

GEOPHAGY BY YELLOWSTONE GRIZZLY BEARS

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Abstract: We documented 12 sites in the Yellowstone ecosystem where grizzly bears (*Ursus arctos horribilis*) had purposefully consumed soil (an activity known as geophagy). We also documented soil in numerous grizzly bear feces. Geophagy primarily occurred at sites barren of vegetation where surficial geology had been modified by geothermal activity. There was no evidence of ungulate use at most sites. Purposeful consumption of soil by bears peaked first from March to May and again from August to October, synchronous with peaks in consumption of ungulate meat and mushrooms. Geophagous soils were distinguished from ungulate mineral licks and soils in general by exceptionally high concentrations of potassium (K) and high concentrations of magnesium (Mg) and sulphur (S). Our results do not support the hypotheses that bears were consuming soil to detoxify secondary compounds in grazed foliage, as postulated for primates, or to supplement dietary sodium, as known for ungulates. Our results suggest that grizzly bears could have been consuming soil as an anti-diarrheal.

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Geophagy and the use of mineral licks have been well-studied and widely documented among primates and ungulates, respectively. Among ungulates, the most consistent primary effect seems to be supplementing dietary sodium (Na; Jones and Hanson 1985, Tracy and McNaughton 1995). Among primates, anthropologists and primatologists speculate that geophagy can supplement dietary minerals, including iron (Fe), copper (Cu), potassium, calcium (Ca), zinc (Zn), and manganese (Mn); produce anti-diarrheal effects; and counter the effects of dietary toxins and gastrointestinal parasites (Loveland et al. 1989, Johns and Duquette 1991, Reid 1992). Primate biologists emphasized the role that clay minerals may play in detoxifying secondary compounds from foliage consumed by monkeys (*Callicebus* spp., *Macaca* spp., *Saguinus* spp.) and great apes (Heymann and Hartmann 1991; Mahaney et al. 1995a,b, 1996; Müller et al. 1997).

Geophagy among bears (Ursidae) has been noted only rarely and anecdotally (Chatelain 1950, Jones and Hanson 1985). Even so, given their simple digestive tract and omnivorous diet, it would not be surprising if bears consumed soil largely for the same reasons as primates. Many bear diets include forbs that contain potentially deleterious compounds such as soluble phenolics and alkaloids (e.g., fireweed [*Epilobium angustifolium*] and horsetail [*Equisetum arvense*]; Kingsbury 1964, Robbins et al. 1991). Conversely, the prevalence of meat in many bears' diets (a rich source of Na) and marked dissimilarities between the gastrointestinal tracts of ungulates and ursids suggest that bears should not have Na deficiencies as do

elk (*Cervus elpahus*) and bison (*Bos bison*). Furthermore, the dramatic physiological transitions associated with hibernation impose unique demands on bear physiology that might be alleviated in unanticipated ways by the consumption of soil.

We observed several instances of geophagy by grizzly bears in the Yellowstone ecosystem beginning in 1986 as well as numerous occurrences of soil in their feces. We speculate that geophagy by bears may play a role in maintaining physiological homeostasis and may highlight physiological stressors not previously recognized for bears. Given our limited observations of overt geophagy, our intent here is to refine research hypotheses. We hope to stimulate further inquiry into geophagy among bears in this and other populations.

We used information obtained during this study and other published information on the mineral content of soils at ungulate mineral licks and soils elsewhere in our study area to test the following hypotheses (H_a): (1) mineral content of soils consumed by bears differed from that of samples representative of Yellowstone National Park (YNP) at large; (2) mineral content of soils consumed by bears differed from that of mineral licks used by ungulates in the Rocky Mountains; (3) soil was positively associated with excavated foods (i.e., roots, rodents, and ants [primarily *Camponotus* spp. and *Formica* spp.]) in bear feces; (4) soil was positively associated with foliage in feces; and (5) the consumption of soil coincided with the temporal consumption of foliage, controlling for the effects of consuming excavated foods.

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STUDY AREA AND METHODS

Our study area was the approximate 23,000-km² range of Yellowstone's grizzly bear population, including parts of Wyoming, Montana, and Idaho. We collected feces throughout this range. Geophagy sites were found only in YNP, which comprised <1/2 of the study area (about 9,000 km²). Additional information on the study area can be found in Knight and Eberhardt (1985), Mattson et al. (1991), and Mattson (1997a,b).

