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Endozoochorous Spread of Nonnative Plant Species by White-Tailed Deer, Odocoileus Virginianus

Andrew Jordan Spychalla

ENDOZOOCHOROUS SPREAD OF NONNATIVE PLANT SPECIES BY WHITE-TAILED DEER, *ODOCOILEUS VIRGINIANUS*, AND ELK, *CERVUS ELAPHUS* IN THE MISSOURI OZARKS

A Master's Thesis

Presented to

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In Partial Fulfillment

Of the Requirements for the Degree

Master of Science, Biology

By

Andrew Jordan Spychalla

August 2016

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ABSTRACT

Movement of plant seeds can be facilitated by endozoochory in white-tailed deer (*Odocoileus virginianus*) and elk (*Cervus elaphus*), but at rates that are unknown in natural systems. Spread of planted forage crops into wildlands, or nonnative invasive weeds into food plots would affect ecosystem processes and management costs. To address endozoochory, collections of fecal pellets from both ungulate species were done at the Current River Conservation Area in Southeastern Missouri. Randomly chosen individual pellets collected from nine food plots were planted in a greenhouse setting. After cold stratification of pellets (2°C at 15 days), pellets were either left whole or broken apart to simulate natural decomposition or weathering. Significantly more seeds germinated from pellets which were broken apart, indicating some decomposition may be an important factor for germination from fecal pellets. Data supports studies showing spread of plant species by deer and elk, both nonnative and native. Both species more successfully dispersed viable seed from nonnative species throughout the study; however, no native forage species germinated from elk pellets. Seeds of plants consumed by these wild ungulate species may contribute to same-season growth of invasive plant species, which will certainly result in novel seed banks via this dispersal mechanism.

KEYWORDS: Cervidae, Ozarks, endozoochory, invasive, dispersal, richness

This abstract is approved as to form and content

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Chairperson, Advisory Committee
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I. INTRODUCTION TO ENDOZOOCHORY

How introduced plant species spread after introduction is of particular interest in many landscapes (Cain et al. 2000, Auffret et al. 2014). For example, in the United States, 98% of crop and livestock species are nonnative (Pimentel et al. 2000). Whether native or not, once introduced to novel areas, plant species can move around using the landscape's natural seed dispersal mechanisms. Wind, water, or gravity can move seeds from a flowering plant to the soil, to germinate and begin the cycle again. Animals can also move seeds around an ecosystem through the process of zoochory. For example, mammal species in North America are able to spread seeds by two main zoochorous means; by collection and deposition off of the hide of an animal, and from ingestion and defecation. The ingestion and defecation of seeds, known as endozoochory, allows for longer distance dispersals than other mechanisms might provide. Thought of as a common occurrence mostly in birds, endozoochory in ungulates including many cervid species has been shown to move plant seed around an environment (Myers et al. 2004, Bartuszevige et al. 2008, Blyth et al. 2013, Auffret et al. 2014, Polak et al. 2014). This regional movement of seeds by wild and domestic animals has been examined in only a few regions of the United States (Myers et al. 2004, Bartuszevige et al. 2008, Blyth et al. 2013). Therefore, dispersal of both native and nonnative plants has been shown to be facilitated by white-tailed deer (*Odocoileus virginianus*) and elk (*Cervus elaphus*), however the extent has not been adequately studied enough to provide reliable management advice for many regions of North America. While same-season germination rates can be high in plant species with high seed production, the effect of nonnative or

invasive plant competition is usually not seen as a problem in the same season. However, additions of these nonnative, weedy, or invasive seeds to the seed bank of an area over a number of years can change competition regimes of plant species and alter plant communities for long periods of time (Howe et al. 2004, Blyth et al. 2013).

The study of cervid capabilities to spread seeds across a landscape has mainly been focused on long-distance dispersal (Walker 1994, Cain et al. 2000, Howe et al. 2004). Research has been conducted in certain areas of the United States regarding cervid seed dispersal, but very few have focused on nonnative plants, and none of these have been conducted in the Ozarks. Seed ingestion and defecation by cervid mammals is rarely the main mechanism for dispersal of plant species, but it can have compounding effects on germination rates in many areas (Pakeman 2001).

Nonnative Plant Species and Endozoochory

Nonnative plant species are introductions to new places, regardless of their status as harmful; while invasive plant species enter into a novel area, outcompete the native plants, reproduce and spread (Randall et al. 2008). It has been accepted in many situations that invasive species are second only to habitat destruction in terms of threatening biodiversity worldwide (Pimm et al. 1989). These invasive plants are often ones which have evolved to use many different vectors for seed dispersal, of which endozoochory in cervids is one. In terms of management, controlling nonnative or invasive plants is rarely done before an invasion has advanced to a late stage. The literature contains many ways to reduce growth of certain invasive or weedy species, but hardly does it provide details on how to manage these species over entire habitats, unless

it is a high-intensity eradication regime (Davies et al. 2007). These eradication programs may reduce the number of invasive species, but often do so at the cost of losing native species in the process, and they are not recommended (Blackburn et al. 2010). Endozoochory is a mechanism that can slowly add nonnative seed to a novel area, and those seeds can germinate over a number of years. However, some habitat managers have created proactive control approaches, which have been found to be the most successful and cost-efficient ways to handle problem species (Simberloff 2008). Nonnative plant species are often adapted to growing in habitats with high disturbance, and habitat fragmentation and land use changes offer more opportunities for their introduction and spread by endozoochory.

Seed Dispersal by Endozoochory in Cervids

Both elk and white-tailed deer can facilitate the spread of non-native plants into distant areas at higher rates due to endozoochorous means. Seeds that are consumed by ungulates can at times pass through the gut tract not fully digested and be deposited in the fecal pellets (Olson 1999). This indigestible nature of a seed and an incomplete breakdown of the seeds coat can result in whole, healthy seeds being moved around the landscape (Barnes et al. 1992). These fecal pellets, upon breaking down, can release the seeds into the soil thus allowing them to germinate (Auffret et al. 2014). Because seeds get partially broken down by the gut tract and microbes of the rumen, seeds in fecal pellets are seen to germinate into seedlings faster than those not ingested (Polak et al. 2014). From time of ingestion to time of defecation, the literature shows gut retention time of captive white-tailed deer to be 12-65 hours (Mautz et al. 1971, Vellend 2003) and

between 14-60 hours for captive elk (Renecker et al. 1990, Jiang et al. 1996). In the wild however, because of metabolic requirements of a non-captive environment, gut retention time of deer is 23 hours (Mautz et al. 1971, Pakeman 2001), and elk is 14-41 hours (Milne et al. 1978, Pakeman 2001). These numbers differ due to the metabolic requirement of animals based on their body size, with a portion coming from nutrients of the particular diet they have consumed (Kleiber 1947).

