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Effects of Black-tailed Prairie Dogs (*Cynomys ludovicianus*) on Soil Erosion

Senior Thesis

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Sponsor: University of North Dakota Geology & Geological Engineering Dept.
Abstract

The rates of natural erosion are poorly understood, especially with respect to influences by fauna. Soil traps were implemented in a prairie dog town 14 miles NW of Killdeer, ND to measure and compare erosion rates within the prairie dog town to those of a control site comprised of natural prairie grasses and void of prairie dogs. Results from 81 days (May 31st-September 20th) include a total of 27,492.6 grams collected among three boxes dispersed throughout one alluvial plume downhill of an active prairie dog hole and 49 grams collected among two boxes placed outside the prairie dog town in the designated control site. The study shows that erosion rates are much higher within the prairie dog colony compared to a similar area absent of any prairie dog influences.
**Introduction and Motivation**

An increase in erosion can have several impacts on an ecosystem: The loss of the nutrient-rich topsoil leaves the surface lacking of vegetative cover, which in turn creates a hard, more compact soil profile. A compact soil surface means surface runoff water increases substantially, and cuts into funneled areas with much more force, causing ravines and gullies to form. These muddied waters can have a devastating impact on aquatic life accustomed to clear waters, and can quickly throw the entire system out of balance. By having ravines and gullies further incised, coupled with a reduction in soil stability from vegetative removal, mass wasting is also more prone to occur (Leopold 1935).

Conservationists recognize black-tailed prairie dogs (*Cynomys ludovicianus*) as a keystone species in North American grassland ecosystems because of their role as a primary prey species for threatened and endangered predators like the black-footed ferret, burrowing owl, ferruginous hawk, and swift fox, and because they have a profound influence on biodiversity, nutrient cycling, environmental heterogeneity, hydrology, and landscape architecture within their colony's confines (Coppock et al. 1983; Uresk 1985; Archer et al. 1987; Cid et al. 1991; Weltzin et al. 1997; Pacheco et al. 1999-2000). Their propensity for burrowing, foraging, and clipping vast quantities of vegetation makes them capable landscape architects, although it's unclear whether they have a net impact that promotes or impedes soil erosion. Furthermore, it's interesting to try multiplying their environmental impact across the continent by some fifty times in order to get a sense of the magnitude their impact was prior to European agricultural practices wiped most of them out. Today, it's estimated that the total prairie dog population is 2% or less of what it was prior to Euro-American agricultural settlement (Wiens 2008).

The study site is a typical semi-arid environment located in the Killdeer Mountains in western North Dakota, on the eastern edge of the badlands. The surface geology in the study
area is classified as part of the Sentinel Butte Formation from the Eocene-Paleocene epochs, and is comprised of “alternating beds of grayish brown to gray sandstone, siltstone, mudstone, claystone, and lignite” (Murphy 2004). The study site’s surface geology may also contain sediment from the Golden Valley Formation, which is broken up into two members, the Camels Butte Member and the Bear Den Member. The Camels Butte Member is made up of alternating beds of yellowish brown to brown micaceous sandstone, siltstone, mudstone, claystone, and lignite. The Bear Den Member has brightly colored kaolinitic claystone, mudstone, and sandstone typically overlain with either a thin silicious bed called silcrete, or lignite (Murphy 2004).