We collected feces and documented geophagy sites primarily while ground sampling aerial-telemetry locations of radiomarked bears. We also described feeding activities where they occurred. Details of these methods can be found in Mattson et al. (1991) and Mattson (1997a,b). Although we began collecting feces in 1977, we analyzed soil content only during 1982–92. We described fecal content by volume (ml) and percent composition during 1989–92. At each geophagy site, we described obvious geologic characteristics (e.g., nature and extent of geothermal activity), noted bear trails and activity of other species, and measured the dimensions (dm³) of excavations. We monitored bear use of 2 geophagy sites bi-weekly, 15 March–15 May 1987–90, as part of a study of carrion use by grizzly bears on ungulate winter ranges (Green et al. 1997).

We collected soils from 3 geophagy sites, including the 2 sites monitored bi-weekly, and had them analyzed for content (in µg/g) of 11 minerals: Ca, Cu, Fe, K, Mg, Mn, Na, phosphorus (P), S, Zn, and soluble chloride (as NaCl, sodium chloride). Soils were prepared by nitric acid digestion and mineral concentrations were measured with an atomic absorption spectrophotometer. We obtained soil mineral concentrations (Ca, K, Mg, and Na) for soils representative of different habitat types in YNP from Trettin (1985). Jones and Hanson (1985) provided information on these 4 minerals as well as S for ungulate mineral lick sites from the Rocky Mountains. We transformed all measurements to µg/g for statistical analysis.

We tested for differences among soils from grizzly bear geophagy sites, representative soils from Yellowstone National Park, and ungulate mineral lick sites by multivariate analysis of variance (MANOVA; Johnson and Wichern 1992). We used the Wilks' lambda statistic and $\alpha = 0.1$ as criteria for testing hypothesized differences. However, the probability of committing a type I error probably deviated from 0.1 because we did not employ a randomized sampling design. Given a global difference among types, we followed the logic of least significant differences (LSD) and made pair-wise comparisons using Hotelling's T^2 test (Johnson and Wichern 1992). Differences among types were summarized by canonical

variables. We interpreted the degree and nature of association between mineral content and soil types from standardized canonical coefficients.

We analyzed associations between year, month, diet items, and soil in feces by analysis of covariance (ANCOVA; Zar 1984). We consolidated diet items into the following groups: foliage, ungulate meat, rodents, roots, whitebark pine (*Pinus albicaulis*) seeds, and ants. Consumption of rodents, roots, and ants is highly associated with excavation from a soil matrix (Craighead et al. 1995; Mattson 1997a,c). We used all of these categories as covariates to collectively control for the effects of soil ingestion incidental to the consumption of other foods. We adjusted soil content in feces to account for the effects of covariates by use of population marginal means (Searle et al. 1980). This integrated approach also more reliably estimated partial relationships between soil and other diet items in bear feces. We transformed data for this and the previous analysis by $\ln([\text{ml or } \mu\text{g/g}] + 1)$ to normalize distributions.

We used analysis of variance (ANOVA) and population marginal means to similarly control for the effects of year in estimates of percent soil in feces by month. Given a significant global test, we compared means among months by LSD, with individual years as observations. We transformed data for this analysis to logits ($\ln[p / (1 - p)]$), again to normalize the distribution. We estimated relative amounts of total defecated soil by month by multiplying mean percent soil in feces by an index of the number of feces defecated (Mattson et al. 1991).

RESULTS

Feces

We collected 4,257 scats over 11 years during August–September, 10 years during April–July, 9 years during October, and 4 years during March. Monthly sample sizes were consistently smaller during March and October compared to other months. The proportionate occurrence of soil in grizzly bear feces differed among months and years (including March and October: $F = 1.91$; 17, 57 df; $P = 0.036$; excluding March and October: $F = 2.02$; 15, 46 df; $P = 0.035$); variation among years was probably due to variation in feeding activities involving the incidental ingestion of soil. Soil was proportionately most abundant in feces during April and August and least abundant during June and October (Fig. 1a). Adjusting for different monthly defecation rates, the pattern of absolute defecation of soil peaked highest during July–September with a secondary peak in April

