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# Influence of cattle grazing practices on dung beetle (Coleoptera: Scarabaeoidea) communities in the Sandhill rangelands of Central Nebraska

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# INFLUENCE OF CATTLE GRAZING PRACTICES ON DUNG BEETLE (COLEOPTERA: SCARABAEOIDEA) COMMUNITIES IN THE SANDHILL RANGELANDS OF CENTRAL NEBRASKA

by

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INFLUENCE OF CATTLE GRAZING PRACTICES ON DUNG BEETLE (COLEOPTERA: SCARABAEOIDEA) COMMUNITIES IN THE SANDHILL RANGELANDS OF CENTRAL NEBRASKA

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Dung beetles (Coleoptera: Scarabaeoidea) have a significant role in regulating the ecosystem services they provide on rangelands. Colonization of dung piles by dung beetles can help facilitate the decomposition of dung, control dung-breeding pests, and cycle important nutrients into the soil to improve pasture quality. Cattle are grazed on pastures at various stocking densities depending on the type of grazing practice. The influence of grazing practices on dung beetle communities and services remains largely unknown.

Our first study investigated dung beetle activity across different cattle grazing practices to determine how grazing might influence dung beetle abundance and diversity. Dung beetle populations were monitored throughout the grazing season on pastures that were grazed under various practices: non-grazed/hay, continuous grazing, low-stocking rotational grazing, and high-stocking (mob) rotational grazing. Results from this study showed significantly higher dung beetle diversity on pastures exposed to rotational grazing practices compared to continuous grazing or no grazing. In some cases, dung beetle abundance and species richness were significantly greater on pastures that were grazed through high-stocking rotational grazing compared to low-stocking rotational or continuous grazing treatments. Based on these data,

rotational cattle grazing may favor the colonization of dung beetles on rangeland, regardless of stocking density.

Our second study investigated whether dung beetles exhibit preferences for dung from cattle exposed to different grazing practices. Dung from cattle in three separate grazing practices were used to test dung beetle preference: continuous grazing, low-stocking rotational grazing, and high-stocking rotational grazing. Dung beetle abundance was measured as well as the nutrient and physical properties of each dung type. Results of the study revealed no significant differences in dung beetle abundance between dung collected from each grazing practice. Nutritional content, pH, moisture, and dry matter levels also were not significantly different. However, the results indicated varying dung beetle species composition on dung from the continuous versus rotational grazing practices. Overall, cattle grazing practices may not affect dung composition or its influence on dung beetle preferences.

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# CHAPTER 1

LITERATURE REVIEW

## Introduction

Dung beetles are coprophagous insects in the order Coleoptera and the families Scarabaeidae and Geotrupidae (Halffter and Matthews 1966). The two Coleopteran families include the subfamilies Scarabaeinae (Scarabaeidae), Aphodiinae (Scarabaeidae), and Geotrupinae (Geotrupidae) that are referred to as true dung beetles (Hanski and Cambefort 1991; Bertone 2004). Dung beetles have a critical role in the decomposition process of animal waste and the cycling of soil nutrients in a wide variety of ecosystems.

Dung beetles make up an essential portion of dung feeding organisms. In many ecosystems, they are the most abundant insects present on dung (Hanski and Cambefort 1991). The ecological linkages that dung beetles developed with mammals over the last ~ 40 million years have resulted in their life cycles relying entirely on animal dung (Hanski and Cambefort 1991). Recent discoveries indicate that dung beetles may have evolved through coprophagy of dinosaur dung prior to the occurrence of mammals in the fossil records (Chin and Gill 1996). The long evolutionary history of dung beetles has allowed them to thrive in a broad range of different habitats (Hanski and Cambefort 1991). Dung beetles have been found on every continent in the world except Antarctica (Hanski and Cambefort 1991).

Dung beetles act as one of the most important organisms on earth by providing key ecosystem services through the consumption of animal dung (Bornemissza 1960). The liquid components of dung are fed upon by adult beetles, while the fibrous materials are utilized to brood the next generation (Halffter and Matthews 1966). By breaking down dung and burying it underground, dung beetles work to cycle soil nutrients, contribute to bioturbation, and mitigate greenhouse gases by removing dung from the surface (Bang et al. 2005; Yamada et al. 2007; Nichols 2008; Penttilä et al. 2013).

The vital role that dung beetles have in the function of many ecosystems can be visualized when there is an absence of dung beetles. An example of this type of scenario is when cattle were first brought to Australia (Bornemissza 1976). The local population of dung beetles were adapted to feeding on dung from the native marsupial fauna and did not have any adaptations to the dung of bovine animals (Bornemissza 1960; Bornemissza 1976). Without dung beetles feeding on and breaking down the cattle dung, dung began to build up in areas where cattle were present (Bornemissza 1976). The excess of dung also contributed to large emergences of dung-breeding pests, namely flies, which caused further issues in the region (Bornemissza 1976). To combat the problem of having cattle dung not decomposing, exotic dung beetles were brought to Australia (Bornemissza 1976). *Onthophagus gazela* was the chosen species to be introduced and help remedy the situation (Bornemissza 1976). The project was called the Australian Dung Beetle Project; led by Dr. George Bornemissza from 1965 to 1975 (Bornemissza 1976). The example in Australia provides a prime illustration that appropriate levels of dung beetle activity are critical for the preservation of any grazed rangeland ecosystem.

Dung beetles make up a huge portion of the scarabs in the world. There are approximately 35,000 species in the superfamily Scarabaeoidea which contains over 6,000 known species of dung beetles (Simmons and Ridsdill-Smith 2011). There are 10 families containing 1,500 species of scarabs spread throughout North America (Ratcliffe and Paulsen 2008). Dung beetles were introduced to the United States, although not to the extent of the Australian project. The beetles that have been introduced include *Onthophagus gazela* in 1972 and *Onthophagus taurus* a few years later (Blume and Aga 1978; Hoebeke and Beucke 1997). Other species have been introduced to the United States, although not having as large of an impact as the two previously mentioned species. In Nebraska, there are currently around 300 identified species from 7 different families (Ratcliffe and Paulsen 2008).

With currently over 6 million cattle being fed in Nebraska, dung beetle populations have a steady source of food and habitat (NDA 2016). Nebraska has a diverse landscape throughout the state, providing a broad range of habitat for dung beetles (Ratcliffe and Paulsen 2008). Dung beetles can be found across Nebraska from the far eastern edges all the way to the western panhandle (Ratcliffe and Paulsen 2008). The state is split into glaciated and unglaciated sections with habitats that include short and tallgrass prairie, Sand Hills prairie, deciduous forest, and Ponderosa pine forests (Ratcliffe and Paulsen 2008). Across the varying habitats, dung beetles work to breakdown dung deposited by vertebrate animals, mostly cattle, and cycle it into the soil (Ratcliffe and Paulsen 2008). In doing so, dung beetles have been found to improve soil quality and forage production (Halffter and Matthews 1966; Hutton and Giller 2003; Walters 2008; O'Hae 2010). The abilities of dung beetles to improve pasture production with their presence has caught the interest of many farmers and ranchers in Nebraska.

Grazing practices being implemented on rangeland can have an effect on forage production as well as dung beetle activity. Common grazing practices like continuous and rotational grazing can alter rangeland ecosystems and change the grassland community (Holechek et al. 2011). Certain grazing practices have been found to favor the growth and quality of forages over that of others (Hickman et al. 2004). However, little has been studied about the impact that grazing practices have on dung beetle fauna in the ecosystem (Lee and Wall 2006; Yamada et al. 2007).

**Dung Beetle Biology**

Dung beetles have evolved to adapt to many different habitats across the world. Species with various niche preferences can thrive in habitats primarily depending on their temperature and moisture tolerances (Hanski and Cambefort 1991). These niche preferences drive the variation in dung beetle assemblages across latitudinal gradients (Halffter and Matthews 1966). Most dung beetles will exhibit some form of seasonal activity, especially those present in more temperate climates (Hanski and Cambefort 1991). In such areas, dung beetles typically overwinter as adults by burrowing deep tunnels underground without burying dung (Kirk 1983). Adults will remain at the ends of the burrows until the following spring when they emerge and mate to produce the next generation of dung beetles (Kirk 1983). However, some species in the genus *Geotrupes* have been found to oviposit in the autumn months and will overwinter as larvae and pupae, as well as adults (Kirk 1983).

Along with the surrounding environment, dung beetles can also have specific preferences to types of animal dung (Hanski and Cambefort 1991; Estrada et al. 1993). The beetles are attracted to different dung types based on the condition and odor (Doube 1987; Dormont et al. 2004; Whipple and Hoback 2012). Previous studies have found that most dung beetles prefer dung from omnivorous animals compared to that of carnivores or herbivores (Scholtz et al. 2009; Whipple and Hoback 2012). Even though there is much variation, dung beetle preferences often overlap and allow for multiple species to coexist and compete across habitats and dung types (Horgan 2005; Scholtz et al. 2009).

Dung beetles are able to use animal dung through various morphological adaptations. Many dung beetles have specialized mouthparts that are designed for consuming dung (Halffter and Matthews 1966). Adults primarily feed on the liquid constituents while the fibrous materials are used for nesting (Halffter and Matthews 1966; Aschenborn et al. 1989). Dung beetles do this through the use of modified mandibles that are equipped with delicate fringes used for filtering out the liquid constituents (Halffter and Matthews 1966; Holter et al. 2002). Furthermore, the mandibles of most dung beetles are modified for grinding the fine particles in the liquids (Halffter and Matthews 1966; Holter et al. 2002). To find food, dung beetles rely on olfactory and tactile stimuli to seek out fresh dung (Halffter and Matthews 1966; Hanski and Cambefort 1991). Most dung beetles search for food by walking or by flight, and some species will search by opening their antennae to detect odors in the air for directional cues (Halffter and Matthews 1966).

Dung beetles are typically categorized based on their nesting behavior with three major guilds consistently appearing throughout the literature. The three guilds include endocoprids, paracoprids, and telecoprids (Hanski and Cambefort 1991; Simmons and Ridsdill-Smith 2011). Endocoprids nest within dung pats, paracoprids nest in burrows in the soil underneath dung pats, and telecoprids nest in a separate ball of dung, called a brood ball, that is formed from the original dung pat and buried underground some distance away (Hanski and Cambefort 1991). The names of these three groups have been further simplified to being known as dwellers (endocoprids), tunnelers (paracoprids), and rollers (telecoprids) (Hanski and Cambefort 1991; Simmons and Ridsdill-Smith 2011). Some dung beetle species are also recognized as kleptoparasites, which nest in dung that has already been buried by another dung beetle (Doube 1990). These beetles are not considered to be "true dung beetles" and will therefore not be included in this manuscript (Hanski and Cambefort 1991). Doube (1990) has described extensively how different subgroups have also been recognized within each of the listed groups on the basis of larval provisioning, nest construction, and breeding activity, but mostly how the beetles use and disrupt dung. The classification of subgroups has been described in multiple ways and continues to be a debated topic when considering higher dung beetle classification (Hanski and Cambefort 1991; Ratcliffe and Paulsen 2008; Simmons and Ridsdill-Smith 2011).

The endocoprids, commonly referred to as “dwellers,” are a type of dung beetle that burrow into dung pats to eat and lay eggs. Most of the dweller species are in the subfamily Aphodiinae and genus *Aphodius* (Hanski and Cambefort 1991; Ratcliffe and Paulsen 2008). These dung beetles are all relatively small in size (length < 10 mm) and are most commonly found in northern temperate regions; however, some exist in subtropical and tropical regions as well (Hanski and Cambefort 1991). Adults form egg-filled brood balls within the dung pats where larvae will hatch out and complete their development (Simmons and Ridsdill-Smith 2011). Dweller species spend their entire juvenile life, from egg to pupae, inside dung pats (Hanski and Cambefort 1991). They prefer large droppings, especially bovine dung, where they interact with a large range of other insects (Hanski and Cambefort 1991; Ratcliffe and Paulsen 2008). Dwellers often compete for food and space in the dung pat as both adults and larvae (Hanski and Cambefort 1991; Ratcliffe and Paulsen 2008).

