

CONSUMPTION OF EARTHWORMS BY YELLOWSTONE GRIZZLY BEARS

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Abstract: There are very few records, primarily from Eurasia, of bears consuming earthworms (class Oligocheata). Sign of grizzly bears (*Ursus arctos horribilis*) eating earthworms was observed at 20 sites during a radiotelemetry study of the Yellowstone population, 1977–92, and on 14 additional occasions during direct observations, 1985–96. Relative frequency and intensity of earthworm consumption peaked during April and May and declined thereafter. No consumption of earthworms was detected after June. In general, soils were wet to saturated from snowmelt at the time they were excavated by bears to consume earthworms. At fine scales, earthworm use was positively associated with nearness to a forest edge and with cover of bluegrasses (*Poa* spp.). Excavations tended to be larger in total size during months when regional precipitation was greater; depths averaged 0.9 dm. These depths together with other site characteristics suggest that the bears consumed anecic species of earthworm, most likely non-natives of the family Lumbricidae. At two sites, we estimated that 120–170 earthworms m⁻² were available to the bears, totaling 4,000–7,900 for the entire feeding sites. This potentially amounted to 0.9–1.8 kg of worms, comprised of 60–70% protein (dry weight). Earthworms are a unique high-quality bear food that may have been overlooked in other areas. Given the continuing invasion of previously-glaciated boreal and montane regions in North America by non-native earthworms, consumption of worms by bears may become more widespread.

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Earthworms (class Oligocheata) are eaten by numerous types of birds and mammals including species as large as red foxes (*Vulpes vulpes*), raccoons (*Procyon lotor*), southern opossums (*Didelphis marsupialis*), and European badgers (*Meles meles*; MacDonald 1983, Edwards and Bohlen 1996). Although earthworms must either be opportunistically consumed on the soil surface or extracted from a soil matrix, they provide a substantial nutritional reward. On average, earthworms contain 60–70% crude protein (dry weight) and very little crude fiber (<5%), which results in a high concentration of highly digestible energy (16–17 kJ/g; Grant 1955, Sabine 1983, Lee 1985).

Ursids also consume earthworms, although records of such consumption are rare and wholly anecdotal. Most observations come from brown bears (*Ursus arctos*) in Eurasia, including European Russia (Ognev 1931), Siberia (Ustinov 1965), and the Russian Far East (Stroganov 1962). In North America, the only record of bears consuming earthworms comes from grizzly bears (*U. a. horribilis*) in the Yellowstone region and is limited to brief references by Craighead and Mitchell (1982) and Craighead et al. (1995).

We observed grizzly bears consuming earthworms in the Yellowstone region during direct observations, 1985–96, and while investigating radiotelemetry locations of marked bears, 1977–92. In this paper we describe consumption of earthworms by these bears as well as temporal and site features associated with this activity. Because virtually nothing is known about exploitation of earthworms by bears, our statistical analysis was exploratory. Explanatory variables were chosen for consideration based on field observations and our knowledge of grizzly bear and earthworm ecology.

STUDY AREA

The approximately 23,000 km² study area, from 43°30′ to 45°15′ N latitude and 109°30′ to 111°30′ W longitude, corresponded to the known range of Yellowstone's grizzly bear population. Most of the area occupied by grizzly bears was >2100 m elevation and consisted of remote mountains and plateaus surrounded by valleys and plains more intensively settled or used by humans. Annual temperatures averaged about 0°C whereas monthly averages ranged from -2°C to 13°C during April through October. Precipitation varied in amount and timing with elevation and region and fell mostly as snow that accumulated to 20–260 cm, depending on location, before melting during March–June (Dirks and Martner 1982).

About 75% of the study area was forested, and most of this forest was dominated by lodgepole pine (*Pinus contorta*; Despain 1990). Non-forest areas occurred as isolated mesic or wet meadows at mid-elevations of the extensive plateaus of Yellowstone National Park (YNP); to the north, as extensive lower-elevation grasslands, often co-dominated by sagebrush (*Artemisia* spp.); and, especially in the mountainous eastern parts of the study area, as alpine tundra and rock. Bison (*Bison bison*) were abundant in northern and central YNP, whereas wapiti (*Cervus elaphus*) were abundant throughout grizzly bear range. Craighead et al. (1995) described the study area in detail.

METHODS

Direct observations of grizzly bears were made April–November of most years, 1985–96, primarily within YNP. Observations concentrated on but were not exclusive to crepuscular hours and were aided by binoculars and Nikon

EDIF 20-power spotting scopes. Bears were identified by sex and age class based on their radiomark or physical characteristics (French et al. 1994). Subadults (<5 yrs) were distinguished by their smaller size and shorter body length compared to adult females with offspring observed in the same area. Adult males were identified by genitalia and were also distinguished by their large size. In some cases, subadult males were also identified by genitalia.