Cervid species, having large home ranges, are able to move species of plants into areas where they have not been known to exist previously (Gill et al. 2001). In some habitats, the lack of food in a certain area coupled with abundance in another can exacerbate the amount of nonnative material being brought in. This trend can be even greater when there are similar seed-spreading species with diet requirements that may overlap at times (Bartuszevige et al. 2008). The territories of white-tailed deer and elk can overlap in favorable habitats, with the overall territory sizes being estimated at 23.2-31.5 ha (Labisky et al. 1998) and 40-5179 ha, respectively (Szemethy 1994, MDC 2010). Home ranges of these species in the early months of the year might also be influenced by the inability of female deer with offspring to move throughout their entire range. The ingestion and defecation of a plant's seeding body by cervid species could alter plant communities miles away, adding new seeds to the seed bank over time. However with landscapes that are being altered more often and a changing global climate, it is unclear if same-season movement and germination of seed may become a more important factor to those plant communities.

Introduced Species and Endozoochory in Missouri

The Missouri Department of Conservation has created a list of Problem Plants and Animals in Missouri (MDC 2015). There are 28 plant species listed, and they were a priority target for this project. While not every one of the 28 species listed can be spread by mammals, the seeds of the grasses and small forb species are able to be dispersed if the seeds survive the gut tract. Also important are the species planted as forage for animals. Planted forage regimes take into account many different requirements. Ease of growth, ease of care, a species weed status, and nutrition are all important factors that determine if a plant species will be used in a forage operation. Even species that are of good quality forage, but are seen as nonnative or weedy in other systems such as row crops may be considered. However, using some nonnative species is a risk to the plant community of surrounding areas, as some plants with ruderal characteristics or ones which are able to outcompete native species have a tendency to become invasive in many places.

II. RATIONALE FOR STUDY

Nonnative plants, especially weedy or invasive species have differences in germination and growth that allow for them to compete with native species (Pimentel et al. 2000). Seeds which are able to begin germination at the earliest of Growing Degree Days (GDD's) well into the late fall, can outgrow native species that may begin germinating later. Studies regarding movement of plant species by cervids have focused on the best growing periods of late spring into the summer, but a more comprehensive view of germination should include collections starting in early spring and continuing into the fall (Bartuszevige et al. 2008, Auffret et al. 2014). Beginning a study in the early spring, and collecting late into the fall, ensures a more complete collection of the primary growth that is being browsed by the cervid species. Studying same season germination of seedlings grown from cervid fecal pellets can show which nonnative species are being moved around on a regional scale.

Habitat fragmentation and land use change that has been occurring in most of the United States, including much of Missouri, results in a decreasing amount of quality forested land each year (USDA 2009). While Missouri is actually one of the few states that has had a net forested acreage increase over the past three decades, small-scale fragmentation of high quality forested land cancels out some of the ecosystem services that might have been available had those areas been left whole (USDA FS 2008). While

the chance for seed germination isn't extremely high in every environment, and most plants aren't adapted solely for spread by cervid defecation, it is an often overlooked means of seed dispersal. Abundance of cervids, as well as the seasonal changes in the plant community will determine the possibility for nonnative or invasive plants to be spread into novel areas (Forsyth et al. 2007). Also, the indirect competition between the cervid species will determine both which species of plants are consumed, and how far the seeds are spread when the animals travel throughout their home range (Levin et al. 2003). As elk themselves are a recently re-introduced species into Missouri, their choices of what to consume may be different than those of deer, which will determine what species they may spread in their fecal pellets. These nonnative plant species have impacts on the seed bank of the area, but are also able to set seed and germinate again in the same season which will is a main focus of this study.

III. QUESTIONS AND HYPOTHESES

The goal of this study was to evaluate cervid spread of nonnative plant seeds. Germination of those seeds contained in both deer and elk fecal pellets collected at the Current River Conservation Area was compared. All plant species' seeds have specific environmental cues that causes them to break seed dormancy and begin germination. Also, each seeding species has its own mechanism for dispersal. This study examined roles of white-tailed deer and elk as a dispersal mechanism for seeds that would be returned to the soil after ingestion and defecation. These seeds were given an opportunity under favorable greenhouse conditions to germinate from the fecal pellets in the same growing season.

Decomposition of these fecal pellets which results in exposed seeds was also compared between the two cervid species, to understand its role in germination success of ingested seeds. I wanted to better understand which plant species were being moved around the landscape by this process of endozoochory, and at what time of the growing season it occurred most. Plant species begin seeding at different times, and if certain invasive species were known to produce seeds during certain conditions, endozoochory could become an important mechanism for their spread.

Species of plant seedlings that germinated from the pellets were noted. Seedlings were identified on an individual basis, as well as put in one of four categories. The

categories that were used were: Native Forage, Native Non-forage, Nonnative Forage, and Nonnative Non-forage. With this distinction, while artificial, I was better able to determine which types of species were more likely to be moved by endozoochory. Within the Nonnative Non-Forage species, it was important to determine which species being moved were invasive or noxious weed species. Other weed species germinating from pellets that are problems in agricultural or turfgrass industries were also examined closely.

I hypothesized that facilitation of nonnative plant germination would be greater throughout the growing season than native species, as these species may better be able to utilize this dispersal mechanism and fill unused niches in the environment. While some of the nonnative species in the Ozarks are now naturalized across the area, and the entire United States of America, these species can be competitive with the natives of the area. I also hypothesized that these nonnative plants present would germinate more often than native species from within fecal pellets that had been broken apart to more expose the seeds.

IV. METHODS

Study Sites

All research took place at the 11,853 hectare Current River Conservation Area in Southeastern Missouri (Appendix A). This conservation area in the counties of Reynolds, Shannon, and Carter, contains suitable habitat for both cervid species, which have ample opportunity to alter plant community structure in and around the forest. Elevation ranges throughout the area from 160 to 300 meters above sea level. The Ozark Mountains of the area are dominated by oak and hickory forests, and the acorn crop produced is a large factor for deer presence. Food plots are also located throughout the conservation area, planted with forage and maintained to provide food to the majority of the area's game species such as: turkey, deer, and now elk.