Paracoprids, also called “tunnelers,” burrow underneath dung pats and nest in chambers filled with dung. Tunnelers occur primarily in the subfamilies Scarabaeinae and Geotrupinae (Hanski and Cambefort 1991; Ratcliffe and Paulsen 2008). Tunnelers can range in length from around 13 mm to < 10 mm (Ratcliffe and Paulsen 2008). Hanski and Cambefort (1991) found that most of the larger tunneler species tend to be nocturnal while the smaller species are typically diurnal. Tunnelers have a broad scope of habitats that range anywhere from temperate to tropical regions (Hanski and Cambefort 1991; Simmons and Ridsdill-Smith 2011). Both sexes will arrive at a dung pat where mating happens quickly above ground followed by the mating pairs digging tunnels underneath the pat (Hanski and Cambefort 1991; Simmons and Ridsdill-Smith 2011). Tunnelers will form brood chambers underground, and then fill these chambers with small dung balls containing individual eggs (Nichols et al. 2008; Simmons and Ridsdill-Smith 2011). There can be much variation within the structure of nesting burrows between different tunneler species (Hanski and Cambefort 1991). Burrows range from very primitive, simple tunnels with only one brood chamber to a complex series of tunnels consisting of multiple brood chambers (Hanski and Cambefort 1991).

The dung beetle guild known as the telecoprids or "rollers" form balls of dung from dung pats and roll them away to bury underground. Rollers consist of members from subfamily Scarabaeinae (Hanski and Cambefort 1991; Ratcliffe and Paulsen 2008). These beetles make up the largest of the dung beetles and are usually > 10 mm in length with a number of species reaching over 20 mm in more subtropical and tropical regions of the world (Hanski and Cambefort 1991; Ratcliffe and Paulsen 2008). Rollers are similar to tunnelers in that they bury dung beneath the soil; however, rollers move dung some distance away instead of digging directly under dung pats (Simmons and Ridsdill-Smith 2011). Brood balls are often rolled by both members of a mating pair with the male mainly acting as protector to defend the ball from theft by other beetles (Hanski and Cambefort 1991). Combat over brood balls occurs frequently among rollers, usually between the same species but sometimes between different species (Hanski and Cambefort 1991). Rollers will transport their balls of dung up to 15 m away from the original dung pat before forming a nest with it underground (Simmons and Ridsdill-Smith 2011). Mating pairs usually cooperate until copulation occurs in the burrow and the female lays her eggs in the nest (Hanski and Cambefort 1991).

Dung beetles can undergo fierce competition for food and breeding space around dung pats. Nearly all dung beetle species exhibit some type of maternal care which is likely important to guard against other dung beetles (Simmons and Ridsdill-Smith 2011). Depending on the guild, body size, and speed of the dung beetle, some species are more competitive than others (Peck and Forsyth 1982; Hanski and Cambefort 1991; Simmons and Ridsdill-Smith 2011). Dwellers are usually the smallest dung beetles and exhibit the most vulnerable nesting behaviors (Hanski and Cambefort 1991). Due to their size and presence inside dung pats, dweller species can easily be disturbed by other beetles (Doube 1990; Hanski and Cambefort 1991). The activity of certain dung beetle species can also be limited by the number of other dung beetles competing for the same resources (Horgan 2005; Doube 1990). Several species of *Onthophagus* have been found to only be able to use about half of a dung pat in optimal conditions (Doube 1990). When forced to compete with higher numbers of other beetles, this efficiency can be depleted to much lower levels (Doube 1990). Other dung beetles are able to use nearly 100% of a dung pat, enabling them to be highly competitive compared to other beetles (Peck and Forsyth 1982; Doube 1990). Differences in diurnal and nocturnal activity between dung beetle species can also lead to diffuse competition between beetles (Peck and Forsyth 1982). However, most dung beetles are diurnal which causes more intense diffuse competition for the nocturnal species (Doube 1990).

## Nebraska Dung Beetle Taxonomy

Dung beetle taxonomy has been studied extensively and is now relatively well understood. However, the organization of certain subfamilies, Aphodiinae in particular, remain topics of debate (Ratcliffe and Paulsen 2008). The following list is a current taxonomic classification of the Scarabaeiodea that are associated with dung in Nebraska. It consists of the families Scarabaeidae and Geotrupidae with only the major dung beetle tribes and genera being included. This list has been constructed based on the works of Hanski and Cambefort (1991), Bertone (2004), and Ratcliffe and Paulsen (2008).

Family: Scarabaeidae

- Subfamily: Aphodiinae
  - Tribe – Aphodiini
    - Genus – *Aphodius*
    - Genus – *Diapterna*
  - Tribe – Eupariini
    - Genus – *Ataenius*
- Subfamily: Dynastinae [1]
- Subfamily: Scarabaeinae
  - Tribe – Coprini
    - Genus – *Copris*
  - Tribe – Canthonini
    - Genus – *Canthon*
    - Genus – *Melanocanthon*
  - Tribe – Onthophagini
    - Genus – *Onthophagus*
  - Tribe – Phanaeini
    - Genus – *Phanaeus*

Family: Geotrupidae

- Subfamily: Bolboceratinae [1]

Subfamily: Geotrupinae

Tribe – Geotrupini

Genus – *Geotrupes*

[1] Although not considered true dung beetles, members of the subfamilies Dynastinae and Bolboceratinae have been included for the purposes of this study due to their attraction to dung and likely role in dung decomposition on Nebraska rangelands.

## Ecosystem Services Attributed to Dung Beetle Activity

Dung beetles have an important role in regulating grassland ecosystems. In pastures, dung beetles help regulate the ecosystem as decomposers; removing dung from the surface and burying it underground to feed their offspring (Nichols et al. 2008). Dispersing and incorporating dung into the soil provides important benefits to agricultural systems through ecosystem functions such as nutrient cycling, pest suppression, and trophic regulation (Nichols et al. 2008).

Dung decomposition is a critical service that dung beetles provide in rangeland ecosystems. Dung beetles bury dung underground which helps mitigate potentially harmful greenhouse gas emissions and releases important nutrients like nitrogen, phosphorous, potassium, and magnesium into the soil (Yamada et al. 2007; Penttilä et al. 2013). These nutrient pulses in the soil then become available to pasture flora to improve soil fertility and forage production (Bang et al. 2005; Yamada et al. 2007). Some studies have found that nutrient mobilization and the bioturbation caused by dung beetle activity may outperform the plant growth benefits from that of chemical fertilizer applications (Fincher 1981; Miranda et al. 2000).

Another ecosystem service that dung beetles contribute to is the reduction of livestock pests in the pasture. These pests include parasites such as flies, nematodes, and protozoa that infest or prey on cattle and can cause economic damage (Byford et al. 1992). By breaking down dung pats, dung beetles provide biological control of pests by disrupting the pest life cycle

(Fincher 1973). Some research has indicated that increased dung beetle abundance in cattle pastures can result in decreased pest emergence from manure (Bryan 1973; Fincher 1973; Fincher 1975). Fincher (1975) found that cattle grazed on pastures without dung beetles had nine times the number of parasites compared to cattle in pastures where dung beetle populations were high. By reducing the number of pests in pastures, dung beetles can help to minimize the management costs associated with livestock pests (Fincher 1981; Losey and Vaughan 2006).

Dung beetles play an integral part in the sustainability of livestock production in the United States and around the world. According to Losey and Vaughan (2006), the ecosystem services provided by dung beetles have an economic value of over $380 million annually in the United States. This value mostly comes from the reduction in costs of fertilizer application, pest management, and production loss due to poor forage quality and pest outbreaks (Fincher 1981). With pasture systems making up nearly 80% of agricultural land across the world, the presence and services provided by dung beetles form a huge importance to ecosystem health on a global scale (Steinfield et al. 2006).

## Cattle Grazing Practices in Nebraska

Grazing systems are specified plans that were established to manage livestock feeding on rangeland and other grassland ecosystems (Holechek et al. 2011; Schacht et al. 2011). Ranchers wanted to have control over when and where livestock were grazed in order to optimize their land use and grazing operations (Holechek et al. 2011). The concept of specialized grazing systems was first developed in the United States during the early 1900s and became popular by the 1950s (Holechek et al. 2011). Grazing systems have become important tools for ranchers across Nebraska and the Great Plains to achieve their rangeland management objectives (Schacht et al. 2011).

There are different types of grazing systems utilized by ranchers based on the kind of land management that is desired. As a whole, these grazing systems can be broadly categorized into two main practices, continuous grazing and rotational grazing (Heath et al. 1985). Both are commonly used throughout Nebraska rangeland (Heath et al. 1985; Schacht et al. 2011). In the case of continuous grazing, cattle are left to graze on a pasture for an extended period of time with little or no rest to the plants (Holechek et al. 2011). Rotational grazing on the other had involves dividing a pasture into multiple paddocks and rotating cattle through each one individually over the course of the grazing season (Holechek et al. 2011). Rotational grazing can be further divided up into categories based on the stocking densities of livestock on a specific area of ground (Heath et al. 1985; Holechek et al. 2011). Ranchers may choose to graze cattle less intensively by keeping them in low to medium stocking densities, or they can graze them in a high or ultra-high densities to increase the grazing intensity on the land (Holechek et al. 2011). Cattle are grazed on pasture at different stocking densities depending on the type of grazing practice being implemented (Holechek et al. 2011).

Continuous grazing, also referred to as traditional grazing, involves letting cattle graze freely in an undivided pasture all season long. It is critical that the stocking density of continuously grazed pastures is low because ranchers must allow there to be enough forage available to carry the animals through the entire season (Holechek et al. 2011). At such low stocking densities, cattle have maximum dietary selectivity and will therefore preferentially feed on forbs and reduce the grazing pressure on grasses (Holechek et al. 2011). In doing so, cattle will typically graze in a less efficient manner and leave behind large amounts of less-desired forage in the pasture (Holechek et al. 2011; Schacht et al. 2011). This preferential feeding can result in widespread patchiness throughout the pasture (Knapp et al. 1999).

Rotational grazing is the other common grazing practice that ranchers often use. This type of grazing splits a pasture into multiple, smaller paddocks which are then grazed individually (Holechek et al. 2011; Schacht et al. 2011). In this system, cattle are moved from one paddock to the next as the available forage becomes depleted (Holechek et al. 2011). Rotational grazing was originally invented to help enhance the grazing efficiency of cattle on rangeland (Heady 1961). It can allow for more uniform forage utilization by reducing the selective grazing habits of cattle (Heady 1961; Holechek et al. 2011). For many ranchers, rotational grazing is considered to be the superior strategy for managing rangeland, however this has been a consistently debated topic (Walton et al. 1981; Briske et al. 2008; Derner et al. 2008). Since its introduction, multiple variations of rotational grazing have been developed and classified based on the size of the grazing paddocks and the animal stocking density (Holechek et al. 2011; Schacht et al. 2011).

One of the more intense, higher density forms of rotational grazing is commonly referred to as high-stocking rotational grazing or “mob” grazing (Thomas 2012). This high-intensity, short-duration grazing practice involves grazing large densities of cattle (~ 500 AU $ha^{-1}$) in small paddocks for short time durations (Gompert 2009; Thomas 2012). High-stocking rotational grazing is more labor intensive than other forms of rotational grazing by requiring more frequent movements of the cattle (Gompert 2009). Numerous studies have found that high-stocking rotational grazing may reduce selective grazing, increase harvest efficiency, and provide more uniform dung and urine deposition (Aarons et al. 2009; Moir et al. 2010; Thomas 2012). The extent of the benefits attributed to this grazing practice remains controversial as described by Holechek et al. (2000). Nevertheless, grazing cattle via high-stocking rotational grazing continues to be a practice of growing popularity among ranchers (Thomas 2012).

## Dung Beetles and Livestock Grazing

Dung beetles and livestock are essential for sustaining agricultural grassland ecosystems. Dung beetles are able to provide the ecosystem services that are necessary to support animal grazing and large-scale livestock production (Nichols et al. 2008). In turn, livestock grazing provides the fertilizer and forage maintenance needed to keep rangelands in optimal condition (Aarons et al. 2009). This relationship between dung beetles, livestock, and rangeland health can be influenced through dung utilization and the type grazing practices that are implemented.

