments may ingest much soil or sediment. Earthworms are typically 20–30% soil. Acid-insoluble ash contents of earthworms have been measured as [illegible] and 24% (this study) and 5–41% (Stafford and McGrath 1986). Soil contents have been estimated at 30% (Beyer et al. 1993) and about [illegible] (Hendriksen 1991). Aquatic organisms may contain considerable amounts of sediment; the burrowing mayfly (*Hexagenia limbata*) is estimated to contain 12% sediment (Hare et al. 1989). We suggest that the high concentrations of lead reported in tadpoles (Birdsall et al. 1986) are probably associated with ingested sediment.

MANAGEMENT IMPLICATIONS

Analyzing scat is a means of estimating exposure of wildlife to soil (Arthur and Alldredge 1979, Arthur and Gates 1988) and some contaminants (Clark et al. 1982, Mason et al. 1992). Soil or contaminants in scat may be assumed to be from recent exposure because food moves through the gut of most animals in a few hours or at most in a few days (large mammals). Scat may be used to estimate exposure without harming an animal and, in many instances, without capturing it. Analysis of scat to estimate exposure of wildlife to contaminants is best suited to contaminants that are poorly absorbed from the

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ates 1988) and some con-
l. 1982, Mason et al. 1992).
in scat may be assumed to
osure because food moves
ost animals in a few hours,
ays (large mammals). Scat
ate exposure without harm-
n many instances, without
is of scat to estimate expo-
ntaminants is best suited to
e poorly absorbed from the

gut, so that absorption and excretion can be ignored. In addition to knowing rates of soil ingestion for evaluating hazards of environmental contaminants to wildlife, we need to learn about the bioavailability of soil-bound environmental contaminants.

Studies on cattle (Fries 1982, Russell et al. 1985, Fries and Jacobs 1986), sheep (Fries and Marrow 1982), and swine (Fries et al. 1982*b*) have shown that soil was the main source of exposure to environmental contaminants that included lead, polychlorinated biphenyls, polybrominated biphenyls, hexachlorobenzene, and DDT. Because soil-ingestion rates of some wildlife species are estimated to be at least as great as those for domestic species, we conclude that soil ingestion is also an important route of exposure to environmental contaminants for wildlife. When an environmental contaminant is present at high concentrations in soil but at low concentrations in an animal's food, soil-ingestion rates should help in evaluating toxic risks to wildlife.

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