Bears were trapped, marked, and radiolocated according to methods described by Knight and Eberhardt (1985) and Blanchard and Knight (1991). A subset of radiolocations was visited and described according to methods in Mattson (1997, 2000). Field crews also described sites where grizzly bear feeding or bedding sign was encountered en route to and from telemetry locations. At each location, field crews located a variable-radius forest inventory plot at the center of grizzly bear activity. Percent ground cover was visually estimated for all graminoids, forbs, and shrubs within 10 m of plot center, and individual plant species were listed and ascribed an index of abundance (1–5; 1 = present but rare and 5 = dominant).

Field crews described all feeding sign and collected all feces (scats) encountered during 1977–92. During 1986–92 descriptions of feeding activity included counts and measurements of excavations. For excavations of earthworms, length, width, and depth (all in dm) were measured and multiplied to estimate excavated volume. At 2 sites where earthworms had been excavated, we estimated number of earthworms potentially available to bears. We did this by excavating clumps of sod similar in surface area and depth to those overturned by the bear and counting the number of earthworms exposed on the bottom. We estimated total available earthworm volume and protein based on individual worm sizes (0.231 g/worm) and nutrient contents from Sabine (1983) and Lee (1985).

We used logistic regression analysis (Demaris 1992) to specify the effects of explanatory variables on the log odds that a bear excavated earthworms at a given location. Radiotelemetry locations or feeding sites were units of analysis. We specified 2 types of models: one using only data from telemetry locations, including sites where no feeding sign had been found, and the other using only data from sites with feeding and bedding sign of all types, but including plots not at telemetry locations. We gave priority to the first type of model and used the second type to confirm patterns. Given that excavation of earthworms had occurred, we used multiple linear regression (Weisberg 1985) to specify the effects of explanatory variables on total volume of excavations. We used maximum likelihood methods for parameter estimation and the sample-size-adjusted version of Akaike's Information Criterion (AIC_c ; Burnham and Anderson 1998) for model selection. We used change-in- AIC_c (Δ) to quantify the

relative effect of each variable in a given model (Burnham and Anderson 1998). Because the value of AIC_c is affected by sample size, Δ is comparable within but not among models. We did not base our analysis on statistical hypothesis testing for reasons well stated elsewhere (Johnson 1999) and present P -values solely for confirmation.

We considered both proximal and distal effects in the analysis (Mattson 2000). Distal effects were those operational at broad temporal and spatial scales, whereas proximal effects were operational at the scale of the immediate site. Proximal effects were represented by measures taken at telemetry locations or other sites of grizzly bear activity. Distal effects were enumerated from other sources. Monthly temperatures ($^{\circ}C$) and precipitation (cm) were taken from regional summaries published by the U.S. National Oceanic and Atmospheric Administration (1977–92). Date of snow melt (i.e., first spring day with 0 cm of snow recorded on the ground) was taken from records for Yellowstone Lake weather station — the station nearest most of the earthworm consumption observed during this study. Grizzly bear activity sites were associated with the spatial extent of habitat types and ungulate winter ranges in surrounding life-range-size areas on the basis of the Bear Management Units (BMUs) where they occurred (Fig. 1; Mattson 2000). Mattson (2000) provided a more detailed description of these distal factors and their sources.

RESULTS

During 1977–92, 1,853 telemetry locations from 140 radiomarked bears were investigated to determine activity of the associated animal. Feeding sign was found at 2,769 sites, including 1,744 sites not associated with telemetry locations. Sample sizes used to parameterize individual models and for statistical tests were typically less than given here because of missing data for some explanatory variable.

During radiotelemetry investigations, sign of feeding on earthworms (shallow to moderately deep excavations in sod and mud) was found at 20 sites, 6 of which were at telemetry locations of 6 individual radiomarked bears. Three of these bears were adult females, 2 were subadult males (weaned but <5 yrs old), and 1 was an adult male. No recognized remains of earthworms were found in the 6,662 feces collected during this study. Grizzly bears were visually observed feeding on earthworms on 14 occasions. Of these bears, 4 were identified as adult females with cubs (2 with new cubs, 1 with yearlings, and 1 with 2-yr-olds), 9 were identified as subadults (5 males and 4 females), and 1 was identified as an adult male. Almost all telemetry-based records of earthworm consumption by grizzly bears occurred in BMUs of eastern and central