Timely dung decomposition is necessary in cattle-grazed rangeland ecosystems. It has been found that if dung pats are not degraded relatively quickly, their presence can deter cattle grazing for up to two years (Dohi et al. 1991; Walters 2008). The colonization of dung beetles works to remedy this situation by breaking down dung pats through their regular activity (Hanski and Cambefort 1991; Simmons and Ridsdill-Smith 2011). The faster decomposition rates can help to mitigate the amount of greenhouse gasses that are emitted from dung pats on the soil surface (Bang et al. 2005; Yamada et al. 2007; Penttilä et al. 2013; Slade et al. 2016). By burying the dung underground, dung beetles also act as important contributors to overall soil fertility by cycling nutrients to create healthier rangelands (Mittal 1993; Estrada et al. 1998; Walters 2008).

Livestock management practices can have an effect on the plant communities that are being grazed upon. Different grazing practices, depending mostly on animal stocking densities, can have varying effects on rangeland (Heath et al. 1985; Holechek et al. 2011). It has been seen that at higher stocking rates, rotational cattle grazing may have the ability to improve plant diversity and overall rangeland health (Hickman et al. 2004; Barnes and Howell 2013). The high-intensity grazing can also be useful for weed control by allowing more even utilization of forage (Frost and Launchbaugh 2003). Grazing cattle in such a way may be able to improve pasture productivity and the overall profitability of the beef industry (Thomas 2012; Herrero and Thornton 2013).

Along with improving the rangeland itself, different grazing practices may also influence dung beetle populations within the system. Several studies have already proven that grazing activities can have a positive impact on the abundance and diversity of dung beetles (Hutton and Giller 2003; Verdú et al. 2007; Numa et al. 2010). However, very little research has been done on how different grazing practices might affect dung beetles (Lee and Wall 2006; Yamada et al. 2007). Preliminary data from a study by Whipple (2011) revealed that rotational cattle grazing may favor dung beetle colonization. It was found that rotationally grazed pastures yielded over six times as many dung beetles and twice as many dung beetle species compared to continuously grazed pastures. The difference in abundance and diversity between the two grazing practices could be from several management factors, but stocking density and a higher concentration of dung pats may have had the strongest influence (Richards and Wolton 1976; Whipple 2011).

**Research Objectives**

The impacts that cattle grazing practices have on dung beetle assemblages in Nebraska rangeland has not been extensively studied. There is increasing concern over maintaining adequate levels dung beetle activity as it is a critical part of sustaining healthy rangeland ecosystems (Hutton and Giller 2003; O'Hae 2010; Beynon et al. 2012). It has become important to researchers as well as producers throughout Nebraska to evaluate the abundance and diversity of dung beetles in cattle-grazed systems. The need for knowledge on this topic sets up the objectives of this research.

- To quantify the overall abundance of dung beetles on rangeland across various cattle grazing practices (Chapter 2)

- To evaluate the levels of species diversity of dung beetles on rangeland across various cattle grazing practices (Chapter 2)
- To evaluate whether or not dung beetles exhibit preferences for dung from cattle grazed in one grazing practice over that of another (Chapter 3)

# CHAPTER 2

## COMPARISON OF ABUNDANCE AND SPECIES DIVERSITY OF DUNG BEETLES (COLEOPTERA: SCARABAEOIDEA) BETWEEN CATTLE GRAZING PRACTICES IN CENTRAL NEBRASKA

### Introduction

Dung beetles have an important role in the function of many ecosystems. Their activities involve the removal of animal dung from the soil surface by breaking it down and burying it underground (Hanski and Cambefort 1991; Simmons and Ridsdill-Smith 2011). Dung beetles do this through consuming dung and using it for nesting purposes to brood the next generation of coprophagous beetles (Halffter and Matthews 1966). By removing dung from the surface, dung beetles perform key ecosystem services; nutrient cycling, greenhouse gas mitigation, parasite suppression, and overall trophic regulation (Bang et al. 2005; Yamada et al. 2007; Nichols et al. 2008; Penttilä et al. 2013).

Dung beetle activity is recognized as being highly important for ranching practices by maintaining healthy cattle-grazed rangeland ecosystems (Aarons et al. 2009). Cattle can produce an average of ~ 10 dung pats per day, with each pat covering an average of ~ 0.08 $m^2$ of surface area (Bornemissza 1960, Fincher 1981). Therefore, an individual cow can foul almost 1 $m^2$ of pasture each day (Fincher 1981). The effects of cattle defecation are then amplified, as cattle are typically grazed in large herds (Fincher 1981). With such an abundant source of dung, dung beetles act as important decomposers while also reducing dung-breeding pests and recycling nutrients into the soil (Nichols et al. 2008).

Nitrogen from dung is a key source of fertilizer on rangeland; however, close to 80% of nitrogen is usually lost as ammonia through volatilization (Gillard 1967). In some cases, dung beetle activity can reduce these nitrogen losses to nearly 5% (Gillard 1967). Along with boosting pasture fertility and forage production, dung beetle activity can also act as biological pest control (Estrada et al. 1998; Walters 2008). Dung beetles provide biological control services by disrupting the life cycles of many dung-breeding pests, and, thereby, decreasing their emergence rates on the pasture (Bryan 1973; Fincher 1973; Fincher 1975). The services provided by dung beetles have been estimated to have an economic value of over $380 million each year in the United States (Losey and Vaughan 2006).

Nebraska has over 9 million hectares of rangeland and pasture, most of which is used for grazing cattle (NDA 2016). Cattle are managed on the rangeland in numerous ways with two of the most common practices being continuous and rotational grazing (Heath et al. 1985). Continuous grazing involves cattle that are grazed in a single, open pasture for the duration of the grazing season (Holechek et al. 2011). This type of grazing requires low cattle stocking rates to ensure that there is enough forage to last the entire grazing season (Holechek et al. 2011). The other common type of cattle grazing is rotational grazing. This grazing practice involves splitting pastures into multiple paddocks with cattle being rotated through each paddock as available forage becomes depleted (Holechek et al. 2011). In rotational grazing, cattle may be stocked at higher densities than that of continuous grazing (Holechek et al. 2011). One variation of rotational grazing involves a more labor-intensive approach that is usually referred to as as high-stocking rotational grazing or “mob” grazing (Thomas 2012). High-stocking rotational grazing involves the rotation of high densities of cattle (~ 500 AU $ha^{-1}$) through small paddocks for short time durations of one day or less (Gompert 2009; Thomas 2012). The goal behind high-stocking rotational grazing is to improve pasture productivity by increasing cattle grazing efficiency and allowing for more uniform dung and urine deposition across the pasture (Aarons et al. 2009; Moir et al. 2010; Thomas 2012).

Several studies have found that consistent cattle grazing can positively influence dung beetle populations (Hutton and Giller 2003; Verdú et al. 2007; Numa et al. 2010). However, the impact that specific grazing practices have on dung beetle activity remains largely unknown (Lee and Wall 2006; Yamada et al. 2007). In cattle-grazed pastures, Whipple (2011) indicated that rotational grazing produces over six times the number of dung beetles and twice the number of dung beetle species relative to continuous grazing (Whipple 2011). Although several factors could influence dung beetle abundance between grazing practices, higher stocking density and increased dung pat concentration could be the most influential (Whipple 2011). With dung beetle populations declining in recent years due to habitat fragmentation and elevated pest management, ranchers are continually looking for ways to conserve dung beetle populations in their pastures (Hutton and Giller 2003; Slade et al. 2016). Intensifying grazing practices that promote dung beetle activity could be beneficial for ranchers by improving the ecosystem services they provide on rangeland.

The objective of this study was to quantify dung beetle activity between cattle grazing practices on rangeland to determine the influence of cattle stocking density on dung beetle populations. It is hypothesized that cattle grazing practices with higher stocking density will favor (1) dung beetle abundance as well as (2) dung beetle species diversity.

## Materials and Methods

**Study site description.** This study was conducted during the 2014 and 2015 grazing seasons on rangelands in the Sandhills Ecoregion of Nebraska (Ahlbrandt and Fryberger 1980).

This ecoregion is composed of grass-covered sand dunes and sub-irrigated meadows with numerous lakes and wetlands spread throughout (Ahlbrandt and Fryberger 1980; McNab and Avers 1994). The Sandhill rangelands are primarily made up of mixed-grass prairie with combinations of plant species that are tolerant to sandy conditions (McNab and Avers 1994). Reedgrass and bluestem varieties are among the most dominant grasses found throughout the region (McNab and Avers 1994). The growing season lasts ~ 150 days with annual precipitation ranging from 430 – 580 mm and temperature averages of ~ 10 °C (McNab and Avers 1994).

Research was conducted on three individual ranches in the northeastern Sandhills. The ranches were the University of Nebraska-Lincoln's Barta Brothers Ranch, and two private, commercial ranches – the Rick Marshall ranch (Rusty Star Ranch) and the Randall Shinn ranch. The Barta Brothers Ranch was located in Rock County approximately 11 km west of Rose, Nebraska (42°13'N; 99°38'W). The Rick Marshall ranch was located in Brown County approximately 32 km south of Johnstown, Nebraska (42°19'N; 100°4'W). The Randall Shinn ranch was located in Rock County approximately 14 km south of Newport, Nebraska (42°29' N; 99°20'W). Research was conducted in the lowland, sub-irrigated meadow pastures at all three ranch locations. Samples were also taken in the sandy upland pasture at the Rick Marshall ranch.

**Experimental design and procedures.** The study used a repeated measures design with pitfall traps to collect dung beetle samples. The pitfall traps were placed in randomized transects throughout each study pasture. Within the transects, traps were spaced ~ 50 m apart from each other to ensure that no interference occurred (Larsen and Forsyth 2005). Pitfall traps were designed similar to Ratcliffe (2013), but using 500 ml Nalgene jars and steel cover plates (Figures 2.1 and 2.2). Each trap was baited with a 20-ml vial containing approximately 10-20 ml of homogenized primate dung from chimpanzees fed on a standard diet. Chimpanzee dung was used as bait on the basis that dung beetles exhibit higher attraction to primate dung compared to that of other animals (Whipple and Hoback 2012). For a killing agent, Nalgene jars were filled with approximately 50-100 ml of a 50% Ethylene glycol/water solution. Following similar methods to Whipple and Hoback (2012), the traps were baited for 7-day intervals within 14-day periods. This allowed the traps to be temporarily sealed up in case of heavy rain or a flooding event. Traps were collected at the end of each 14-day period and bait vials were replaced with fresh dung for the following period.

Pitfall traps were used to monitor dung beetle activity on pastures under the influence of each grazing treatment. In 2014 and 2015, research began in early June when cattle were placed onto pasture and continued until cattle were removed in late August/September. Following collection, samples were taken to the laboratory where dung beetles were counted and identified to species according to Ratcliffe and Paulsen (2008).

At Barta Brothers Ranch (BBR), traps were set up throughout the cattle-grazed meadow in each of five grazing treatments. The treatments had two replications that were grazed by two separate groups of cattle. The grazing treatments were continuous, low-stocking rotational which consisted of once-over and twice-over rotational treatments, high-stocking rotational, and no graze/hay as the control (Table 2.1). In the continuous treatment, cattle were grazed at low stocking densities (< 1 AU $ha^{-1}$) and were kept in a single open pasture for the duration of the grazing season. For the once-over rotational treatment, cattle were grazed at low stocking densities (~ 20 AU $ha^{-1}$) and were moved to a new paddock every 3-4 weeks. These cattle were rotated through their pasture once each season. In the twice-over rotational treatment, cattle were also grazed at low stocking densities (~ 20 AU $ha^{-1}$), but were moved to a new paddock every 1-2 weeks. These cattle were rotated through their pasture twice each season. For the high-stocking rotational treatment, cattle were grazed at ultra-high stocking densities (~ 500 AU $ha^{-1}$) and were moved to a new paddock two times per day. These cattle were rotated through their pasture once each season. Lastly, the no graze/hay treatment had no cattle present throughout the grazing season. There was a total of 60 traps at BBR with 30 traps in each of the two pasture replicates.

At the Rick Marshall ranch location, traps were set up in transects throughout meadow and upland pastures. In the meadow site, there were two grazing treatments consisting of low-stocking rotational (~ 20 AU $ha^{-1}$) and high-stocking rotational (~ 500 AU $ha^{-1}$). The low-stocking rotational treatment was similar to the twice-over treatment at BBR, but with cattle being rotated to a different paddock every week. The high-stocking rotational treatment was similar to the high-stocking rotational treatment at BBR. In the upland site, there was only one treatment, high-stocking rotational. The grazing procedure was similar to the high-stocking rotational treatment in the meadow site. At the Marshall ranch, there was a total of 30 traps in the meadow pasture and 15 traps in the upland pasture.