**Previous Research**

Ideal habitat for prairie dogs includes flat or gently sloping topography with short- or mixed- grasses and other low-lying flora typical of western prairies. They prefer a wide range of soil types that support burrowing systems, but most often burrow in silty loamy clay soil (Clippinger 1989). Their propensity for congregating in large colonies, sometimes called towns, along with a wide array of habits that impact their environment for better or worse, makes them very capable of altering the surrounding ecosystem (Clippinger 1989). Prairie dogs prefer areas with very low and sparse vegetation. Their combination of burrowing and clipping roots that penetrate the roofs of their burrows, and on the surface clipping most plants that grow above their line of sight or thicker than they can see through, serve as factors that enhance soil structure, water filtration, and plant growth (North American Conservation Plan 2005). However, constant clipping causes grasses to grow weak and less competitive among other plant species. Archer et al. (1987) found that grass cover decreased by 50% over just two years of prairie dog pressure in a mixed-prairie site in Wind Cave National Park, in South Dakota. Osborn and Allan (1949) found that prairie dogs would abandon or gradually be eliminated from a site if they and other herbivores could not keep the grass clipped down.
Prior to human settlement, they thrived in the presence of the American bison (*Bison bison*). Their distribution often expanded with the introduction of cattle and rangeland characteristic to the cattle’s presence.

The primary reason for removing prairie dogs in the past was due to the assumption that they were a viable competitor with cattle when it came to foraging for grasses. But Uresk (1985) found that when prairie dogs were poisoned out of overgrazed cattle rangeland, plant productivity did not improve. Furthermore, cattle foraging on rangeland shared with prairie dogs showed no noticeable weight loss when compared to cattle that had foraged on lands with no prairie dogs present (O'Meilia et al 1982). In fact, it appears that cattle and bison actually prefer grazing in and around prairie dog colonies (Knowles 1986; Coppock et al. 1983a), which, at least in the case of cattle, may further degrade the overgrazed condition of the rangeland. The black-tailed prairie dog’s habit of invading overgrazed rangeland tends to incriminate them, creating the concept that they are the cause of rangeland degradation, when in fact their presence is an indication that the rangeland has already deterred due to human and/or cattle presence (Weins 2008).

While it appears that their foraging isn’t a significant factor in increasing soil erosion as previously thought, burrowing does appear to ultimately increase soil erosion, although some aspects of burrowing work to reduce the rate. Koford (1958) discussed how burrowing activity increased the rate of soil weathering and mixed soils from lower layers with those at the surface, along with organic matter like “clipped roots, grass leaves, feces, urine, and insect remains”. The burrows also aerate the soil and increase the depth at which water can penetrate. He makes a key point by stating that “the many generations of prairie dogs living in the same locality deepen the soil and add to its productivity” (Koford 1958).

The same research quantified the average volumetric soil content of prairie dog mounds in northern Colorado as about 3 cubic feet. By using a rate of 25 mounds per acre
[0.405 hectare], he initially calculated “the weight of the soil in mounds to be over 3 tons (approximately 2721.5 kg)”. He calculated the volume of soil extracted from burrows of known lengths, used an assumed 5 inch hole diameter, “and a soil weight of 80 pounds per cubic foot” that yielded “an estimated volume of 4 tons of earth raised from the twenty-five surface holes per acre” (Koford 1958).

Another study carried out in Thorp (1949) found that “activities of [prairie dogs and American badgers] actually altered the original soil from silt loam to loam”. The average weight of mounds in his study area was calculated to be 3,770 lbs., with the largest mound measuring 24 feet in diameter and weighing 22,360 lbs. The total amount of soil estimated to have been excavated by prairie dogs and badgers was estimated to weigh 32.5 tons per acre (Thorp 1949).

A study done on banner-tailed kangaroo rats living among nutrient-rich sediments found that sediments were transported by wind and water after the kangaroo rats constructed their mounds. Researchers found this led to a localized depletion of carbon and nitrogen in the vicinity of the mound. However, in contrast to the rats' contributions to nutrient depletion within the soil, the same study found that seeds that were cached by kangaroo rats underground began to break down and create small pockets of concentrated nutrients that acted as hot spots for germinating seeds and other biological activity (Krogh et al. 2002).