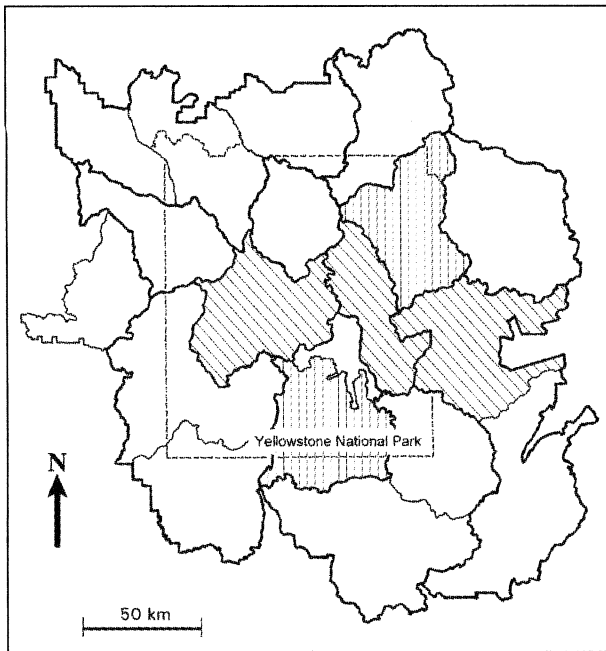


Fig. 1. Bear Management Units (BMUs) where Yellowstone grizzly bears consumed earthworms, 1977–92. Solid lines delineate the 18 BMUs comprising the Yellowstone Grizzly Bear Recovery Area; the dashed line delineates Yellowstone National Park. More than 5 instances of earthworm consumption were recorded in BMUs denoted by diagonal hatching, a single instance in BMUs denoted by vertical hatching.

parts of the study area, with 18 of the 20 total instances recorded in just 3 BMUs (Fig. 1). Within these 3 focal BMUs, 2 of 10 radiomarked bears with ≥ 10 observations of feeding or bedding activity were observed to consume earthworms.

The effects of days since snow melt, extent of bison winter range, distance to forest edge, and abundance of *Poa* spp. were specified in logistic regression models of log odds that a bear had consumed earthworms at a site. The model based on telemetry locations was:

$$\text{Logit}(p) = -7.7 + 0.024bison^2 - 0.63\ln(edge + 1)$$

where $n = 2,088$, $R_L^2 = 0.98$, 334 df, $G^2 = 26$, and $P(\text{goodness-of-fit}) = 1.00$; and where *bison* was the percent of the BMU containing a location that consisted of bison winter range and *edge* was the distance, in m, to a forest edge. The effect of *bison* ($\Delta = 10.4$) was stronger than the effect of *edge* ($\Delta = 5.0$). The model based on feeding and bedding sites, including sites not associated with telemetry locations, was:

$$\text{Logit}(p) = -4.8 + 0.0065bison^2 - 0.52snowmelt + 0.46Poa$$

where $n = 1,630$, $R_L^2 = 0.96$, 1,000 df, $G^2 = 106$, and

$P(\text{goodness-of-fit}) = 1.00$; and where *snowmelt* was number of days after terminal snow melt at Yellowstone Lake weather station and *Poa* was the indexed abundance of all *Poa* spp. at the activity site. The effect of *snowmelt* ($\Delta = 23.7$) was stronger than either the effects of *bison* ($\Delta = 2.3$) or *Poa* ($\Delta = 3.6$).

Consumption of earthworms peaked during the last 2 weeks of April and the first 2 weeks of May (Fig. 2). No known or probable consumption of earthworms occurred after June. This temporal pattern was consistent with the apparent effects of snowmelt. Odds of earthworm consumption at feeding sites peaked at snowmelt and declined dramatically thereafter (Fig. 3c). Odds of consumption were also greatest in BMUs with the most extensive bison winter range (Fig. 3a).

Consumption of earthworms was most often observed in swales wetter than surrounding sites because of drainage or snow drift. These sites tended to have greater cover of *Poa* spp., most often of the non-native Kentucky bluegrass (*P. pratensis*), compared to other sites where grizzly bears had fed or bedded (Fig. 3b). These sites also were more likely to occur close to a forest edge compared to other telemetry locations (Fig. 3d).

Total volumes excavated by bears while feeding on earthworms tended to peak during April (Fig. 2). Volumes (y , in dm^3 , natural-log transformed) were strongly positively related to precipitation during the contemporaneous month (*ppt*):

$$y = 4.8 + 0.043ppt^2$$

with $n = 14$; $r^2 = 0.50$; 1, 12 df; $F = 11.8$; $P = 0.005$.