At the Randall Shinn ranch, traps were set up in transects throughout the meadow for 2014 grazing season only. Research was not conducted at this ranch in 2015. There were two grazing treatments at the Shinn ranch consisting of low-stocking rotational (~ 20 AU $ha^{-1}$) and high-stocking rotational (~ 500 AU $ha^{-1}$). The low-stocking rotational treatment was performed the same way as the low-stocking rotational treatment at the Marshall ranch. The high-stocking rotational treatment was also performed similarly to the high-stocking rotational treatment at the Marshall ranch. There were a total of 18 traps in the pasture at the Shinn ranch.

**Statistical procedures.** To compare dung beetle activity between the grazing treatments, four indices were generated for each treatment each year. The indices were peak abundance per trap, species richness, Simpson's diversity index, and Simpson's evenness. Peak abundance can be defined as areas where cattle were present and dung beetle abundance was the highest. It was used to counteract the absence of cattle in paddocks that were not being grazed in the rotational grazing treatments. Species richness, or species count, was expressed as the total number of species that were captured in each grazing treatment. Simpson's diversity index quantifies the diversity in a habitat by accounting for species richness as well as the relative abundance of each species in a sample (Magurran and McGill 2011). Simpson's diversity index is calculated by the following equation:

$$D = \Sigma p_i^2$$

where $p_i$ represents the proportion of abundance for species $i$ (Magurran and McGill 2011). Simpson's diversity index can be summarized as, "the probability that two individuals drawn at random from an infinite community would belong to the same species" (Magurran and McGill 2011). The reciprocal of Simpson's diversity index is the most common form used to measure diversity (Magurran and McGill 2011). The reciprocal index ranges on a scale from 1 to the maximum number of species collected, with higher values signifying more diversity in a sample (Magurran and McGill 2011). The reciprocal index was used to determine dung beetle diversity across each grazing treatment. Lastly, Simpson's evenness is a measure of the relative abundance of species in a community (Magurran and McGill 2011). It can be calculated using the reciprocal Simpson's diversity index as follows:

$$E = (1/D)/S$$

where $1/D$ represents the reciprocal of Simpson's diversity index, and $S$ represents the total number of species in the community (Magurran and McGill 2011). Simpson's evenness ranges on a scale from 0-1, with 0 indicating maximum unevenness and 1 indicating perfect evenness (Magurran and McGill 2011).

All data gathered for this study were analyzed using LS-means implemented in the PROC GLIMMIX procedure with SAS statistical software version 9.4 (2013). Significantly different treatment means were separated using a Tukey's HSD mean comparison test with an $\alpha = 0.05$ significance level. Mean comparisons with marginal significance ($P \leq 0.08$) are also discussed.

## Results

**Dung beetle collection totals.** Across all grazing treatments in 2014, a total of 760 dung beetles were collected at BBR, 394 at the Marshall ranch meadow, 67 in the Marshall ranch uplands, and 564 at the Shinn ranch, with a grand total of 1,785. In 2015, a total of 1,441 were collected at BBR, 538 at the Marshall ranch meadow, and 428 at the Marshall ranch uplands, with a grand total of 2,407. The overall total number of dung beetles collected through both years of this study was 4,192.

In 2014, there were a total of 12 dung beetle species collected at BBR (Table 2.2), 10 at the Marshall ranch meadow (Table 2.3), 7 at the Marshall ranch uplands (Table 2.4), and 13 at the Shinn ranch (Table 2.5). In 2015, there were 12 species collected at BBR (Table 2.2), 9 at the Marshall ranch meadow (Table 2.3), and 12 at the Marshall ranch uplands (Table 2.4). The overall total number of species collected through both years was 22, with 15 identified as new county records for Rock and/or Brown counties in Nebraska. *Onthophagus* spp. were the most consistently dominant dung beetles across all locations in 2014 and 2015 (Tables 2.2, 2.3, 2.4, and 2.5).

**Barta Brothers Ranch.** The average peak dung beetle abundances on the grazed treatments were consistently higher than that of the non-grazed control treatment during both 2014 and 2015 (Figure 2.3). In 2014, peak abundance in the high-stocking rotational treatment was significantly higher than both the once-over ($F_{1,86} = 10.49$, $P = 0.0017$) and the twice-over

($F_{1,86}$ = 9.47, $P$ = 0.0028) rotational treatments (Figure 2.3). The high-stocking rotational treatment was also approaching significance over the continuous treatment ($P$ = 0.0831) (Figure 2.3). In 2015, results indicated significantly higher peak abundance in the high-stocking rotational treatment over the once-over and twice-over rotational and the continuous treatments ($F_{1,104}$ = 14.87, $P$ = 0.0002; $F_{1,104}$ = 6.02, $P$ = 0.0158; $F_{1,104}$ = 16.38, $P$ < 0.0001) (Figure 2.3).

In terms of species richness, all grazed treatments over both years were significantly higher than the non-grazed control treatment, except for 2014 with the continuous treatment showing only marginal significance over the control ($P$ = 0.0624) (Figure 2.4). In both 2014 and 2015, species richness in the high-stocking rotational treatment was significantly greater than the once-over (2014: $F_{1,5}$ = 17.53, $P$ = 0.0086, and 2015: $F_{1,5}$ = 19.26, $P$ = 0.0071) and twice-over (2014: $F_{1,5}$ = 17.53, $P$ = 0.0086, and 2015: $F_{1,5}$ = 12.32, $P$ = 0.0171) low-stocking rotational treatments and the continuous treatment (2014: $F_{1,5}$ = 22.78, $P$ = 0.0050, and 2015: $F_{1,5}$ = 27.66, $P$ = 0.0033) (Figure 2.4).

The Simpson's diversity indexes calculated in 2014 and 2015 were considerably greater for all rotationally grazed treatments compared to the continuous and control treatments (Figure 2.5). Compared to the continuous treatment, Simpson's diversity in the high-stocking rotational (2014: $F_{1,5}$ = 10.19, $P$ = 0.0242, and 2015: $F_{1,5}$ = 7.74, $P$ = 0.0388) and the once-over (2014: $F_{1,5}$ = 9.31, $P$ = 0.0284, and 2015: $F_{1,5}$ = 9.42, $P$ = 0.0278) and twice-over (2014: $F_{1,5}$ = 8.22, $P$ = 0.0351, and 2015: $F_{1,5}$ = 6.91, $P$ = 0.0466) low-stocking rotational treatments were all significantly higher (Figure 2.4). No significant differences were observed between the continuously grazed treatment and the non-grazed control (2014: $P$ = 0.9702, and 2015: $P$ = 0.9993) (Figure 2.5).

The Simpson's evenness values that were calculated in both 2014 and 2015 had only one major difference between treatments (Figure 2.6). In 2015, the non-grazed control treatment had significantly higher evenness compared to the high-stocking rotational ($F_{1,5}$ = 25.60, $P$ = 0.0039) and the once-over ($F_{1,5}$ = 11.26, $P$ = 0.0202) and twice-over ($F_{1,5}$ = 19.39, $P$ = 0.0070) low-stocking rotational treatments, as well as the continuous treatment ($F_{1,5}$ = 26.92, $P$ = 0.0035) (Figure 2.6). However, this significance is most likely indicative of the simple lack of dung beetles collected in the control treatment for that year. No other significant differences were observed between treatments in either of the two years.

**Rick Marshall ranch.** Peak abundance of dung beetles varied across the grazing treatments in 2014 but not in 2015. In 2014, the meadow high-stocking rotational treatment had significantly higher peak abundance ($F_{1,6}$ = 6.53, $P$ = 0.0432) than the upland high-stocking rotational treatment (Table 2.6). Similarly, the low-stocking rotational treatment showed slightly greater peak abundance than the upland high-stocking rotational treatment, however this was only marginally significant ($P$ = 0.0596) (Table 2.6). Results from 2015 had no significant differences between treatments.

Species richness was considerably different between two of the grazing treatments at the Marshall ranch in 2014 (Table 2.6). The low-stocking rotational treatment had significantly higher species richness compared to the upland high-stocking rotational treatment ($F_{1,9}$ = 6.03, $P$ = 0.0364) (Table 2.6). No other differences in species richness were found in 2014 or 2015.

Due to having no treatment replicates at the Marshall ranch, no treatment means could be calculated for Simpson's diversity index or Simpson's evenness; therefore, statistical comparisons could not be made for these values (Table 2.6).

**Randall Shinn ranch.** As mentioned earlier in this chapter, data was collected from the Shinn ranch only during the 2014 grazing season. There were no significant differences in peak abundance between the low-stocking rotational and the high-stocking rotational treatment (Table 2.7). However, the high-stocking rotational treatment showed significantly higher dung beetle species richness than in the low-stocking rotational treatment ($F_{1,12} = 6.90$, $P = 0.0221$) (Table 2.7).

Similar to the data collected at the Marshall ranch, the Shinn ranch also did not have treatment replicates. Statistical comparisons for Simpson's diversity index or Simpson's evenness could not be made as means could not calculated for these values (Table 2.7).

## Discussion and Conclusions

The conservation and promotion of dung beetles continues to be a subject of ongoing concern among ecologists as well as ranching communities around the world (Barbero et al. 1999; Hutton and Giller 2003). The ecosystem services provided by dung beetles are necessary for the function of many cattle-grazed rangeland ecosystems (Nichols et al. 2008; Slade et al. 2016). Dung beetle populations have continued to decline in recent years due to changes in agricultural practices, habitat loss, and pesticide usage (Hutton and Giller 2003; Slade et al. 2016). Their critical role in preserving ecosystem sustainability has made the conservation of dung beetles recognized as an increasingly important agenda (Barbero et al. 1999; Scholtz et al. 2009). Finding the best grazing practices that are able to maintain adequate abundance and diversity within the dung beetle community is key to keeping rangelands healthy enough to sustain cattle production.

The results of this study indicate that some cattle grazing practices may be more favorable toward the colonization of dung beetles. Observations made it clear that overall dung beetle diversity could be improved with rotational grazing practices compared to continuous grazing (Figure 2.5). These findings support previous research by Whipple (2011) where higher dung beetle abundances and species numbers were reported in rotationally grazed pastures. Furthermore, higher stocking densities may also be a factor in promoting dung beetle populations, as abundance and species richness (but not diversity) were significantly greater in high-stocking rotational treatments over low-stocking rotational and continuous treatments (Figures 2.3 and 2.4). However, this trend may not always be the case as indicated by some of the outcomes at the other studied ranch locations (Tables 2.6 and 2.7).

At the Barta Brothers Ranch, Simpson's diversity indices revealed that rotational grazing may support a more abundant and diverse community of dung beetles over that of continuous grazing or no grazing (Figure 2.5). However, the similarity in Simpson's diversity among the rotational treatments is contradicted with the high-stocking rotational treatment showing greater abundance and species richness than the low-stocking rotational treatments (Figures 2.3 and 2.4). The relative evenness of species distribution may play a role because Simpson's evenness appeared lower, although not significant, in the high-stocking rotational treatment (Figure 2.6). The relationship between Simpson's evenness and Simpson's diversity allows the lower evenness in the high-stocking rotational treatment to bring the diversity index value closer to that of the other rotational grazing treatments (Magurran and McGill 2011). Nonetheless, the higher abundance and species richness resulting from the high-stocking rotational treatment suggests that stocking density may have a greater effect on the dung beetle community beyond the utilization of rotational or continuous grazing. This could be due to an increase in the concentration and dispersal of dung pats throughout a pasture that is associated with stocking cattle at higher densities (Richards and Wolton 1976; Whipple 2011). More cattle and increased dung deposition could prove to be more influential for attracting dung beetles. Since dung beetles are attracted to dung primarily by odor, high-stocking rotational or other forms of rotational grazing may favor the colonization of dung beetles (Whipple 2011). In turn, having more dung beetles could boost nutrient cycling, carbon sequestration, and mitigation of greenhouse gas emissions (Dormont et al. 2004; Penttilä et al. 2013; Slade et al. 2016).