Research done on American badgers (Taxidea taxus) found “concentrations of active C and total amounts of N, S, and C were 43, 32, 25, and 52% lower, respectively, in mound soils compared to inter-mound soils”. They found the C:N ratio of mound soils to be ~25:1, significantly larger than that of either pit or inter-mound soils, which were ~15:1. They also found strong positive relationships between the mass of litter trapped in the badger pits and the amount of active carbon in the soil immediately underneath the litter (Eldridge et al. 2009), which may also apply to abandoned prairie dog burrows, only on a smaller scale.
Concentrations of soluble cations were typically significantly lower in mound soils compared to inter-mound and pit soils, while concentrations of both soluble and exchangeable Na+ were greater in mounds, which is consistent with a correlation between an increase in Na+ levels and soil depth. Exchangeable Ca²⁺ concentrations were found to be greater in mound and pit soils compared to inter-mound soils, although the degree of differences varied depending on what species of plants were present. Exchangeable K+ declines from mound to intermound soils, although the degree of this also varies depending on the dominant plant species present. There were no relations of Mg²⁺ concentrations between differences in microsites, plant communities, or burning treatment (Eldridge 2009).

In two other studies done by Eldridge, it was found that badgers reduced levels of total, mineral, and mineralizable N in mound soils by digging up N-poor subsoil and dispersing it in a mound at the surface of pits. He goes on to state that this is consistent with lower N and C levels in the mounds of many fossorial and semi-fossorial mammals worldwide (Eldridge 2008; Eldridge 2000; Whitford 1999).

In a semi-arid region similar to the area in which this research was done, Eldridge categorized badger pits into three different age groups, depending on physical characteristics of the excavated soil mounds. Active mounds had loose, powdery soil and an average age of 2-3 weeks. Crusted mounds had formed a thin crust on the surface from the impact of raindrops, and recovering mounds had a cryptogamic crust, dominated by organic activity and/or colonized by vascular plants. Over a 6 year period, they found no mounds to maintain a crust for more than a year. The study concluded that given their effect on C:N ratios in the soil mounds they create, badgers could play an important role in the recovery of indigenous shrub-steppe vegetation by creating patches in soil and vegetation in areas affected by wildfires (Eldridge 2009).
Methods

The goal of this research was to quantitatively measure erosion rates within a prairie dog town and compare sediment accumulation amounts with a similar procedure done at a control site void of prairie dogs, but adjacent to the town. Criteria for selecting the control site adjacent to the prairie dog town included similar elevation, soil types, topography, and livestock impact, of course with careful monitoring done ahead of time to confirm that the prairie dogs did not cross over into the control site on their daily foraging trips. The idea was to compare two sites with minimal influences from cattle that resemble each other in every way, except one had generations upon generations of prairie dogs inhabiting it, and the other did not.

Sediment measurements were made by burying hand-built wooden boxes with dimensions approximately 34.25 cm long by 18.7 cm wide that served as alluvial sediment traps. They were constructed so that they would be deep enough that any runoff water would not be able to accumulate to the point of overflow. Prior to deploying sediment traps in the study area, it was assumed that the region's characteristically high temperatures and very dry conditions would quickly evaporate any water the traps collect, so that only alluvial sediments are left behind. Three were dispersed throughout an alluvial plume downhill of an active prairie dog hole located near the crest of a hill. Box 1 was laterally centered in the plume and placed 1.32 meters from the edge of the hole. Box 2 was placed 2.78 meters from the hole and staggered to the western side so that the box overlapped both the edge of Box 1 and the edge of the plume, specifically to catch any sediment carried around the western edge of Box 1. Box 3 was placed 4.51 meters from the hole and offset slightly to the eastern edge, to collect sediment downhill of Box 1 and alluvial sediment that was transported beyond the eastern extent of Box 1. Figure 1 indicates the locations of Boxes 1-3 with relation to the approximate boundary of the plume and the approximate downhill direction transported soil.
will follow.

![Figure 1](image)

**Figure 1**: A photo taken of the plume with Boxes 1-3 set in place. The orange dotted line indicates the approximate boundary of the plume. The arrow indicates the direction of downhill slope.

The section of hill slope in which we set the boxes dipped at 9°. The sediment traps were monitored for a period of 81 days throughout the summer, and accumulation amounts were collected and recorded on three different occasions.