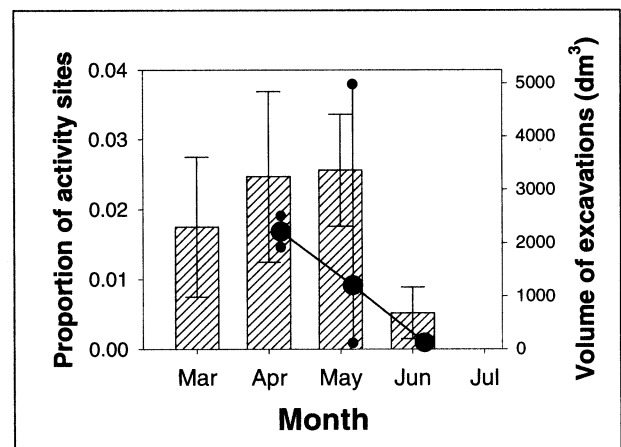


Fig. 2. Monthly earthworm consumption by Yellowstone grizzly bears, 1977–92. Bars (± 1 SE) correspond to the proportion of feedings sites where evidence of earthworm consumption was found and large solid dots the median volume of excavations. The small dots above and below medians for April and May denote the lower and upper limits of the 75% and 25% quartiles, respectively.

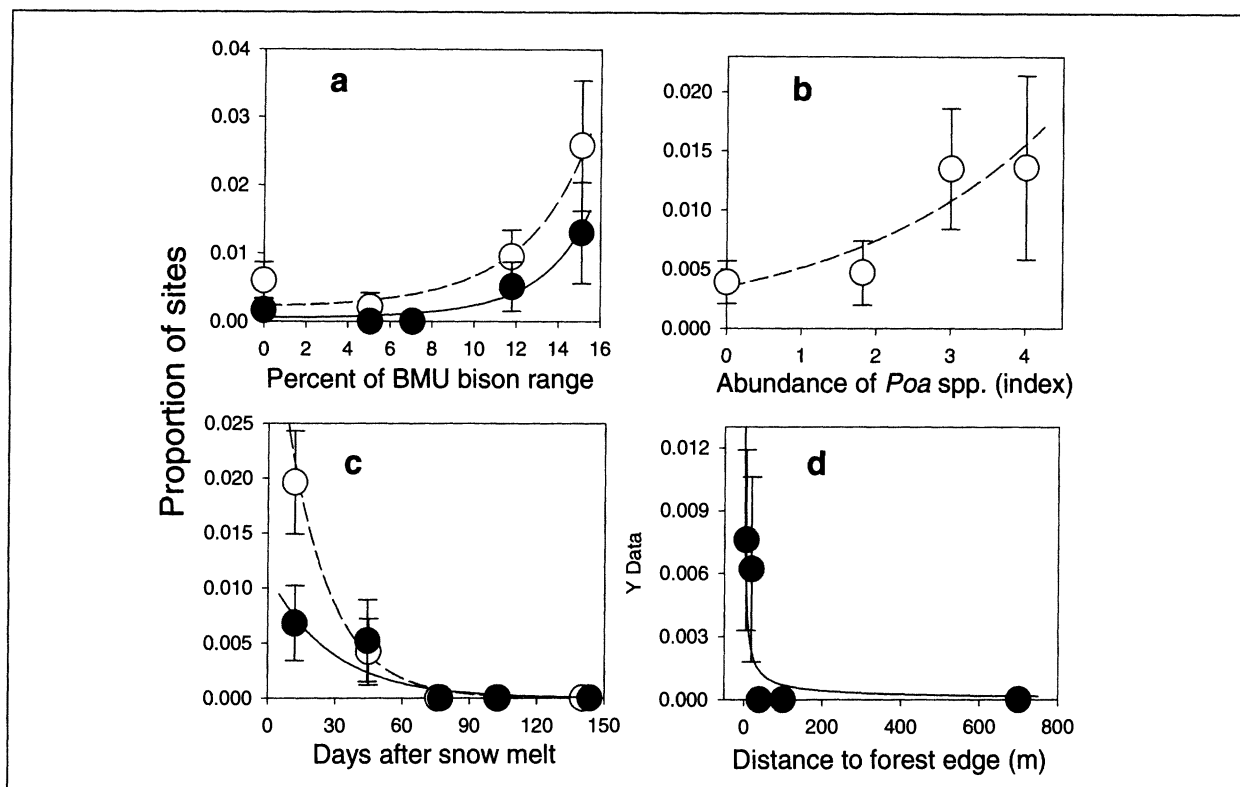


Fig. 3. Univariate relations between proportion of sites where Yellowstone grizzly bears consumed earthworms, 1977-92, and distal or proximal factors with the greatest apparent effects on this behavior: (a) extent of bison winter range in the surrounding Bear Management Unit (BMU), (b) abundance of *Poa* spp. at the site, (c) number of days after snowmelt, and (d) distance to nearest forest edge. With the exception of the relation for *Poa* spp., circles and associated SE bars are for proportions by quintiles of the data and illustrate goodness-of-fit (univariate). For *Poa* spp., circles denote proportions by indexed values of *Poa* spp. abundance. Solid circles and lines are for telemetry locations; open circles and dashed lines are for feeding and bedding sites.