Elk were re-introduced to Missouri at the nearby Peck Ranch Conservation Area in 2011. Estimates of their numbers have reached approximately 130 individuals (Mr. David Hasenbeck, Missouri Elk Program Manager, Personal Communication). The entire elk restoration zone comprises 346 square miles, 79% of which is accessible to the public, and that zone includes all of the Current River Conservation Area. Deer are abundant in this south-eastern region of Missouri. In the three counties that the conservation is in, harvest numbers from the 2015 November firearm season alone total 3,896 individuals (MDC 2015 Deer Harvest Summary). The quality of the forests in this

area, as well as planted food plots gives these species a habitat in which they can survive and reproduce well.

All samples of feces were taken from the northeastern side of the Current River Conservation Area, in what was historically referred to as Deer Run State Forest (Dr. Paul Porneluzi, Central Methodist University, Personal Communication). Collections were taken from 9 of the 66 food plots on the property, plots: 5, 9, 14, 22, 39, 49, 54, 60, and 62 (Appendix B). The food plots were chosen as collection sites due to assumed increased relative density of deer and elk in a common area for grazing, and because fecal pellets would be easier to find. The 9 sites while chosen randomly, were haphazardly spaced throughout the entire area of food plots and ranged in size as well as plant composition.

Data Collection Methods

Twenty-two collections were conducted over 217 days, from 11 April 2015, to 14 November 2015. These collections were spaced approximately 10 days apart, allowing animals to return to the food plots numerous times and deposit fresh feces. Collection dates occurred: April 11, 19, 26, May 2, 10, 23, 31, June 6, 14, 28, July 8, 17, August 1, 15, 22, September 5, 19, 26, October 3, 17, November 1, and 14.

To ensure random sampling across all of the plots of varying plant compositions, points were generated at each site using a random point generator from GeoMidpoint™. This was done to reduce a collection bias that may be present, knowing that the same species of plants will not be present throughout each collection location. At each of the 9 food plots, 2 of these random collection points were made. At each geographic collection

point, circles were walked outward to find fecal pellets. Fresh fecal pellets were collected, those being the ones with the most fresh color and/or warmest to the touch. If fresh feces were not available at the collection point, the first pellet grouping found was collected. This was the case for collecting both white-tailed deer and elk feces. Pellet groupings were collected only based on the randomized location. No attempt was made to balance each plot with one elk and one deer pellet grouping, simply whichever two were found first.

Once a pellet grouping was collected, 4 individual pellets were randomly selected and the rest left in the plot. The 4 selected pellets would be lightly washed off, to remove any extra debris or seeds that may have come in contact with them after defecation. All fecal samples were cold-stratified in full darkness for 15 days at 2°C. The literature highlights some problems with long-term cold stratification in some plant species, even in climates where true winters take place (Milberg et al. 1998, Baskin et al. 2003). This short time frame allowed seeds to break some physical dormancy if required, and still provided an opportunity for same-season germination to occur if other seed requirements were met (Farmer et al. 1970, Schutz et al. 1999). The process of digestion provided opportunity for both physical and chemical natural scarification for whatever seed was present, so an acid wash to break the seed coat was not used (Howard 1986, Hock et al. 2006).

After this 15 days of cold stratification at 2°C, the four pellets were planted in a greenhouse on the campus of Missouri State University. Two were planted whole as the control group, and two were broken apart for the experimental group; to determine if seedling emergence would change after decomposition of the pellet. Throughout the

study period, 1,584 individual pellets were planted into trays in the greenhouse setting. Based on the experimental design and the lower number of elk in the area in relation to deer, 1,184 of the planted pellets were collected from deer and the remaining 400 were from elk. Elk pellets were not found at each plot on each collection day, but throughout the span of the experiment all plots yielded elk pellets for collection. The experimental (broken) group was used to simulate weathering or decomposition which might be conditions that would occur in the field. The growing medium used was a horticultural grade sphagnum peat and perlite formulation containing 0.05% Nitrogen (N), 0.01% Phosphate (P_2O_5), and 0.05% Potash (K_2O). Pellets were planted in 72-well growing trays, covered with a plastic cover for 15 days, and then left to grow either until a seedling germinated or when the greenhouse portion of the experiment ended in late January, 2016. Pellets in the soil were kept watered to maintain a moist soil, never allowed to completely dry out. Upon germination of a seedling, it was identified as soon as possible to allow space for other seeds to germinate, or was given time to develop if it could not be accurately identified when small. Twelve seedlings from the experiment died before they were able to be identified to the species level, and were removed from the experiment entirely.

Data Analysis

Many observed 0's were present in the data set, and the populations of both cervids, and the combined groups' pellets which had germinating seeds were non-normal (Anderson-Darling test, $P = <0.005$). Because of the non-normal data, non-parametric means tests were used to look for trends in germination. Kruskal-Wallis tests were used

to compare each cervid species germination to collection date as well as collection site to determine differences, and chi-square tests compared those individual trends. The many 0's of the study were included as an ordinal rank, as only 34% of the total pellets planted produced 1 or more germinant. For all statistical testing, a α-value of 0.05was used to test for significance. For analyses, equal probability of germination was assumed across treatment (broken or unbroken), cervid species, plot, and collection. Chi-square tests were used to compare unbroken and broken pellet germination in deer, elk, and across both species. It was assumed that from deer and elk pellets, one seedling would emerge from each. Chi-square tests were also used to compare between specific plots and collection times throughout the study, assuming that wherever pellets were collected from at a given date, seedlings would emerge from all pellets the same.

V. RESULTS

Seedling Germination from Deer and Elk Pellets

A total of 1,584 pellets were collected and planted in the greenhouse. Seeds germinated from 406 individual pellets. From those 406 individual pellets, a total of 469 seedlings emerged. As the study took place in a greenhouse, seedlings emerged throughout the entirety of the study, from April of 2015 through January of 2016. The number of total elk pellets collected (400) was fewer than deer pellets (1184) due to only ~130 elk living in the area, and collection was done at random in each food plot. However, the number of expected seedlings per pellet was greater in elk than deer pellets (Figure 1, Table 1). Of the 1,184 deer pellets planted in the greenhouse, 303 total seedlings emerged from 283 of those pellets. Overall, 23.90% of the deer pellets planted produced one or more seedlings. In comparison, from the 400 elk pellets planted in the greenhouse, 166 seedlings germinated from 123 of the pellets. Overall, one or more seedling germinated from 30.75% of elk pellets planted. Elk were the only species from which a pellet produced more than 5 seedlings. There were occurrences of 7, 8, 10, and 11 individual seedlings emerging from a single elk pellet.