**Results**

Boxes were monitored for a total of 81 days and visited three times. At each visit, the accumulated soil in each box was collected, bagged, and brought back to the lab to be dried and weighed. Boxes were implemented May 31\textsuperscript{st}, 2009 and were allowed to collect sediment for a total of 81 days. The first period lasted 14 days, until June 14\textsuperscript{th}. In that time, 3.64 cm of rain fell, causing Box 1 collected 498.6 grams of soil. Box 2 collected 97.9 grams, and Box 3 collected 57.8 grams. In the control site, Box 4 and 5 each collected 1.5 grams of soil.

The next period ran from June 14\textsuperscript{th} to July 27\textsuperscript{th}, a span of 43 days. In that period of time 11.26 cm of precipitation fell, which caused 14,174.9 grams of sediment to collect in Box 1. 3,453.5 grams of sediment collected in Box 2, and 8,514.0 grams collected in Box 3. Box 4
collected 28.2 grams of sediment collected in Box 4, and 9.0 grams collected in Box 5.

The final period ran from July 27th to September 20th, for a period of 24 days. A total of 6.87 cm of precipitation fell, which caused Box 1 to collect 948.7 grams of soil. Box 2 collected 96.6 grams and Box 3 collected 100.6 grams of soil. In the control site, Box 4 collected 4.8 grams of soil and Box 5 collected 4.0 grams.

Cumulatively, in 81 days 21.77 cm of precipitation fell. It caused Box 1 to collect a total of 15,622.2 grams of soil, Box 2 to collect 3,648.0 grams of soil, and Box 3 to collect 8,672.4 grams of soil. There is a stark contrast in the control site, where Box 4 caught a cumulative amount of 34.5 grams of sediment, while Box 5 collected 14.5 grams. It should be noted that the majority of sediment collected in Boxes 4 and 5 were dried grasses. Table 1 summarizes these results, and Figure 2 presents the periodic results of each of the boxes' accumulation totals in a graphic context. Figure 3 is a graph of periodic precipitation totals throughout the duration of the study.

<table>
<thead>
<tr>
<th>Date</th>
<th>Box 1</th>
<th>Box 2</th>
<th>Box 3</th>
<th>Box 4</th>
<th>Box 5</th>
<th>Precipitation</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>05/31/09-06/14/09</td>
<td>498.6 g</td>
<td>97.9 g</td>
<td>57.8 g</td>
<td>1.5 g</td>
<td>1.5 g</td>
<td>3.64 cm</td>
<td>14 days</td>
</tr>
<tr>
<td>06/14/09-07/27/09</td>
<td>14174.9 g</td>
<td>3453.5 g</td>
<td>8514.0 g</td>
<td>28.2 g</td>
<td>9.0 g</td>
<td>11.26 cm</td>
<td>43 days</td>
</tr>
<tr>
<td>07/27/09-09/20/09</td>
<td>948.7 g</td>
<td>96.6 g</td>
<td>100.6 g</td>
<td>4.8 g</td>
<td>4.0 g</td>
<td>6.87 cm</td>
<td>24 days</td>
</tr>
<tr>
<td>Total</td>
<td>15622.2 g</td>
<td>3648.0 g</td>
<td>8672.4 g</td>
<td>34.5 g</td>
<td>14.5 g</td>
<td>21.77 cm</td>
<td>81 days</td>
</tr>
</tbody>
</table>

Table 1: Accumulation amounts collected in each box from each period, along with cumulative regional precipitation levels and the duration of each period.
**Figure 2:** A graph representing the periodic sediment totals of each box along a logarithmic y-axis.

**Figure 3:** A graph representing the periodic precipitation totals throughout the duration of the study.
Discussion

Clippinger (1989) cites a wide range of burrow densities, from King (1955) documenting 143 burrows per hectare in South Dakota, to Clark et al. (1982) reporting 33 burrows per hectare in New Mexico. A rough calculation of the prairie dog town's surface area equates to 156,000 meters², which is the same as 15.6 hectares. Figure 4 is a satellite image taken from Google Earth with simple geometric polygons overlaying the image to indicate the approximate boundaries that were measured using Google Earth and used to calculate the surface area of the town.