Mean depths of excavations averaged 0.9 (SD = 0.4) for the 15 feeding sites where this dimension was estimated.

While feeding on earthworms, grizzly bears pulled back or flipped over clumps of dirt and vegetation and consumed worms exposed on the bottom. They extracted the worms by facile use of lips and tongue. At two sites we estimated that 120-170 earthworms/m² were available to the bear, totaling 4,000-7,900 worms for the entire feeding sites. This amounted to 0.9-1.8 kg of food (assuming 0.231 g/worm) or 0.5-1.3 kg of crude protein (assuming 60-70% protein).

DISCUSSION

There is no obvious explanation for the relation between extent of bison winter range and consumption of earthworms by Yellowstone grizzly bears. This association is consistent with the fact that most earthworm consumption was observed in Hayden and Pelican Valleys, which contain or are near major bison wintering areas (Meagher 1973). However, exploitation of pocket gophers (*Thomomys talpoides*) by grizzly bears was also strongly

positively associated with bison winter range (Mattson unpublished data). Although bears tended to seek out gophers on sites drier than where they excavated worms, site conditions did overlap, and exploitation of pocket gophers was principally by excavation. It could be that excavation of earthworms was an extension of foraging behavior and strategies already oriented toward subterranean foods, principally pocket gophers and their food caches.

Wet to saturated soils apparently had a substantial effect on the odds that bears consumed earthworms. This was indicated by the marked decline in odds of consumption as time since snow melt increased and by the increase in extent of excavations during periods of greater precipitation. These results parallel those for exploitation of pocket gophers, another excavated food (Mattson unpublished data). Earthworms, like pocket gophers (Turner et al. 1973), tend to be at shallower depths when soils are saturated, presumably to find adequate oxygen (Lee 1985). Moreover, soils are more easily dug by bears when wet compared to when dry (Mattson unpublished data). In short, wet soils likely promoted the efficiency of foraging

for earthworms by increasing their availability while contributing to ease of digging.

The earthworms consumed by Yellowstone grizzly bears were probably non-natives of the family Lumbricidae. There are virtually no native earthworms in regions, like Yellowstone, that were glaciated during the late Pleistocene in North America (Fender 1995). Instead, these regions have been colonized primarily by European Lumbricidae species (Reynold 1995, Edwards and Bohlen 1996). Of the Lumbricidae, *Apporrectodea trapezoides*, *A. tuberculata*, *A. turgida*, *Dendrobaena octaedra*, and *Dendrodrilus rubidus* are within range of our study area (Reynolds 1995). *Dendrobaena octaedra* is the most cold-hardy and a common occupant of heathlands in Europe (Edwards and Bohlen 1996). It is also known to occupy soils in lodgepole pine forests (McLean and Parkinson 1997). Regardless, because of the depths at which bears exploited earthworms during our study, the targeted species were likely anecic (occupants of topsoil) rather than epigeic (of litter) or endogeic (of deep soil; Edwards and Bohlen 1996).

The association of earthworm consumption with what were often non-native bluegrasses is suggestive. Kentucky bluegrass likely arrived early in the Yellowstone region along with non-native clovers (*Trifolium* spp.) and common timothy (*Phleum pratense*) as a result of live-stock rearing and haying that occurred not only on non-park lands but also in YNP (Reinhart et al. 2001). Factors associated with transmission of these non-native plant species also could be the inoculants for non-native earthworms. The earthworms, in turn, could have created soil conditions conducive to the spread and abundance of Kentucky bluegrass.

These results add to the described diversity of grizzly bear foods and foraging behavior. They also provide diagnostic features that may help detect what could become a more common feeding activity in the Yellowstone region and elsewhere. The expansion and local increase of non-native Lumbricidae is on-going (Reynolds 1995, Edwards and Bohlen 1996). This is highlighted by an account of recent invasions of lodgepole pine forests in southern Alberta previously without earthworms (McLean and Parkinson 1997), in habitats much like those found in the Yellowstone region. It is possible that as earthworms colonize more of current North American grizzly bear range, consumption of earthworms will become more common.

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