Pellet Treatment and Temporal Patterns in Germination

Across both deer and elk, significantly more seeds germinated from pellets that had been broken apart (chi-square; P = 0.0036, Table 2). Of the 303 seedlings which germinated from deer pellets, 118 of those emerged from unbroken pellets and 185 emerged from broken pellets. There was a significant effect of treatment on germination from deer pellets (chi-square, P = < 0.001, table 3). Out of 166 seedlings germinating from elk pellets, just over half (85) were from unbroken pellets. Therefore, there was no significant effect of treatment on germination from elk pellets (chi-square; P = 0.7562, Table 3). This is shown comparatively by number of pellets with 1 or more seedlings, and the total number of seedlings which emerged from each species' pellets (Table 4).

Kruskal-Wallis tests identified no significant difference in mean germination between the nine collection sites when looking at both species together (P = 0.238). Neither of the individual species' pellets showed any significant difference in germination based on their collection plot. The only collection plot where there was a significantly greater number of seedlings in pellets was food plot 60 (Table 5). In this plot, 96 deer pellets and 80 elk pellets were collected, from which 23 and 71 seedlings emerged, respectively. Plot 60 was one of two with nearly equal or equal number of pellets collected from deer and elk. Food plot 62 had equal number of deer and elk pellets collected (88 and 88), but only 47 seedlings emerged from pellets collected throughout the study (21 from deer pellets and 26 from elk pellets) (Table 5).

Species Richness and Identity of Cervid Dispersed Seed

Thirty-five different plant species were identified from deer pellets, and after 58% of pellets were planted in the greenhouse (693 of the 1,184) no new species were found

(Figure 2). The collection on 1 August 2015 was the last date a novel species germinated from a pellet. No new species of seedlings germinated during the remaining 24 weeks of the study (Figure 3). Twenty-six different plant species were identified from elk pellets, and after 66% of pellets were planted in the greenhouse (267 of the 400) no more new species were found (Figure 4). Similarly, after 22, August 2015, no new species were found germinating from elk pellets during the remaining 21 weeks of the study (Figure 5). Chi-square tests identified significant differences in seedling emergence during the different fecal collection dates (P = <0.001, Figure 6). The large spike on June 6th is attributed to germination of *Dysphania pumilio* (R. Br) Mosyakin & Clemants., representing 64.86% of that collection dates' seedlings. 41 of those seedlings emerged from elk pellets. Germination of seeds from pellets grown in the greenhouse followed a trend by Growing Degree Days throughout the study, indicating similar seasonal germination in the wild (Figure 7).

Of the 37 total species that germinated from cervid pellets, 23 are listed as nonnative species. Eight out of the 23 are planted for forage in the food plots. Of the remaining 14 native species found, only 2 are planted as forage. Across both deer and elk, more nonnative species were dispersed than native species (Table 6). Elk did not disperse any native forage species throughout the study. When looking at nonnative forage and nonnative non-forage seedlings, more nonnative non-forage species were dispersed successfully by deer. Elk also successfully dispersed more nonnative non-forage than nonnative forage (Table 6). Seedlings growing from the pellets identified as Tall fescue, *Lolium arundinaceum* (Schreb.) S.J. Darbyshire, a weed species in agricultural systems, made up 5.7% of total seedlings. One species from the MDC's list of problem plants and

animals made up 4.6% of all seedlings, Johnsongrass, *Sorghum halepense* (L.) Pers. This noxious weed species is required by state law to be removed on sight if it is present. Clammy goosefoot (*Dysphania pumilio* (R. Br.) Mosyakin & Clemants) represented 17.4% of all seedlings that were produced from deer and elk pellets. This is a species from Australia that is relatively unknown for its forage quality or population characteristics. A master list of species reveals which were successfully moved by each cervid, and how many seedlings of each species were identified in total (Table 7).

VI. DISCUSSION

Germination of seedlings from deer and elk pellets at the Current River Conservation Area revealed new trends on how endozoochory could change plant communities in natural systems. Findings also confirmed studies in other regions showing that these cervid species are capable of moving viable seed throughout the environment (Auffret et al. 2014, Blyth et al. 2013, Bartuszevige et al. 2008, Myers et al. 2004, Polak et al. 2014). By using individual pellets, probability of a germinable seed being carried through the gut tract of a cervid, deposited onto the ground, and then growing into a mature plant could be more accurately estimated. Using this approach instead of using the entire fecal pellet grouping like other research (Milne et al. 1978, Jiang et al. 1996, Blyth et al. 2013), I was also able to study and understand each seedling individually as opposed to an experiment which would resemble a diet study. Throughout the study, 469 seedlings emerged from 406 of the 1,584 total pellets planted. Germination of seedlings did not occur in the majority of the pellets, and some pellets had more than one seedling emerge. Therefore, all seedlings which emerged, were from 25.63% of the pellets that were planted. The overall probability of one seedling emerging from a pellet was 29.61% for both cervid species combined. At over a 25% chance of a pellet

producing a seedling, it is possible that cervids may alter plant communities through ingestion and defecation of plant seeding bodies.

Deer pellets totaled 1,184 in number. 283 of the deer fecal pellets produced at least one seedling (24.74%). Of the 400 total elk pellets, 123 produced at least one seedling (30.50%). While the numbers of pellets from each species were vastly different due to species density in the area, elk pellets did produce more seedlings in comparison. Of the total 37 species which were found throughout the study, deer successfully dispersed 35 and elk dispersed 26. Deer dispersed more species successfully than elk, but based on the sample sizes, both cervids were effective in moving local plant seed.

To simulate natural weathering or erosion that may take place in field conditions, half of the pellets planted were left whole and half were broken apart. Deer pellets had a significant response to being broken apart. Of the 35 plant species whose seeds were dispersed successfully, 13 were from unbroken pellets, and 22 were from broken pellets. Similarly, of the 303 seedlings which germinated from deer pellets, 118 were from unbroken pellets, and 185 were from broken pellets. This may indicate that seeds inside deer pellets are more prone to germination once those pellets have broken down. The response was not found in elk pellets. Of the 26 plant species which germinated from elk pellets, 15 were from unbroken pellets, and 11 were from broken pellets. From unbroken elk pellets 85 of the 166 seedlings were found, while the remaining 81 were from broken pellets. The difference in treatment effects on pellets may be explained by the size of individual elk pellets, and overall number of pellets per defecation from elk. Larger size of both pellets and pellet number, possibly because of a larger amount of food ingested per day by elk, could have led to more seeds per pellets. This could have resulted in elk

pellets not needing to be broken apart to successfully allow seedlings to germinate from within.