At the collaborating ranches, mixed results compound what was seen between rotational treatments at BBR. The fact that the Marshall ranch showed no significant differences in dung beetle abundance or species richness among the rotational grazing treatments in the meadow (Table 2.6) implies that the results seen at BBR may not be ubiquitous. Simpson's diversity and evenness values fluctuated in 2014 and 2015, which further supports these findings (Table 2.6). Values in the upland high-stocking rotational treatment were typically different from the meadow treatments, which may represent the variation between the two habitats and its affect on the community structure (Tables 2.3, 2.4, and 2.6). The 2014 results from the Shinn ranch were similar to the Marshall ranch except that species richness was significantly greater in the high-stocking rotational treatment (Table 2.7). An explanation for the mixed outcomes from the collaborating ranches compared to BBR could be that location can act as a contingent factor for dung beetle assemblages. To better understand this, future research should be expanded to focus on diversifying the areas that are studied. Implementing continuous grazing and different rotational grazing practices on a broader range of grassland habitats could better demonstrate how dung beetle activity might vary depending on location.

Overall, this study contributes useful information to an important knowledge gap regarding the effects of grazing practices on dung beetle communities. It may give ranchers and other pastureland owners valuable insight into how they can graze their livestock and at the same time promote dung beetle populations. Many studies have proven the benefits of dung beetles as they provide many essential ecosystem services (Bang et al. 2005; Yamada et al. 2007; Nichols et al. 2008; Slade et al. 2016). Conserving their populations by implementing grazing practices that favor them could be advantageous by boosting ecosystem functions to provide improved rangeland health in many regions, including Nebraska (Barbero et al. 1999). It has been demonstrated in this study that cattle grazing practices can affect dung beetle activity on rangelands. Furthermore, rotational grazing, and in some cases high-stocking rotational grazing, can help enhance the dung beetle community by promoting abundance as well as species diversity. By implementing rotational grazing practices, dung beetle biodiversity might be strengthened to help build and maintain more sustainable rangeland and grassland ecosystems.

**Table 2.1:** Relative cattle stocking densities that were used for each grazing treatment at the studied ranches in 2014 and 2015.

| Grazing treatment | Stocking density (AU $ha^{-1}$) |
|---|---|
| No graze/hay | 0 |
| Continuous | < 1 |
| Low-stocking rotational (once-over & twice-over) | ~ 20 |
| High-stocking rotational | ~ 500 |

**Table 2.2:** Percent abundance of dung beetle (Coleoptera: Scarabaeoidea) species collected at Barta Brothers Ranch in 2014 and 2015.

| | % Total | | |
|---|---|---|---|
| Species | 2014 [a] | 2015 [b] | 2014/2015 Average |
| *Onthophagus hecate* | 36.58* | 52.05* | 44.32* |
| *Diapterna pinguella* | 41.45* | 23.87* | 32.66* |
| *Onthophagus pennsylvanicus* | 5.53* | 13.95* | 9.74* |
| *Aphodius rusicola* | 8.82* | 1.53 | 5.18* |
| *Ataenius spretulus* | 5.13 | 3.75* | 4.44 |
| *Onthophagus orpheus pseudorpheus* | 0.92 | 1.87 | 1.39 |
| *Aphodius fimetarius* | 0.53 | 1.04 | 0.79 |
| *Aphodius rubeolus* | 0.39 | 0.76 | 0.58 |
| *Aphodius haemorrhoidalis* | 0.26 | 0.76 | 0.51 |
| *Geotrupes opacus* | - | 0.21 | 0.11 |
| *Melanocanthon nigricornis* | - | 0.14 | 0.07 |
| *Aphodius gordoni* | 0.13 | - | 0.06 |
| *Ataenius imbricatus* | 0.13 | - | 0.06 |
| *Canthon pilularius* | 0.13 | - | 0.06 |
| *Bolbocerosoma bruneri* | - | 0.07 | 0.03 |
| Sum | 100 | 100 | 100 |
| Total number of species | 12 | 12 | 15 |

[a] A total of 760 dung beetles were collected across all sampling dates in 2014
[b] A total of 1,441 dung beetles were collected across all sampling dates in 2015
[*] Dung beetle species making up ~ 90% of the total captures within a specified year

**Table 2.3:** Percent abundance of dung beetle (Coleoptera: Scarabaeoidea) species collected in the meadow pasture at the Rick Marshall ranch in 2014 and 2015.

| | % Total | | |
|---|---|---|---|
| Species | 2014 [a] | 2015 [b] | 2014/2015 Average |
| *Diapterna pinguella* | 39.60* | 42.75* | 41.18* |
| *Onthophagus hecate* | 44.16* | 36.62* | 40.39* |
| *Onthophagus pennsylvanicus* | 3.81 | 14.31* | 9.06* |
| *Aphodius rusicola* | 9.90* | 1.49 | 5.69 |
| *Melanocanthon nigricornis* | 0.76 | 1.67 | 1.22 |
| *Geotrupes opacus* | - | 2.04 | 1.02 |
| *Ataenius spretulus* | 0.51 | 0.74 | 0.63 |
| *Copris fricator* | 0.51 | 0.19 | 0.35 |
| *Aphodius rubeolus* | 0.25 | 0.19 | 0.22 |
| *Odenteus filicornis* | 0.25 | - | 0.12 |
| *Onthophagus orpheus pseudorpheus* | 0.25 | - | 0.12 |
| | | | |
| Sum | 100 | 100 | 100 |
| Total number of species | 10 | 9 | 11 |

[a] A total of 394 dung beetles were collected across all sampling dates in 2014
[b] A total of 538 dung beetles were collected across all sampling dates in 2015
* Dung beetle species making up ~ 90% of the total captures within a specified year

**Table 2.4:** Percent abundance of dung beetle (Coleoptera: Scarabaeoidea) species collected in the upland pasture at the Rick Marshall ranch in 2014 and 2015.

| | % Total | | |
|---|---|---|---|
| Species | 2014 [a] | 2015 [b] | 2014/2015 Average |
| *Onthophagus pennsylvanicus* | 28.36* | 43.46* | 35.91* |
| *Onthophagus hecate* | 32.84* | 35.05* | 33.95* |
| *Canthon ebenus* | 29.85* | 7.01* | 18.43* |
| *Geotrupes opacus* | - | 6.54* | 3.27* |
| *Melanocanthon nigricornis* | 4.48 | 1.64 | 3.06 |
| *Onthophagus orpheus pseudorpheus* | 1.49 | 1.87 | 1.68 |
| *Aphodius rubeolus* | 1.49 | 1.64 | 1.57 |
| *Aphodius rusicola* | 1.49 | 0.23 | 0.86 |
| *Canthon pilularius* | - | 1.17 | 0.59 |
| *Aphodius haemorrhoidalis* | - | 0.93 | 0.46 |
| *Copris fricator* | - | 0.23 | 0.11 |
| *Phanaeus vindex* | - | 0.23 | 0.11 |
| | | | |
| Sum | 100 | 100 | 100 |
| Total number of species | 7 | 12 | 12 |

[a] A total of 67 dung beetles were collected across all sampling dates in 2014
[b] A total of 428 dung beetles were collected across all sampling dates in 2015
[*] Dung beetle species making up ~ 90% of the total captures within a specified year

**Table 2.5:** Percent abundance of dung beetle (Coleoptera: Scarabaeoidea) species collected at the Randall Shinn ranch in 2014.

| Species | % Total [a] |
|---|---|
| *Onthophagus hecate* | 57.09* |
| *Ataenius spretulus* | 13.12* |
| *Diapterna pinguella* | 13.12* |
| *Aphodius rusicola* | 10.99* |
| *Onthophagus pennylvanicus* | 3.01 |
| *Aphodius fimetarius* | 0.71 |
| *Bolberocerosoma bruneri* | 0.71 |
| *Aphodius rubeolus* | 0.35 |
| *Aphodius erraticus* | 0.18 |
| *Aphodius granarius* | 0.18 |
| *Aphodius haemorrhoidalis* | 0.18 |
| *Onthophagus orpheus pseudorpheus* | 0.18 |
| *Tomarus relictus* | 0.18 |
| | |
| Sum | 100 |
| Number of species | 13 |

[a] A total of 567 dung beetles were collected across all sampling dates in 2014

* Dung beetle species making up 90% of the total captures within a specified year

**Table 2.6:** Comparisons of dung beetle (Coleoptera: Scarabaeoidea) peak abundance, species richness, Simpson's diversity, and Simpson's evenness across low-stocking (LS) and high-stocking (HS) rotational cattle grazing practices at the Rick Marshall ranch in 2014 and 2015.

| Treatment | Mean peak abundance [a,b] | | Mean species richness [a,b] | | Simpson's diversity | Simpson's evenness |
|---|---|---|---|---|---|---|
| 2014 | | | | | | |
| Rotational LS | 7.31 ± 1.75 | AB | 7.00 ± 1.08 | A | 2.58 | 0.26 |
| Rotational HS | 8.19 ± 2.44 | A | 4.25 ± 0.48 | AB | 2.74 | 0.55 |
| Rotational HS (upland) | 3.50 ± 0.99 | B | 3.00 ± 0.91 | B | 3.57 | 0.51 |
| 2015 | | | | | | |
| Rotational LS | 10.31 ± 5.01 | A | 4.50 ± 0.87 | A | 2.94 | 0.40 |
| Rotational HS | 11.56 ± 4.13 | A | 5.50 ± 0.87 | A | 2.81 | 0.37 |
| Rotational HS (upland) | 13.93 ± 5.90 | A | 5.80 ± 1.46 | A | 3.11 | 0.26 |

[a] Letters indicate significance in columns ($P < 0.05$). Means with the same letter are not significantly different.
[b] Values represent the means with standard error of the mean.

**Table 2.7:** Comparisons of dung beetle (Coleoptera: Scarabaeoidea) peak abundance, species richness, Simpson's diversity, and Simpson's evenness across low-stocking (LS) and high-stocking (HS) rotational cattle grazing practices at the Randall Shinn ranch in 2014.

| Treatment | Mean peak abundance [a,b] | | Mean species richness [a,b] | | Simpson's diversity | Simpson's evenness |
|---|---|---|---|---|---|---|
| 2014 | | | | | | |
| Rotational LS | 6.21 ± 1.45 | A | 8.14 ± 1.06 | B | 2.42 | 0.22 |
| Rotational HS | 11.43 ± 2.20 | A | 12.71 ± 0.52 | A | 2.65 | 0.22 |

[a] Letters indicate significance in columns ($P < 0.05$). Means with the same letter are not significantly different.
[b] Values represent the means with standard error of the mean.

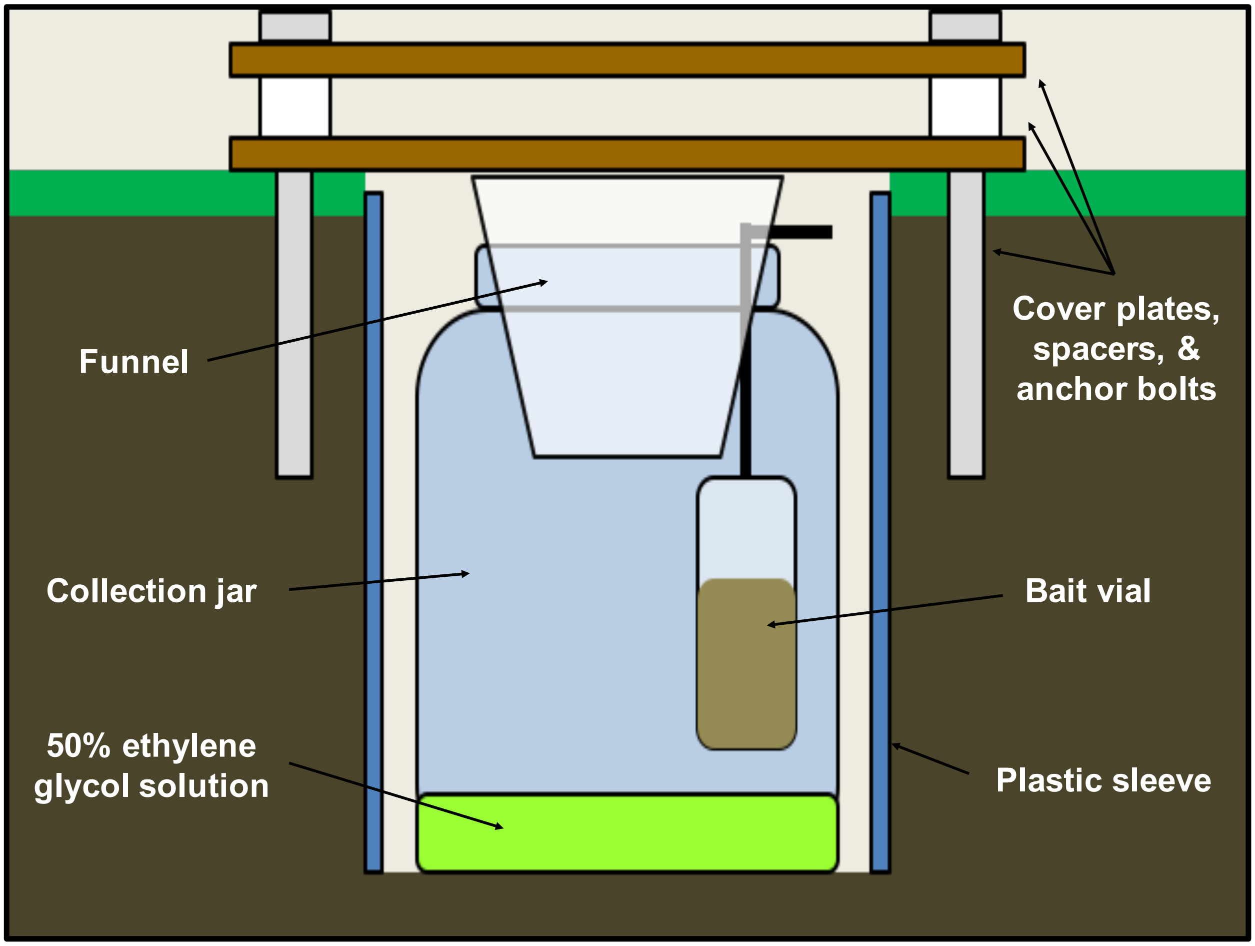



**Figure 2.1:** Diagram of the pitfall trap design that was used to measure dung beetle activity in cattle-grazed pastures during the 2014 and 2015 grazing seasons.