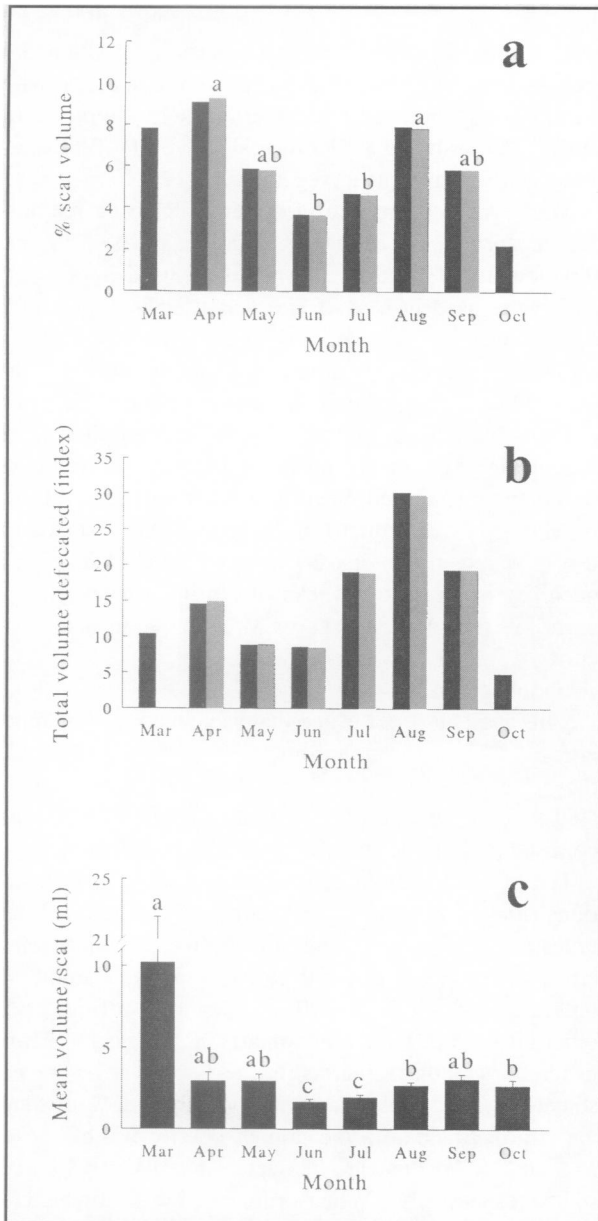


Fig. 1. Soil in the feces of Yellowstone grizzly bears by month (a) as mean percent of relative scat volume controlling for the effects of year, 1982–92, (b) as relative total volume of soil defecated for the same period, and (c) as mean (SE) ml volume per scat controlling for the effects of other diet items in the same feces, 1989–92. The black bars in (a) and (b) are estimates when all months were included in the analysis; stippled bars include only April–September. Bars labeled by the same letter do not differ ($\alpha = 0.1$).

(Fig. 1b). The volume of soil in feces was associated with month (partial $R^2 = 0.02$) and the volume of all other diet items (Σ partial R^2 s = 0.270; $F = 58.07$; 16, 1199 df; $P < 0.0001$), but not year ($P = 0.469$, partial $R^2 = 0.001$). Partial relationships were positive with ants,