Due to the experimental design, the large difference in number of deer versus elk pellets collected was unavoidable. During the scouting phase of the experiment, it was clear that while both deer and elk have large home range sizes, there were times when elk pellets could not be found on sampled food plots. These plots without as many elk feces tended to be the smaller plots located on the northern half of the study. This could be due to the southern plots being nearest to where the elk were released at Peck Ranch, or possibly just a matter of population density when compared to that of deer. All 9 plots used in the study did at some point yield fecal pellet groupings from elk. Two of the southern sites had almost identical number of pellets collected. Site 60, which produced 80 elk pellets from the total 176 collected, had the highest mean germination when comparing collection site at 53%. Site 62 however produced equal number of deer and elk pellets, and those germinated only 27% of the time. Therefore, the probability of seedling germination differing across collection plot was not evident.

Germination followed seasonal trends, as was expected. Higher expected germination in the summer months of species in the field was mimicked by seedlings germinating from the fecal pellets. Growing trends also followed Growing Degree Days (GDD base 50° Farenheit) that were seen in field conditions. The highest mean germination from pellets was observed from June through September. Mean germination slowly increased from April until June, and decreased after September. The choice for using a short window of stratification at a lower than usual temperature might have hindered germination in some species that may have been present in the fecal pellets.

Studies show that the stratification time might be one of the most important factors if a seed will be viable or not (Pipinis et al. 2011, Liu et al. 2011). It might also be a possibility that the greenhouse design created a bias toward weedy, quick germinating plants (Leon et al. 2004). While the goal of the experiment was to understand the role of these cervids in same-season movement of plant species, this does not invalidate the results.

While only one of the plants listed on the Missouri Department of Conservation's list of Problem Plants and Animals was found during this study, it is key to note its background as one of the most wide-spread invasive species found in North America. The perennial invasive Johnson grass (*Sorghum halepense* (L.) Pers.) that made up just under 5% of all seedlings in the study, is listed in Missouri as a noxious weed species. Federal law mandates that noxious weed species are required to be removed by a landowner or manager on sight. This is because their invasive growth habits lend them to grow faster or outcompete many native or planted species simply by crowding them out and depleting resources available to other species. It was, and still is considered one of the world's 10 worst weed species going back decades (Holm et al. 1977). The plant that germinated from seeds in the pellets more than any other was the annual forb Clammy goosefoot (*Dysphania pumilio* (R. Br.) Mosyakin & Clemants). It represented 17.37% of all seedlings in the study, and had a large influence starting from when it first germinated from a cervid pellet, collected on May 31st. Clammy goosefoot is a chenopod species introduced from Australia (Rahiminejad et al. 2004). Deer often preferentially browse on species from the family Amaranthaceae, species like lambsquarters and pigweeds, but these species aren't listed in the literature as being of great quality forage. However,

because of their high amount of seed production, whether browse is preferential on this species or just accidental, the possibility for spread is more likely. Some species in the Chenopodiaceae family are halotoerant, suggesting they are able to grow in less than desirable habitats for most plants, which could also be seen as a trait of a species capable of invading new areas.

During this study, the focus was on the movement of four different groups of plants. Native forage, native non-forage, nonnative forage, and nonnative non-forage were compared to each other to be able to distinguish groups by management need, and to determine if they are problematic plant species. Throughout the study, more nonnative plant species successfully germinated from cervid pellets than did native species. From deer pellets: 12 of the 35 species were native, 2 of those were forage and 10 were non-forage. The 23 remaining species were nonnative, 8 of which were forage species, and 15 of which were not. Alternatively, elk pellets produced no native forage species, and 7 native non-forage species. Nonnative species from elk pellets made up the remaining 73%; 7 of which were nonnative forage and 12 were nonnative non-forage.

Management of the species on a property depends on the type of landscape. Forested lands have different management regimes than a row-cropping agricultural system would. For example, one of the species that was identified quite often was tall fescue, *Lolium arundinaceum* (Schreb.) S.J. Darbyshire. Tall fescue is a weed in many row cropping systems, yet it is grown for forage in pasture habitats. While it is used as forage, it was important to make the distinctions between the native and nonnative species, so use of this research could be tailored to a landowner’s specific situation. Overall movement of nonnative plant seed that successfully germinated from cervid fecal

pellets dwarfed the native counterparts, at 87%. These plants' status as nonnative might have come from the 1600's, or the last decade, but many are naturalized across the country today.

In summary, this study shows potential movement of plants that may become problems in new areas, whether they are considered weedy, invasive, noxious or otherwise. It also reveals that some plants which are already unwanted in certain landscapes can be moved by the process of endozoochory in cervids. Choices made by managers about what to plant, what to manage, and how to do so, are still of vital importance when preserving landscape integrity. Endozoochory is another factor that may need to be researched if there are high numbers of deer present. This process influences what is being dispersed across the landscape by these cervids. Further research might begin with captive experiments; hand-fed animals consuming various plant species and depositing them could be tested for successful germination. Or possibly tracking a single animal and collecting feces while noting plant composition along their path.

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Table 1. Number of plants produced from individual pellets of both cervid species planted in the greenhouse throughout the experiment (April 11th – November 14th, 2015). The effect of treatment (broken vs. unbroken) on pellets producing at least 1 seedling was significant (chi-square; P = 0.0015).

Plants per pellet	Deer Unbroken	Deer Broken	Deer Total	Elk Unbroken	Elk Broken	Elk Total
0	483	418	901	138	139	277
1	101	166	267	57	55	112
2+	8	8	16	5	6	11

Table 2. Number of seedlings germinating between unbroken (control) and broken (treatment) cervid pellets. Assuming equal germination between the groups, significantly more seedlings came from pellets which were broken apart (P = 0.0036). This number was influenced due to the high number of deer pellets (1,184 compared to 400 elk pellets), which had 303 seedlings emerge of the total 469.

Cervid Pellets	Expected Seedlings	Observed Seedlings
Unbroken	234.5	203
Broken	234.5	266
Total	469	469

Table 3. Number of seedlings germinating between unbroken (control) and broken (treatment) effects on deer and elk pellets. Seedlings were expected to germinate equally from broken and unbroken pellets. Seedlings from deer pellets emerged significantly more often from broken pellets ($P = < 0.001$). Seedlings from elk pellets showed no significant difference in emergence from broken or unbroken pellets ($P = 0.7562$).

Deer	Expected	Observed	Elk	Expected	Observed
Unbroken	151.5	118	Unbroken	83	85
Broken	151.5	185	Broken	83	81
Total	303	303	Total	166	166

Table 4. Breakdown of pellets from both cervid species. While seedlings did not emerge from the majority, elk pellets by proportion had more instances of 1 or more seedlings per pellet than did deer. Seedlings also emerged significantly more often from elk pellets (chi-square; P = < 0.001).