**Figure 2.2:** Photograph of a pitfall trap that was used to measure dung beetle activity in cattle-grazed pastures during the 2014 and 2015 grazing seasons.

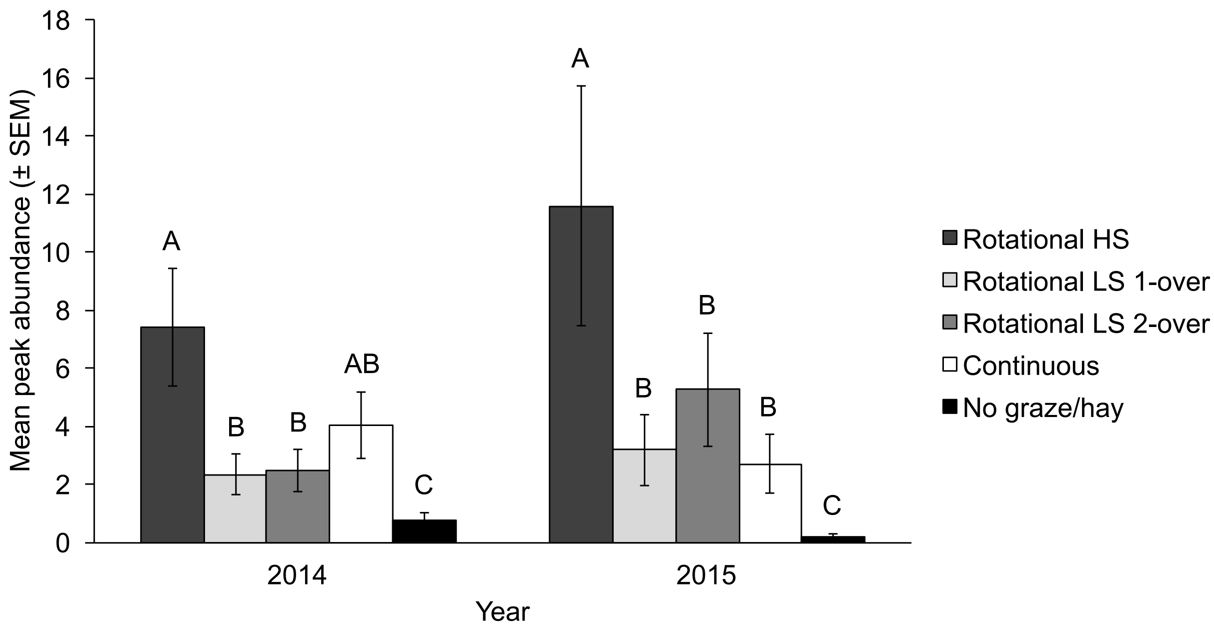



**Figure 2.3:** Mean (± SEM) peak abundance of dung beetles (Coleoptera: Scarabaeoidea) collected across different cattle grazing practices at Barta Brothers Ranch in 2014 and 2015. Grazing treatments were high-stocking (HS) rotational, once-over and twice-over low-stocking (LS) rotational, continuous, and no graze/hay. Letters indicate significance in treatments ($P < 0.05$). Means with the same letters are not significantly different.

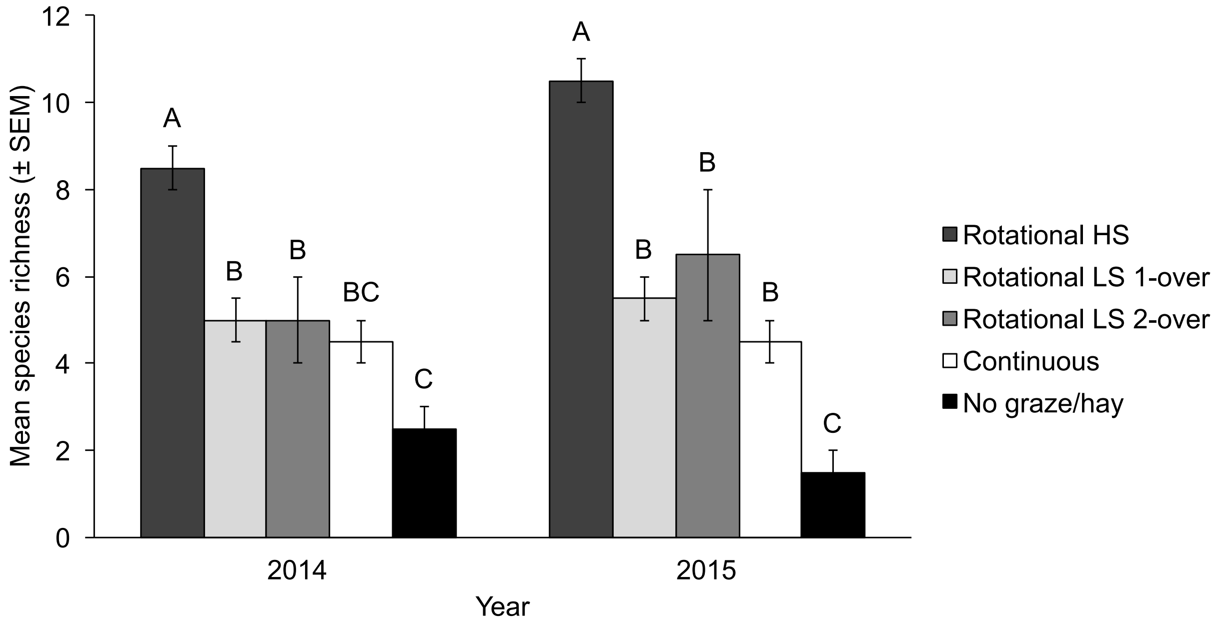



**Figure 2.4:** Mean (± SEM) species richness of dung beetles (Coleoptera: Scarabaeoidea) collected across different cattle grazing practices at Barta Brothers Ranch in 2014 and 2015. Grazing treatments were high-stocking (HS) rotational, once-over and twice-over low-stocking (LS) rotational, continuous, and no graze/hay. Letters indicate significance in treatments ($P < 0.05$). Means with the same letters are not significantly different.

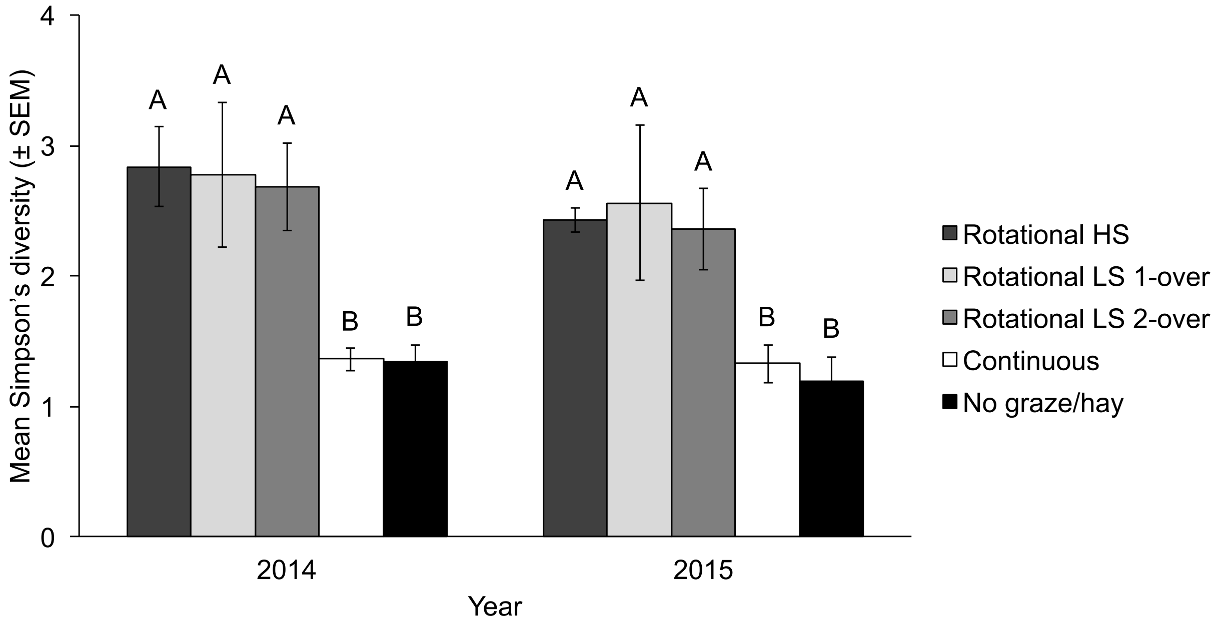



**Figure 2.5:** Mean (± SEM) Simpson's diversity index (1/*D*) of dung beetles (Coleoptera: Scarabaeoidea) collected across different cattle grazing practices at Barta Brothers Ranch in 2014 and 2015. Grazing treatments were high-stocking (HS) rotational, once-over and twice-over low-stocking (LS) rotational, continuous, and no graze/hay. Letters indicate significance in treatments ($P < 0.05$). Means with the same letters are not significantly different.

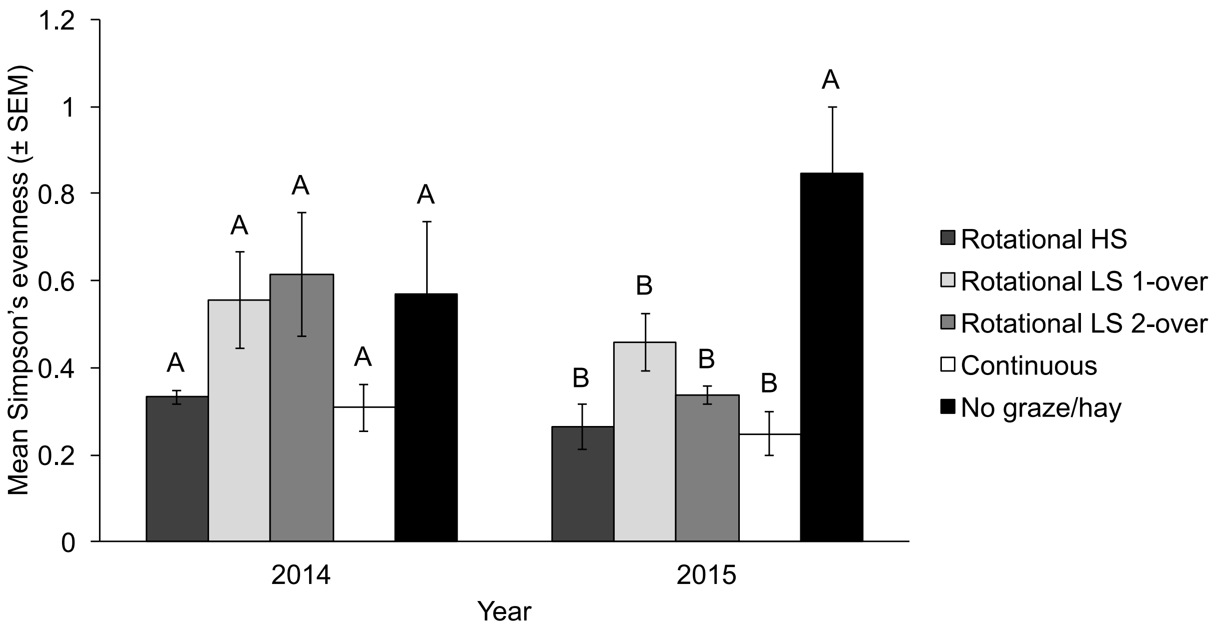



**Figure 2.6:** Mean (± SEM) Simpson's evenness of dung beetles (Coleoptera: Scarabaeoidea) collected across different cattle grazing practices at Barta Brothers Ranch in 2014 and 2015. Grazing treatments were high-stocking (HS) rotational, once-over and twice-over low-stocking (LS) rotational, continuous, and no graze/hay. Letters indicate significance in treatments ($P < 0.05$). Means with the same letters are not significantly different.