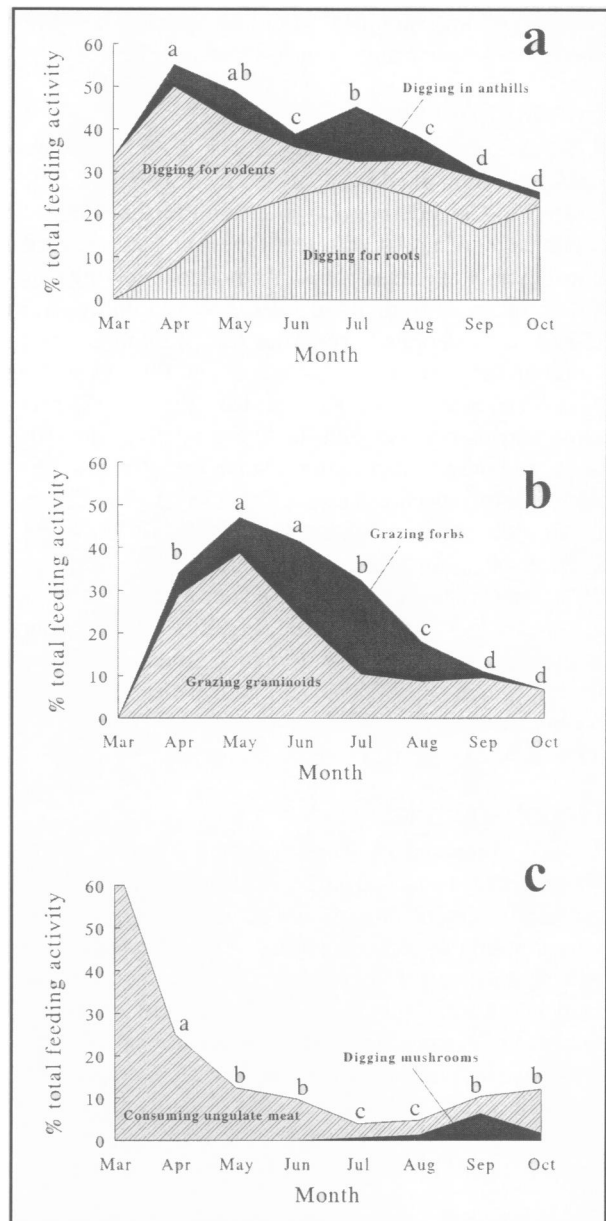


Fig. 2. Percent frequency of feeding activities by radiomarked grizzly bears in the Yellowstone ecosystem, 1986–92, excluding locations where no sign of feeding activity was found for (a) activities involving the excavation of foods from a soil matrix, (b) grazing, and (c) feeding activities consistently associated with diarrhetic feces.

mushrooms, rodents, ungulates, and roots (β coefficients = 0.55, 0.54, 0.43, 0.36, and 0.26, respectively) and negative with foliage and whitebark pine seeds (-0.12 and -0.20, respectively). Controlling for the direct effects of intermixed diet items, what could be construed as pur-

poseful soil ingestion peaked during March–May with a secondary peak during August–October (Fig. 1c).

Feeding Activity

We documented feeding activity at 759 of 1,280 locations of radiomarked bears visited by researchers during 1986–92. Considering only sites with feeding sign, the relative frequency of different types of activity varied considerably among months. Activities involving excavation of foods from a soil matrix peaked during April (55%), then declined thereafter to a minimum during October (25%; $G = 20.0$; 6 df; $P = 0.003$; excluding March because of small sample sizes; Fig. 2a). This decline was associated with declining relative use of rodents and despite increasing relative use of roots. Peak use of anthills occurred during July (13%). Relative frequency of grazing peaked from April–July (32–47%); grazing of graminoids peaked during April–May (29–39%); and grazing of forbs peaked during June–July (18–22%; $G = 76.4$; 6 df; $P < 0.001$; Fig. 2b). The frequency with which bears consumed ungulate meat was highest during March–April (25–67%) and, with use of mushrooms, peaked again during September–October (10–12%; $G = 21.3$; 6 df; $P = 0.002$; Fig. 2c).

Geophagy Sites

We documented 12 geophagy sites. These were sites where grizzly bears had purposefully consumed soil without any apparent opportunity to ingest known foods. Consumption of soil was consistently indicated by deep excavations, grizzly bear claw marks, bear tracks, and evidence at some sites that bears lay on their stomachs at the edge of excavations. We found traditional bear trails at 4 sites. Individual excavations ($n = 21$) averaged 189.6 dm³ (SD = 239.7, range 3.5–795); total excavated volume per site ($n = 11$) averaged 362.1 dm³ (SD = 323.8, range 6.2–1,011). Six of the 11 sites where bear activity

was documented in detail had 1 excavation, 3 sites had 2 excavations, 2 sites had 3 excavations, and 1 site had 4 excavations. All but 1 of the sites were associated with geothermally induced hydrothermal acid alteration of surficial deposits (U.S. Geological Survey 1972); 8 sites were characterized as unvegetated sinter.