		Total Pellets	Pellets with 1+ seedlings	Total Seedlings
Deer	Unbroken	592	109	118
	Broken	592	174	185
Elk	Unbroken	200	62	85
	Broken	200	61	81

Table 5. Number of seedlings that emerged from fecal pellets collected from the 9 plots during the study. Elk pellets represented 45% of the total 176 pellets collected from food plot 60. Seedling emergence from pellets collected from plot 60 was higher than any other plot (94 seedlings). Significantly more of those seedlings were from elk pellets (71) (chi-square; P = < 0.001). Pellets were collected in equal numbers at plot 62, but those pellets showed no significance in number of seedlings which emerged (chi-square; P = 0.4658).

Plot	Deer Pellets	Number of plants	Elk Pellets	Number of plants	Total number of plants
5	160	43	16	6	49
9	112	25	64	22	47
14	156	45	20	6	51
22	164	36	12	2	38
39	132	33	44	12	45
49	140	44	36	9	53
54	136	33	40	12	45
60	96	23	80	71	94
62	88	21	88	26	47
Total	1184	303	400	166	469

Table 6. The four different groups (Native Forage, Native Non-forage, Nonnative Forage, and Nonnative (N.F) Non-forage) used for species-characterization during the study. Seedling number represents the count of plants that emerged from either deer or elk pellets. The count of species represents one of the specific four groups, and how many of those species were moved by each cervid. More nonnative species were moved in this study by endozoochory. Of those introduced plants, more were non-forage species as well.

Species from Deer	Observed	Percentage	Species from Elk	Observed	Percentage
Native Forage	2	5.71%	Native Forage	0	0.00%
Native Non-forage	10	28.57%	Native Non-forage	7	26.92%
Nonnative Forage	8	22.86%	Nonnative Forage	7	26.92%
Nonnative N.F.	15	42.86%	Nonnative N.F.	12	46.16%
Total	35	100%	Total	26	100%

Table 7. List of species (Total = 37) germinating from deer and elk pellets throughout the study. Number of seedlings which emerged is shown, as well as from which cervid the seedling was moved by, and its status and forage standing.

Family	Genus	Species	Authority	Source	# of seedlings	Status	Forage
Amaranthaceae	*Dysphania*	*pumilio*	(R. Br) Mosyakin & Clemants.	Both	82	Nonnative	N
Fabaceae	*Trifolium*	*repens*	L.	Both	44	Nonnative	Y
Fabaceae	*Trifolium*	*pratense*	L.	Both	40	Nonnative	Y
Poaceae	*Setaria*	*viridis*	(L.) Beauv.	Both	33	Nonnative	N
Poaceae	*Dactylis*	*glomerata*	L.	Both	31	Nonnative	Y
Poaceae	*Lolium*	*arundinaceum*	(Schreb.) S.J. Darbyshire	Both	27	Nonnative	Y
Poaceae	*Sorghum*	*halepense*	(L.) Pers.	Both	22	Nonnative	N
Poaceae	*Setaria*	*pumilia*	(Poir.) Roemer & J.A. Schultes	Both	22	Nonnative	N
Poaceae	*Poa*	*annua*	L.	Both	14	Nonnative	N
Poaceae	*Triticum*	*aestivum*	L.	Both	14	Nonnative	Y
Poaceae	*Lolium*	*multiflorum*	Lam.	Both	12	Nonnative	N
Fabaceae	*Melilotus*	*officinalis*	(L.) Lam.	Both	12	Nonnative	N
Poaceae	*Setaria*	*faberi*	Herm.	WTD	11	Nonnative	N
Poaceae	*Bromus*	*tectorum*	L.	Both	10	Nonnative	N
Cyperaceae	*Carex*	*eburnea*	Boott	Both	8	Native	N
Phytolaccaceae	*Phytolacca*	*americana*	L.	Both	8	Native	N
Apiaceae	*Daucus*	*pusillus*	Michx.	Both	8	Native	N
Poaceae	*Panicum*	*capillare*	L.	Both	8	Nonnative	N
Solanaceae	*Solanum*	*carolinense*	L.	Both	6	Native	N

Continued Table 7.

Family	Genus	Species	Authority	Source	# of seedlings	Status	Forage
Poaceae	*Secale*	*cereale*	Lam.	Both	6	Nonnative	Y
Asteraceae	*Cichorium*	*intybus*	L.	Both	5	Nonnative	N
Scrophulariaceae	*Verbascum*	*thapsus*	L.	Both	5	Nonnative	N
Fabaceae	*Medicago*	*sativa*	L.	WTD	4	Nonnative	Y
Plantaginaceae	*Plantago*	*major*	L.	WTD	4	Nonnative	N
Poaceae	*Vulpia*	*myuros*	L.	Both	4	Nonnative	N
Amaranthaceae	*Amaranthus*	*retroflexus*	L.	Both	4	Native	N
Rubiaceae	*Galium*	*aparine*	L.	WTD	3	Native	N
Asteraceae	*Taraxacum*	*officinale*	G.H. Weber ex Wiggers	WTD	3	Native	N
Poaceae	*Schizachyrium*	*scoparium*	(Michx.) Nash.	WTD	3	Native	Y
Poaceae	*Avena*	*sativa*	L.	Both	3	Nonnative	Y
Polygonaceae	*Rumex*	*altissimus*	Wood.	WTD	3	Native	N
Poaceae	*Elymus*	*virginicus*	L.	WTD	3	Native	N
Molluginaceae	*Mollugo*	*verticillate*	L.	Elk	2	Native	N
Asteraceae	*Cirsium*	*altissimum*	L.	WTD	2	Native	N
Poaceae	*Andropogon*	*Gerardi*	Vitman.	WTD	1	Native	Y
Euphorbiaceae	*Euphorbia*	*corollata*	L.	Elk	1	Native	N
Geraniaceae	*Geranium*	*pusillum*	L.	WTD	1	Nonnative	N