By multiplying the surface area of the dog town with the high and low values offered by King 1955 and Clark et al. 1982, a wide range from 515 to 2,231 burrows exhibiting similar erosion patterns are distributed throughout the 156,000 square meters being studied. To extrapolate on that, multiplying the total amount of soil collected in the plume in the 81 day study, 2,7942.6 grams, by the high and low values, 515 and 2,231 burrows, gives a vague range of 14,390 to 62,340 kg of soil that moved in that defined period of time. Dividing by 81 means the erosion rate in the town's area of 156,000 square meters is 178 to 770 kg per day. An estimate of excavated soil caused by prairie dogs and American badgers from Koford (1958) is 32.5 tons per acre [0.405 hectare]. This is equivalent to about 72,798.4 kg, which falls above the range of 14,390 to 62,340 kg I estimated based on high and low values of burrow densities per acre. This could be attributed to the frequency of badger holes factored into the calculations of Koford (1958). Badger burrows are much larger and of a much less population density than prairie dog burrows, so it is possible that a sample size that contains badger holes may skew the calculation to fall above the predicted range, which never took badger holes into consideration.
Figure 4: Satellite image of the study area with the triangle and rectangle indicating the approximate boundaries of the prairie dog town. The circle within the rectangle indicates the location of Boxes 1-3. The circle outside the rectangle indicates the location of Boxes 4 and 5. Image courtesy of Google Earth.

By using the data from Table 1, we can also calculate the amount of soil transported per millimeter of precipitation that fell, reflected in Figure 5.

Figure 5: A graph representing the varying rates of transported sediment to precipitation across different periods and locations.
By looking individually at each box and the region that contributes to it, we know that at Box 1, from May 31st to June 14th, the soil-to-rain ratio was approximately 13.7 g/mm. From June 14th to July 27th, there was a ratio of approximately 125.9 g/mm. From July 27th to September 20th, the ratio had decreased to 3.95 g/mm. At Box 2, the ratio was 2.69 g/mm from May 31st to June 14th. It increased to 30.67 g/mm from June 14th to July 27th, and then reduced to 1.41 g/mm from July 27th to September 20th. At Box 3, the ratio was 1.59 g/mm from May 31st to June 14th, then increased to 75.61 g/mm from June 14th to July 27th, and then dropped to 1.46 g/mm from July 27th to September 20th. Box 4 had a ratio of 0.0142 g/mm from May 31st to June 14th. From June 14th to July 27th it increased to 0.250 g/mm, and then it decreased to 0.070 g/mm from July 27th to September 20th. At Box 5, the ratio from May 31st to June 14th was 0.0142 g/mm. From June 14th to July 27th it increased to 0.080 g/mm, and then decreased down to 0.058 g/mm from July 27th to September 20th. Observe Table 2 for a structured summary of these calculations.

<table>
<thead>
<tr>
<th></th>
<th>May 31st – June 14th</th>
<th>June 14th – July 27th</th>
<th>July 27th – September 20th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Box 1</td>
<td>13.7 g/mm</td>
<td>125.9 g/mm</td>
<td>3.95 g/mm</td>
</tr>
<tr>
<td>Box 2</td>
<td>2.69 g/mm</td>
<td>30.67 g/mm</td>
<td>1.41 g/mm</td>
</tr>
<tr>
<td>Box 3</td>
<td>1.59 g/mm</td>
<td>75.61 g/mm</td>
<td>1.46 g/mm</td>
</tr>
<tr>
<td>Box 4</td>
<td>0.0142 g/mm</td>
<td>0.250 g/mm</td>
<td>0.070 g/mm</td>
</tr>
<tr>
<td>Box 5</td>
<td>0.0142 g/mm</td>
<td>0.080 g/mm</td>
<td>0.058 g/mm</td>
</tr>
</tbody>
</table>

*Table 2:* A compilation of soil-to-precipitation ratios of each box over each of the three accumulation periods.