Most grizzly bear use of geophagy sites occurred during the spring. Based on investigations of the 1,280 radiotelemetry relocations, 3 sites were used in April, 6 sites were used in May, 1 site was used in July, and 2 sites were used in August. Ungulate use (exclusively elk) was observed only at the sites used by bears in August. One of these sites was clearly a mineral lick (we did not obtain a soil sample). During our monitoring of 2 geophagy sites on the northern ungulate winter range in YNP, we observed recent (1–7 day-old) excavations involving 12 bears on 10 of 36 visits. One instance of use occurred in the first 2 weeks of April, 8 instances occurred in the last 2 weeks of April, 2 instances occurred in the first 2 weeks of May, and 1 instance occurred in the last 2 weeks of May.

Geophagy Soils

Soils at all but 1 of the geophagy excavations (the mineral lick) smelled sulphurous. Where tasted (3 sites), they also were salty. At 6 sites, but not closely associated with the excavations, flammable native sulphur was concentrated on the surface by geothermal activity.

The mineral content of soils from geophagy excavations ($n = 3$), of soils representative of different habitat types in YNP ($n = 66$), and of soils from ungulate mineral licks ($n = 61$) differed globally (Wilks' lambda = 0.093; 8, 248 df; $P < 0.0001$) and pair-wise from each other ($P < 0.0001$ for all comparisons; Table 1). Most differences among minerals for the 3 soil types were associated with the first canonical variable (83% of total variation). Standardized canonical coefficients of K, Ca, Mg, and Na for this variable were 1.58, 0.43, -0.19, and -0.95, respectively. When ordinated by the first 2 ca-

Table 1. Concentration of minerals ($\mu\text{g/g}$) in soils from grizzly bear geophagy sites in Yellowstone National Park (YNP; $n = 3$), from ungulate mineral lick sites in the Rocky Mountains ($n = 61$; Jones and Hanson 1985), and from soils representative of different habitat types in YNP ($n = 66$; Trettin 1985).

Mineral	Geophagy sites		Mineral lick sites		Representative sites in YNP	
	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD
K	397.000	289.000	3.10	4.10	36.30	30.60
Mg	49.700	36.900	13.50	36.20	13.90	13.00
Na	68.700	41.300	34.90	57.70	1.34	2.38
Ca	34.700	23.000	20.40	38.50	211.00	207.00
S	0.900	0.350	0.84	0.21		
Fe	320.000	255.000				
Mn	4.000	1.900				
Cu	10.000	6.940				
P	0.027	0.015				
Zn	1.950	1.130				

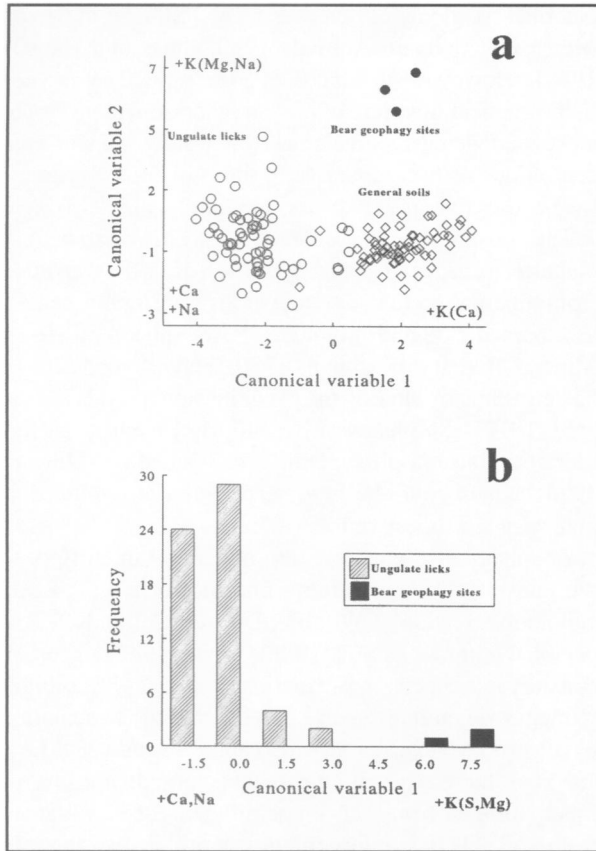


Fig. 3. The ordination of soil samples from grizzly bear geophagy sites in the Yellowstone ecosystem (filled circles), from soils representative of habitat types in Yellowstone National Park (open diamonds; Trettin 1985), and from ungulate mineral lick sites in the Rocky Mountains (open circles; Jones and Hanson 1985) with respect to canonical variables from MANOVA; (a) for all 3 soil types, and (b) comparing only mineral lick and grizzly bear geophagy soils. Interpretation of the canonical variables in terms of soil minerals is based on standardized canonical coefficients.