# CHAPTER 3

EVALUATION OF DUNG BEETLE (COLEOPTERA: SCARABAEOIDEA) ATTRACTION TO CATTLE DUNG ORIGINATING FROM DIFFERING GRAZING PRACTICES

## Introduction

Moisture and nutrient composition of dung can have a large impact on dung beetle activity in rangeland. The amount of fluid in dung is important for its attractiveness and suitability for dung beetles as they obtain the majority of their nutrition from liquid dung (Aschenborn et al. 1989). In fact, Halffter and Matthews (1966) found that adults dung beetles typically feed on the liquid components while the more fibrous materials are used for brooding offspring. Several studies have also found that variations in dung nutrition can alter its attractiveness to many coprophagous insects, including dung beetles (Estrada et al. 1993; Whipple and Hoback 2012). The diet of an animal and the resulting components of its dung can significantly affect dung beetle feeding preferences (Scholtz et al. 2009; Whipple and Hoback 2012). Whipple and Hoback (2012) found that dung beetles were more attracted to dung from omnivorous animals than to dung from herbivores or carnivores. The results may suggest that dung beetles exhibit preferences for dung based on the nutritional value and moisture level associated with animal diet. In a rangeland setting, these preferences could be linked to cattle grazing as cattle diet may vary between different grazing practices.

There are several grazing practices used to manage cattle in rangeland ecosystems with two practices, continuous and rotational grazing, being the most common (Heath et al. 1985). Continuous grazing involves low densities of cattle (< 1 AU $ha^{-1}$) being put out into an open pasture where they left to graze for the entire season (Holechek et al. 2011). Rotational grazing is more complex – breaking the pasture into smaller sections called paddocks which are then grazed individually (Holechek et al. 2011). As the season progresses, higher densities of cattle (~ 20 AU $ha^{-1}$) are rotated between paddocks as available forage becomes depleted (Holechek et al. 2011). Another type of rotational grazing with very high stocking rates is referred to as high-stocking rotational grazing or "mob" grazing (Thomas 2012). High-stocking rotational grazing involves grazing the pasture by rotating high densities of cattle (~ 500 AU $ha^{-1}$) through small-sized paddocks (Gompert 2009; Thomas 2012). High-stocking rotational grazing requires frequent rotations throughout the season so that the pasture does not become damaged from overgrazing (Thomas 2012).

Cattle that are grazed continuously on a pasture may have more dietary selectivity than cattle that are rotationally grazed (Holechek et al. 2011). When put out into pasture, cattle typically prefer to eat the broad-leafed plants like forbs before they eat grasses (Holechek et al. 2011). Cattle are able to exhibit this preferential feeding behavior when they are grazed at lower stocking densities (Holechek et al. 2011; Schacht et al. 2011). At higher stocking densities, cattle must graze on a more diverse range of plants because there is more competition with the other cattle in the pasture (Holechek et al. 2011). In the case of high-stocking rotational grazing, selective grazing can be decreased to increase harvest efficiency in the pasture (Heady 1961; Thomas 2012). These differences in feeding behavior may in turn change the nutritional content of dung through altered diets.

The objective of this study was to determine if dung beetles exhibit a preference for cattle dung depending on the cattle stocking density. Lower stocking densities allow cattle to have more selective diets than cattle grazed at higher stocking densities (Holechek et al. 2011). Theoretically, cattle that have higher selectivity may then produce higher dung quality for dung beetles. It is hypothesized that dung beetles will exhibit a greater attraction to dung from cattle grazed with a more selective grazing diet.

## Materials and Methods

**Study site description.** This study was conducted during the 2015 grazing season at the University of Nebraska-Lincoln's Barta Brothers Ranch in the Sandhills Ecoregion of Nebraska (Ahlbrandt and Fryberger 1980). The Sandhills are primarily composed of sand dunes and wetlands that are overlaid with mixed-grass prairie (Ahlbrandt and Fryberger 1980; McNab and Avers 1994). Annual precipitation is from 430 – 580 mm and the average temperature is ~ 10 °C (McNab and Avers 1994).

The Barta Brothers Ranch was located in Rock County approximately 11 km west of Rose, Nebraska (42°13'N; 99°38'W). Research was done in a lowland, sub-irrigated meadow pasture that was used for haying purposes. The pasture was adjacent to other pastures in the meadow that were being grazed with cattle.

**Experimental design and procedures.** The study was set up as a randomized complete block design consisting of 4 blocks with 4 treatments per block. Treatments consisted of individual pitfall traps that were baited with different types of cattle dung. Three of the treatments were baited with dung from cattle that were grazed at three different stocking densities and the fourth treatment was a non-baited control. The three baited treatments received dung from cattle that were in a high-stocking rotational grazing system (~ 500 AU $ha^{-1}$), a low-stocking rotational grazing system (~ 20 AU $ha^{-1}$), and continuous grazing system (< 1 AU $ha^{-1}$). Each block contained individual pitfall traps that were representative of each treatment, totaling four traps per block.

Pitfall traps were designed similar to the ones utilized in Ratcliffe (2013), except they were modified by using 500 ml Nalgene jars and steel cover plates. Traps were baited with 20-ml vials containing approximately 10-20 ml of fresh cattle dung that was collected from each grazing system. Jars were filled with approximately 50-100 ml of a 50% Ethylene glycol/water solution to act as a killing agent. The pitfall traps were spaced no closer than 50 meters apart to ensure independence (Larsen and Forsyth 2005). Following methods similar to Whipple and Hoback (2012) the traps were baited with cattle dung for 7-day intervals within 14-day periods. After 7 days, the traps were collected and the bait vials were replaced with fresh dung for the next period. Trapping began in mid June after cattle were turned out to pasture and continued through July.

Dung preference was measured based on the abundance of dung beetles collected in the traps for each treatment. After collection, dung beetles were counted and identified to species according to Ratcliffe and Paulsen (2008). Dung samples were sent to Ward Laboratories in Kearney, NE for analysis to compare dung quality between grazing treatments. Moisture, dry matter, and pH were measured along with levels of nitrogen, phosphorous, potassium, calcium, magnesium, sodium, zinc, and iron.

**Statistical procedures.** The data gathered for this study was zero-inflated and was analyzed using a negative binomial regression model implemented in the PROC MEANS procedure with SAS statistical software version 9.4 (2013). Significant differences between treatment means were estimated using an $\alpha = 0.05$ significance level.

**Results**

**Dung beetle preference.** Sampling over the duration of this experiment yielded only 16 dung beetles from 5 different species. The overall mean for the data was 0.3333 with a variance of 0.7801. As the variance was greater than the mean, there was evidence of over-dispersion. Means for dung beetle abundance per trap were then calculated for each treatment using zero-inflated probabilities.

Not including traps where no dung beetles were found, the mean number of beetles per trap were calculated as 1.4051 for the high-stocking rotational treatment, 1.5731 for low-stocking rotational treatment, 2.2147 for continuous treatment, and 0 for the control. The remaining traps containing 0 beetles were then accounted for using percentages based on zero-inflation probability. For example, the estimated zero-inflation probability of the high-stocking rotational treatment was 70.27%, making the remaining 29.73% (100 – 70.27 = 29.73) contain the mean of 1.4051. Therefore, the estimate for overall mean abundance per trap in the high-stocking rotational treatment was 0.2973 x 1.4051 = 0.4177 beetles. Mean abundances for the continuous and low-stocking rotational treatments were also calculated using this method. The rounded calculated means for all treatments along with their associated standard errors are displayed in Table 3.1.

There were no significant differences found between dung beetle abundance across the three baited treatments. Species richness was also totaled for each treatment. Out of the 5 dung beetle species collected in total, the high-stocking rotational treatment and the continuous treatment each contained 3 beetles and the low-stocking rotational treatment contained 2 beetles (Table 3.1).

**Dung analysis.** Dung composition was relatively similar between cattle from the different grazing treatments. Nutrient percentages did not vary from one another by more than 1% (Table 3.2). Similarly, pH, moisture, and dry matter percentages remained consistent across the different treatments (Table 3.2).

## Discussion and Conclusions

It is well documented that animal diet can alter the attractiveness of a dung source to dung beetles (Hanski and Cambefort 1991; Estrada et al. 1993; Horgan 2005; Scholtz et al. 2009; Whipple and Hoback 2012). This attraction varies based on omnivore, carnivore, and herbivore feeding habits, but may also depend on the particular diets within those feeding guilds (Scholtz et al. 2009; Whipple and Hoback 2012). Understanding how differing cattle diets could change dung beetle preferences is important as it may prove beneficial to ranchers. Attracting more dung beetles could improve rangeland by providing more ecosystem services (Estrada et al. 1998; Nichols et al. 2008; Walters 2008). Evaluating the content of cattle dung from different grazing practices can be helpful to determine whether or not a particular dung type might increase the level of attraction for dung beetles.

The results of this study indicate that dung beetles may not have a preference for cattle dung based on grazing practice. However, the number of beetles collected over the duration of the experiment might not have been enough to provide truly meaningful results. The fact that no dung beetles were caught in the non-baited control treatment does suggest that the baited treatments functioned as intended (Table 3.1). Low catch levels of dung beetles in the baited treatments could have been due to the lack of dung pats surrounding the traps. It is recognized that the quantity and spatial distribution of dung pats have a large influence on attracting dung beetles (Horgan 2005). Thus, the bait vials alone may not have been enough to attract larger abundances of dung beetles to the study area. Furthermore, the bait vials were replaced only once per week which could also affect dung beetle attraction. Over time, dung nutrition can decline as the dung decomposes and becomes colonized by fungi and microbes (Hanski and Cambefort

1991; Scholtz et al. 2009). This nutrient decline might have made the bait less attractive in later stages of the sampling periods and contribute to the overall reduction in dung beetle numbers.

No major variations were found among the components of the cattle dung types that were used in this study. Nitrogen content is considered to be a main source for measuring nutrient quality in dung (Holter and Scholtz 2007). However, percent nitrogen along with other nutrients and the physical condition of the dung did not differ extensively among treatments (Table 3.2). Although zinc and iron levels were slightly elevated in cattle dung from the continuous treatment and the high-stocking rotational treatment (~ 400 mg $kg^{-1}$), this has appeared to have no impact on dung beetle attraction (Tables 3.1 and 3.2). Lack of dung variation could suggest that cattle diets may have been nearly identical among treatments as the meadow pastures where cattle were being grazed were relatively homogeneous. Even though grazing practices taking place at the same location did not have any major effect on cattle diet, this could vary if compared between different pasture locations and grazing habitats. Future research may focus on comparing dung from cattle grazed in different locations all together.

It is noteworthy that the two *Aphodius* species collected in this study were only found in the dung from continuously grazed cattle (Table 3.2). The continuous treatment also had an absence of dung beetles from the *Onthophagus* genus that were present in both of the rotational grazing treatments (Table 3.2). These differences in species composition between dung types could be relevant as they may reveal individual species preference for dung. Conducting further research on individual species preference might prove useful for a better understanding of how dung beetles utilize dung on a communal basis.