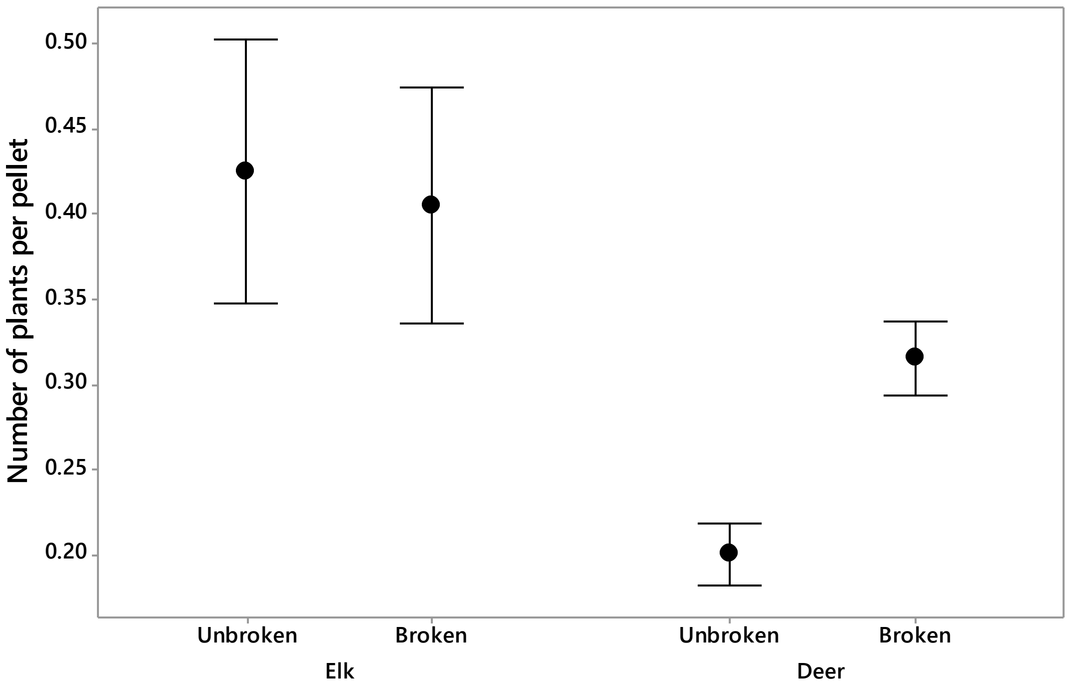


Figure 1. Interval plot showing probability ±1 standard deviation of one individual fecal pellet of either cervid species producing at least 1 germinant throughout the entire study and across all plots. Half of the pellets collected from the field were manually broken apart after collection. Elk pellets with total N = 400, produced 85 seedlings from the unbroken (control) pellets, and 81 from broken pellets. Deer pellets with total N = 1,184 produced 118 seedlings from unbroken pellets, and 185 from broken pellets.

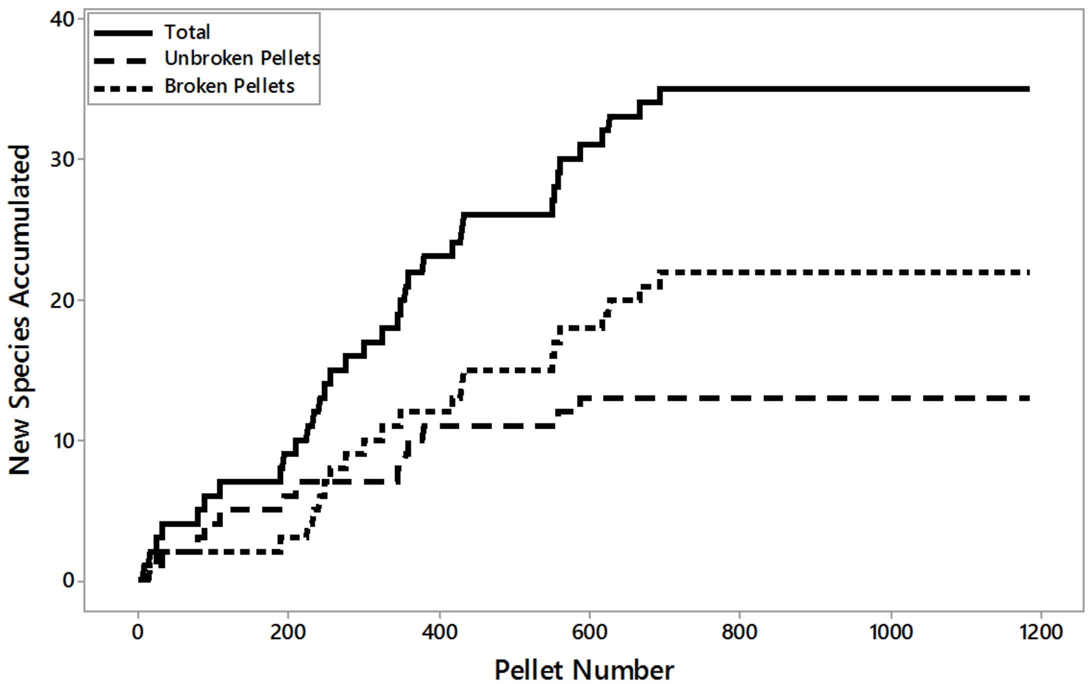


Figure 2. Species accumulation curve for all plant species which germinated from deer pellets planted in the greenhouse. 1,184 individual deer pellets were planted, and the 35 different plant species identified are shown by chronological order and number of pellets collected throughout the study. The top line shows the total species accumulated, the middle line being broken deer pellets and the bottom line is unbroken deer pellets.