nonical variables (Fig. 3a), the 3 soil types were well separated. Geophagy soils were distinguished primarily by very high K content and secondly by high Na and Mg content. Including S as part of the pair-wise comparison of geophagy soils with mineral licks, the standardized canonical coefficients of K, S, Mg, Na, and Ca for the first (and only) canonical variable were 2.08, 0.34, 0.22, -0.44, and -0.74, respectively. In this comparison, geophagy soils were well separated (Fig. 3b) by high K and, to a lesser extent, by high S and Mg content.

DISCUSSION

These results lend provisional support to the hypotheses that soils purposefully consumed by grizzly bears in YNP differed from soils at large (H_1) and from soils

consumed by ungulates at mineral licks (H_2). Similarly, these results support the hypothesis that soil ingestion, purposeful or otherwise, was positively associated with the ingestion of excavated foods (H_3). Our results do not support the hypotheses that soil was associated with foliage in bear feces (H_4) or that ingestion of soil coincided with ingestion of foliage, controlling for the effects of bears eating excavated foods (H_5). These conclusions give rise to several interpretations regarding broader research hypotheses.

Our results suggest the interesting, albeit circumstantial, possibility that grizzly bears consumed soil as an anti-diarrheal. Yellowstone grizzly bears purposefully consumed soil primarily in the spring and again in the fall. This temporal pattern most closely corresponded to their consumption of ungulate meat and mushrooms. Furthermore, many of the feces containing mushrooms and ungulate tissue were diarrheal in nature, especially compared to feces primarily consisting of other food remnants.

Mushrooms and ungulate tissue also were positively associated with soil in individual feces. Although this could be construed as additional evidence for purposeful consumption of soil along with mushrooms and meat, this result may be an artifact of soil contamination. Many of these liquid feces were well-integrated with soil surface material. Regardless, the potential role of soil as an anti-diarrhetic could be better judged if geophagy soils were analyzed for therapeutic clay minerals such as kaolinite, bentonite, or halloysite (Loveland et al. 1989, Reid 1992, Mahaney et al. 1995a,b). Unfortunately, we did not analyze geophagy soils for clay mineral content because of prohibitive cost. Tactile assessment of soils at most geophagy sites suggested that they contained a high silt rather than a high clay fraction.

These results do not suggest that Yellowstone grizzly bears ingested soil to detoxify secondary compounds in forb foliage that they had consumed. We emphasize forbs because they are much more likely than graminoids to contain toxic secondary compounds. By contrast, the principal element complicating mastication and digestion of graminoids is high fiber and silica content (Van Soest 1987, Robbins 1983). Thus, grizzly bears probably exhibit geophagy for reasons different from those postulated for monkeys and great apes.

Similarly, grizzly bears likely consumed soil for different reasons than elk in YNP. In addition to differences in mineral content of geophageous soils and mineral licks, the timing of use differed. Peak geophagy by bears occurred earlier (March–May) than peak lick use by ungulates (usually in June; Jones and Hanson 1985). This conclusion is strengthened by the lack of elk sign at most

grizzly bear geophagy sites. The only coincident elk and bear activity occurred at the few sites used by bears during August. Assuming that elk in YNP use licks primarily to supplement dietary Na (Jones and Hanson 1985, Tracy and McNaughton 1995), it is not surprising that grizzly bears would be ingesting different types of soil for different reasons. It is very unlikely that grizzly bears in the Yellowstone ecosystem experience a Na deficiency given the large amounts of meat they consume from herbivores (Mattson 1997b) and the high Na content of this food (Robbins 1983).

Geophageous soils differed most strikingly from ungulate licks and soils representative of YNP by very high K content and to a lesser extent by high S and Mg content. The implications of this result in terms of both causes and effects are not clear. However, it is possible that the high concentration of K and Mg in geophageous soils were nutritionally beneficial and that the high S content was therapeutic.