In conclusion, this study provides information about the relationship between dung beetle preference and cattle grazing diets. It has been revealed that the composition of dung from cattle in different grazing practices might not differ significantly as long as they are grazed in similar habitats. In turn, grazing practices do not appear to alter the overall abundance of dung beetles on different dung types. This information may be of some value as it shows that grazing practices might not be a factor in affecting dung beetle attraction to cattle dung. However, the data gathered from this study has also displayed evidence that variation in species composition could be present. Questions can then be raised about what other chemical components of dung might be affecting the level of attraction and how this can impact dung beetle abundance and diversity in rangeland ecosystems. Relatively few studies have examined the topic of dung beetle preference and attraction to cattle dung, making it an area of considerable research potential.

**Table 3.1:** Comparison of dung beetle (Coleoptera: Scarabaeoidea) abundance and species richness across cattle dung collected from different grazing practices at the Barta Brothers Ranch in 2015.

| | Dung type | | | |
|---|---|---|---|---|
| Species | High-stocking rotational | Low-stocking rotational | Continuous | Control |
| *Aphodius fimetarius* | 0 | 0 | 1 | 0 |
| *Aphodius rusicola* | 0 | 0 | 1 | 0 |
| *Diapterna pinguella* | 3 | 2 | 3 | 0 |
| *Onthophagus hecate* | 1 | 4 | 0 | 0 |
| *Onthophagus pennsylvanicus* | 1 | 0 | 0 | 0 |
| | | | | |
| Species richness | 3 | 2 | 3 | 0 |
| Abundance/trap | 0.42 ± 0.37 [a] | 0.50 ± 0.29 | 0.42 ± 0.27 | 0 |

[a] Values represent the means with standard error of the mean.

**Table 3.2:** Content analysis of cattle dung collected from different grazing practices at the Barta Brothers Ranch in 2015.

| Dung type | Total N (%) | P (%) | K (%) | Ca (%) | Mg (%) | Na (%) | Zn (mg $kg^{-1}$) | Fe (mg $kg^{-1}$) | pH | Moisture (%) | Dry matter (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| High-stocking rotational | 1.60 | 1.45 | 1.43 | 0.82 | 0.23 | 0.10 | 54.3 | 944.25 | 6.9 | 83.21 | 16.80 |
| Low-stocking rotational | 1.86 | 0.86 | 1.29 | 1.06 | 0.28 | 0.05 | 98.55 | 481.55 | 6.8 | 85.42 | 14.58 |
| Continuous | 2.13 | 1.25 | 0.63 | 1.23 | 0.30 | 0.70 | 468.25 | 553.95 | 6.7 | 82.85 | 17.1 |

# APPENDIX

## Photos of Dung Beetles of the Nebraska Sandhills

**Guide to photo list:**

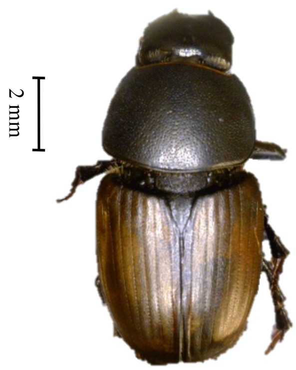
1. *Aphodius erraticus* *
2. *Aphodius fimetarius*
3. *Aphodius gordoni*
4. *Aphodius granarius*
5. *Aphodius heamorrhoidalis*
6. *Aphodius rubeolus*
7. *Aphodius rusicola*
8. *Ataenius spretulus*
9. *Ataenius imbricatus*
10. *Bolbocerosoma bruneri*
11. *Canthon ebenus*
12. *Canthon pilularius*
13. *Copris fricator* (♀)
14. *Diapterna pinguella*
15. *Geotrupes opacus*
16. *Melanocanthon nigricornis*
17. *Odonteus filicornis* (♂)
18. *Onthophagus hecate* (♂)
19. *Onthophagus pennsylvanicus* (♀)

**20.** *Onthophagus orpheus pseudorpheus* (♀)

**21.** *Phanaeus vindex* (♀)

**22.** *Tomarus relictus*

* Size and appearance of dung beetles may vary based on gender.

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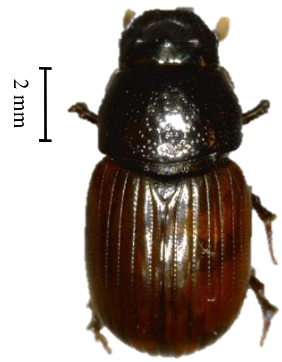


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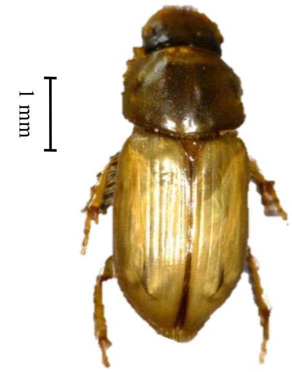


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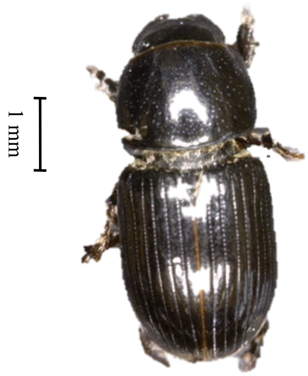


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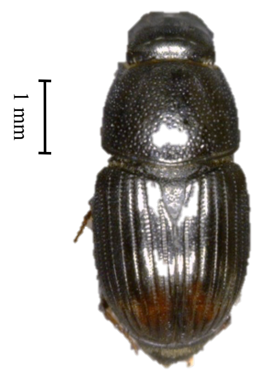


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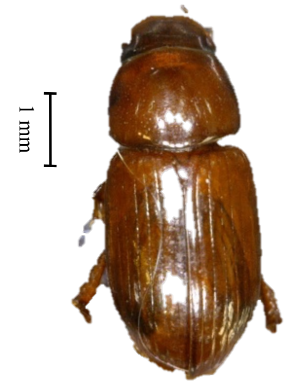


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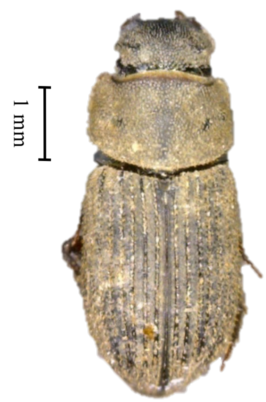
7.

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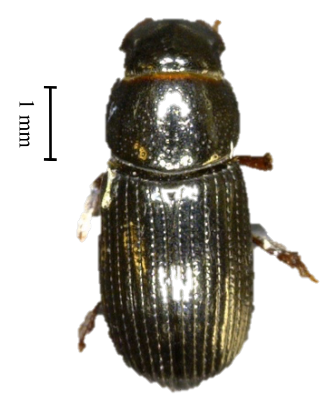


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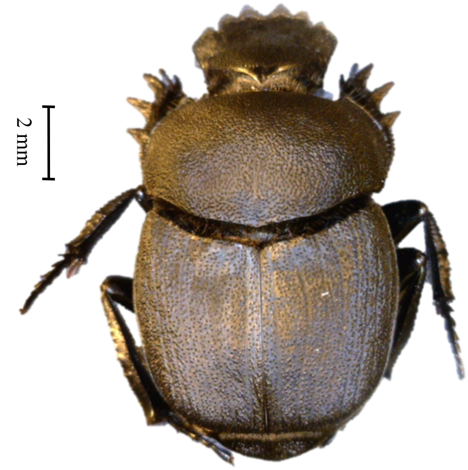


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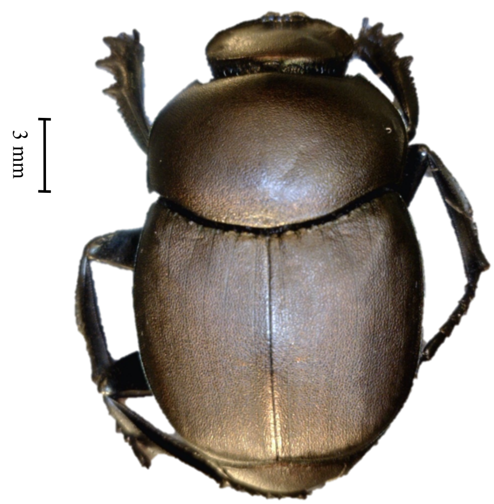


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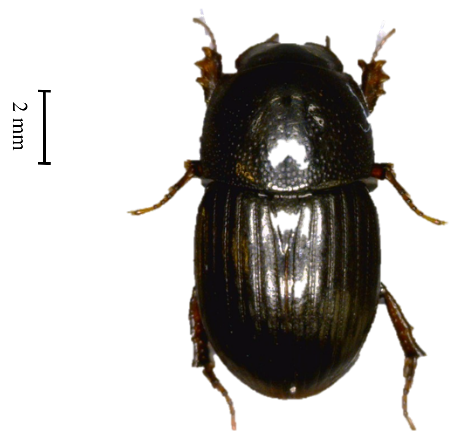


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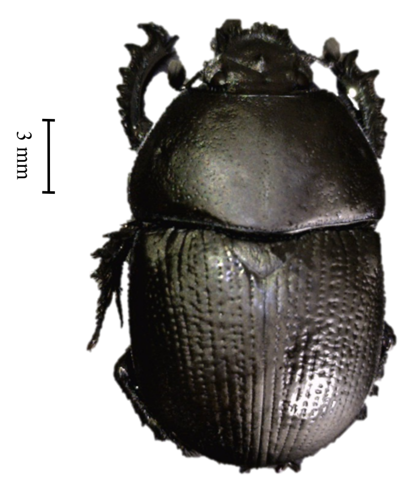


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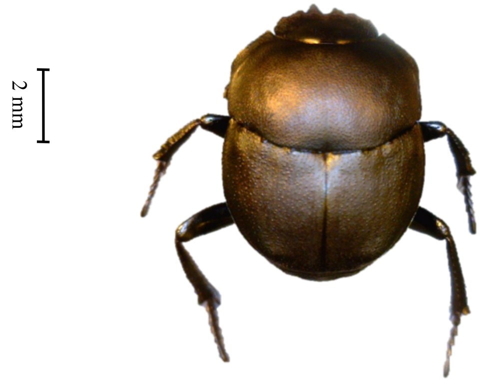


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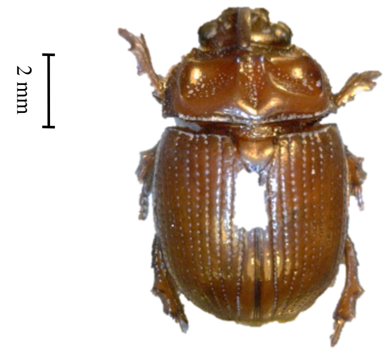


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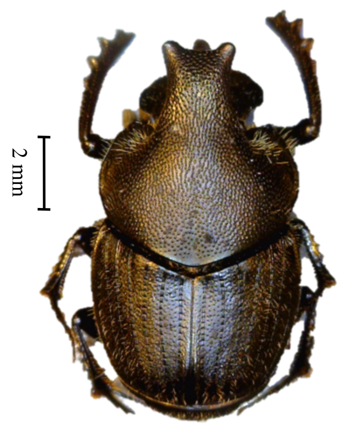


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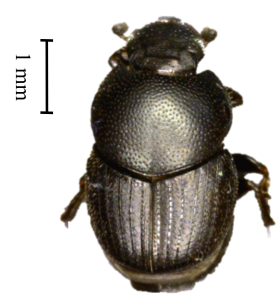


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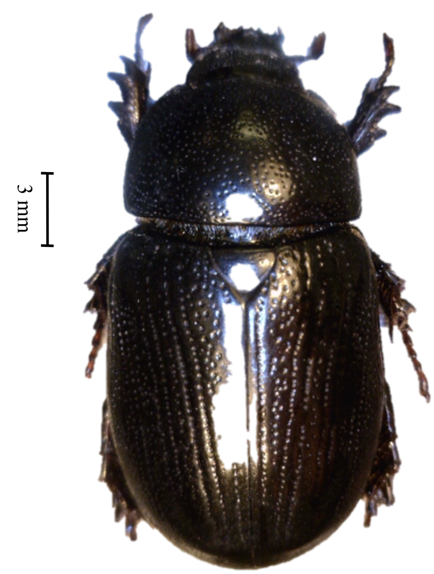


22.

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