One should note that because the sediment collections from Boxes 4 and 5 were primarily dried plant debris likely transported by wind more than precipitation, the ratios of sediment-to-precipitation are less accurate than those of the boxes set in the prairie dog town,
but still demonstrate the stark differences between the two settings. The sharp contrast in results from Boxes 4 and 5 to Boxes 1-3 are likely due to much more dense vegetative cover, which drastically cuts down on the amount of loose topsoil that can be engulfed and transported by precipitation flowing overland. The differences in rates within the plume can be attributed either one or both of two possibilities. The first is simply that prairie dogs may be more active in and around that hole during the middle of the summer as opposed to the beginning or end. This may have something to do with being at a slightly higher elevation, or some other characteristic unique to the area surrounding that hole. The second possibility has to do with the amount of loose topsoil directly uphill from the boxes. As indicated by this and other figures and table, the most transported soil came from the area directly uphill from Box 1, nearest the vicinity of the hole. The reason why Box 3 yielded a higher soil-to-precipitation ratio could easily be explained by the fact that Box 3 is more laterally centered within the plume, and collects from a larger area of the plume than Box 2. Box 2, in contrast, rests near the perimeter where the plume is least defined.

It must be stressed, however, that these figures are all very dependent on the 9° slope we calculated for the plume in which we studied. Obviously, this isn’t the case for much of the prairie dog town, but it does provide some insight, however vague it might be, as to the sheer quantities of topsoil being moved within the prairie dog town, and more specifically the gentle hill on which the bulk of the study rests upon. A second consideration to take in is that it is unlikely that Boxes 1-3 collected all of the sediment moving within the plume. It is a safe assumption to say that the boxes did collect the vast majority of moving topsoil, but this is another reason of why the figures presented within the calculations should only be treated as approximations. The amount of topsoil collected in this study would more than likely be somewhat lower than the actual amount of topsoil moving within the plume.
Conclusions

As the results in Figure 2 show, erosion rates within the prairie dog town are about two orders of magnitude higher than those within the control site. Contrasting the research of Krogh et al. 2002, Eldridge et al. 2009, and others, all of which conducted their research in environments significantly different from that of this research, these results clearly indicate that erosion rates in this prairie dog town are much higher than in uninhabited natural prairie common to this region.

Future Research

After some discussion with Dr. Marinus Otte of North Dakota State University, an extension of this research would be to conduct a chemical analysis of mixed soil samples taken from the prairie dog town, control site, and gravel road overlooking the prairie dog town to the west to identify each area's unique chemical fingerprint. It's been suggested that there is a considerable likelihood of detecting and tracking any unique chemical traces to its source, or at least the layer in which it frequents. This research could even be geared toward a soil quality analysis that measures the impact of wind-blown sediments. Those sediments are carried by what is usually a western wind from any oil tankers that would have deposited it on the gravel road. Any heavy metal particles contained within that wind-blown sediment could be carried over to and included in the soil of the prairie dog town and surrounding areas. A seasonal stream runs through the prairie dog town, while a larger, constant stream runs near the eastern edge of the town. Depending on the quantities of any heavy metals that show up in the soil samples, this may even have consequences on isolated wetland ecosystems in the area.

A second possibility for future research would be to measure the rate at which a hill in which prairie dogs are burrowing shifts over time. We have some idea that excavated soil not only moves in a downhill vector, but also accumulates upward. An economical way to
measure this would be to pound a rebar stake or similar post used to mark the initial height of the surface, and annually record any vertical change the surface may make in relation to the initial mark on the stake. This could also be undertaken by using LiDAR to make a digital scan of the surface height and complexion, and correlate future scans with the original to map the location’s changes in geomorphology.
List of References


Zool. 67:1-123.