Additional Hypotheses

Hibernating grizzly bears could incur K deficiencies (hypokalemia). Potassium undergoes considerable concentration in the bladder during hibernation (about 3.5 times normal levels; Levinsky and Berliner 1959; Brown et al. 1968, 1971). At the same time, urine volume remains relatively constant (Nelson et al. 1975), although diminished from the volume found in active animals (e.g., Levinsky and Berliner 1959). Hibernation engenders classic conditions for the development of hypokalemia: decreased dietary intake of K, intestinal obstruction, and renal excretion of K (or concentration in the bladder; Blood et al. 1979). Although levels of K in blood serum show relatively little variation between hibernating and active bears (Nelson et al. 1973), measures of plasma or serum K do not reliably indicate the status of the body's K pool (Blood et al. 1979).

If bears emerging from hibernation experienced a K deficiency, they may not have been easily able to remedy their condition. In normal situations, herbivores can boost K intake by consuming rapidly growing vegetal material that is typically rich in K (Robbins 1983). However, such foods are not readily available to bears in the Yellowstone ecosystem until late April. Our results suggest that geophagy by grizzly bears peaks in March and April. If bears are K-deficient, this condition may be exacerbated by diarrhea from consuming carrion (cf. Newberne 1970).

If grizzly bears during our study were not K-deficient, they risked damagingly high levels of K (hyperkalemia) by geophagy. This risk would have been off-set somewhat by the relatively high levels of Mg in geophageous soils (Mg can serve as an antidote to high levels of K;

National Academy of Sciences [NAS] Subcommittee on Mineral Toxicity in Animals 1980, Jones and Hanson 1985). However, such a risk is corroborated by records in the medical literature of human practitioners of geophagy experiencing hyperkalemia by ingesting soil with concentrations of K comparable to those of soils consumed by Yellowstone grizzly bears (Gelfand et al. 1975).

The consumption of elemental S may have had beneficial effects, especially during or soon after the transition from hibernation to active metabolism. Sulphur can act as a parasiticide and fungicide (NAS Subcommittee on Mineral Toxicity in Animals 1980), and can also act as a bacteriostatic by altering the pH of intestinal fluids (Blood et al. 1979). Sulphates of Na and Mg together can further stimulate motility of the small intestine (Howard 1986), which could be very beneficial after winter dormancy of the digestive tract.

Geophagy also could restore beneficial microflora to the intestines of bears after winter dormancy (T. Beck, Colorado Division of Wildlife, Denver, Colorado, USA, personal communication, 1998). There is evidence that considerable digestion of fiber can occur in the colon of monogastric animals such as swine due to fermentation by anaerobic bacteria (Argenzio and Stevens 1984, Low 1985). If these types of intestinal bacteria do not survive hibernation in bears, an innoculum might be obtained from soil. This would explain the primary spring, but not the secondary late-season peak in soil consumption. It would also not fit the apparent selective orientation of bears in our study toward homogeneous sites characterized by exceptionally high levels of K, S, and Mg.

RECOMMENDATIONS

Our results cannot conclusively demonstrate the causes or consequences of geophagy to Yellowstone's grizzly bears. However, they are a basis for recommending additional research that may provide additional insights.

1. Analysis of soils from geophagy sites for clay minerals such as kaolinite, bentonite, or halloysite would further elucidate whether bears consumed this soil for its anti-diarrheal properties.
2. Soil from geophagy sites could be fed to captive bears experiencing experimentally-induced diarrhea to directly test for anti-diarrheal effects.
3. Further insight into the distribution and abundance of K in grizzly bears during and shortly after hibernation could provide a basis for testing the hypothesis that grizzly bears are K-deficient upon den emergence.
4. Additional information on the year-round dynamics of populations of parasites and bacteria in the

gastrointestinal tract of wild bears could provide additional insight into stressors that might be alleviated by the administration of parasiticides and bacteriostatics or, conversely, the potential for augmentation of beneficial micorflora by ingestion of soil.

5. The effects of geophagous soils as parasiticides and bacteriostatics could be tested by administering them to captive bears experiencing experimentally-induced levels of parasites or bacteria.

Our results suggest that the purposeful consumption of soil by Yellowstone grizzly bears may play a role in their maintenance of physiological homeostasis, especially during spring. Sites where grizzly bears traditionally consume soil may therefore warrant special protection, not only to ensure that grizzly bears have access to these locations, but also to minimize the potential for undesirable encounters between humans and bears.

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