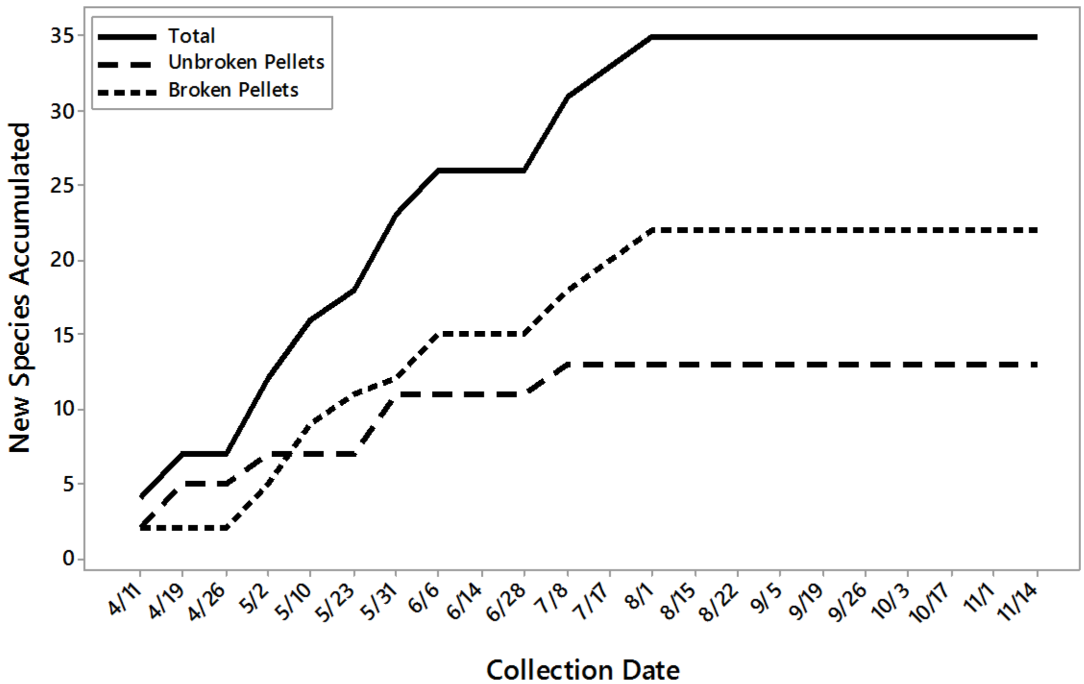


Figure 3. Plant species accumulation from deer pellets through each of the 22 collection dates throughout the experiment. The top line shows the total (35) species accumulated, those from unbroken (13) and broken (22) deer pellets.

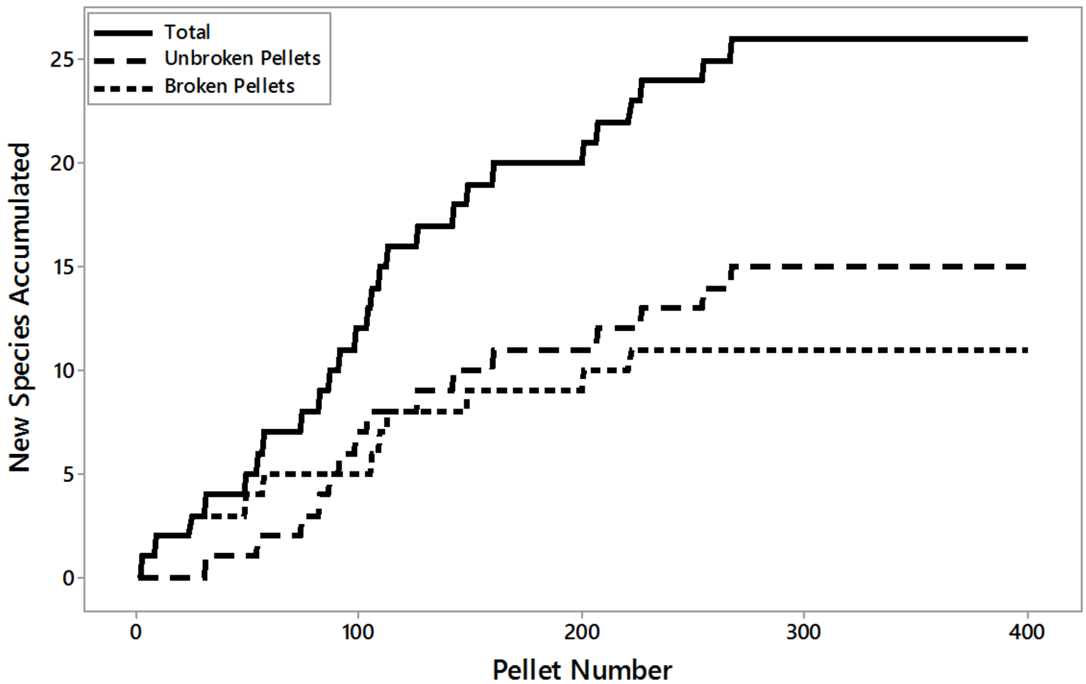


Figure 4. Species accumulation curve for all plant species which germinated from elk pellets planted in the greenhouse. 400 individual elk pellets were planted, and 26 different plant species identified are shown by chronological order and number of pellets collected throughout the study. The top line shows the total species accumulated, the middle line being unbroken elk pellets and the bottom line is broken elk pellets.

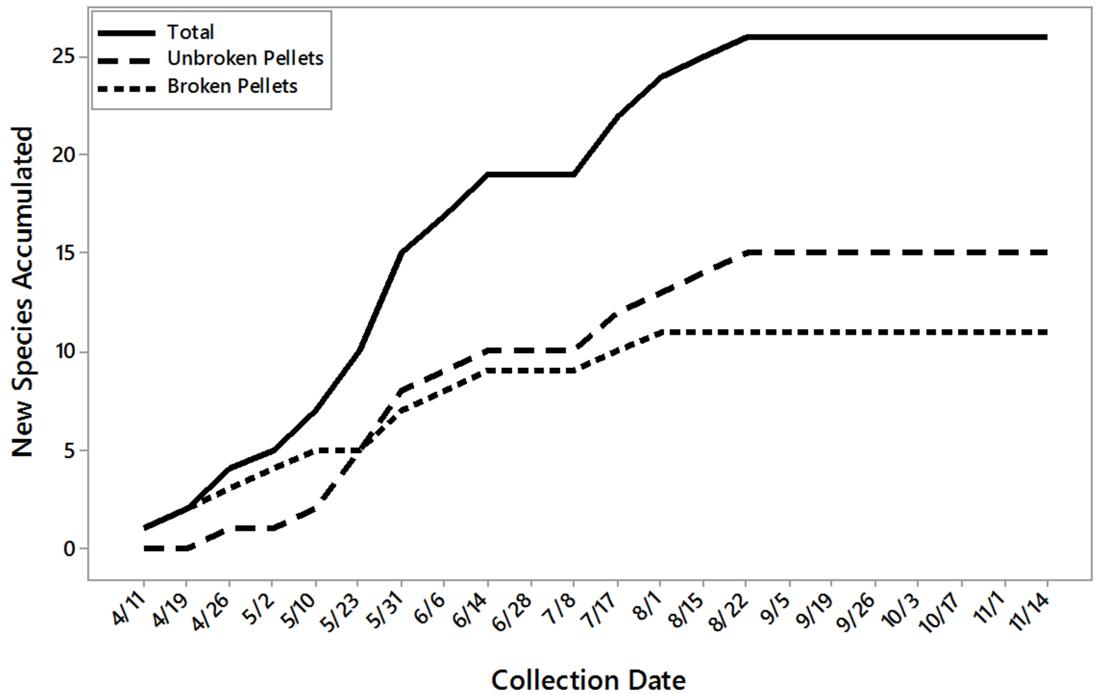


Figure 5. Plant species accumulation from elk pellets through each of the 22 collection dates throughout the experiment. The top line shows the total (26) species accumulated, those from unbroken (15) and broken (11) elk pellets.

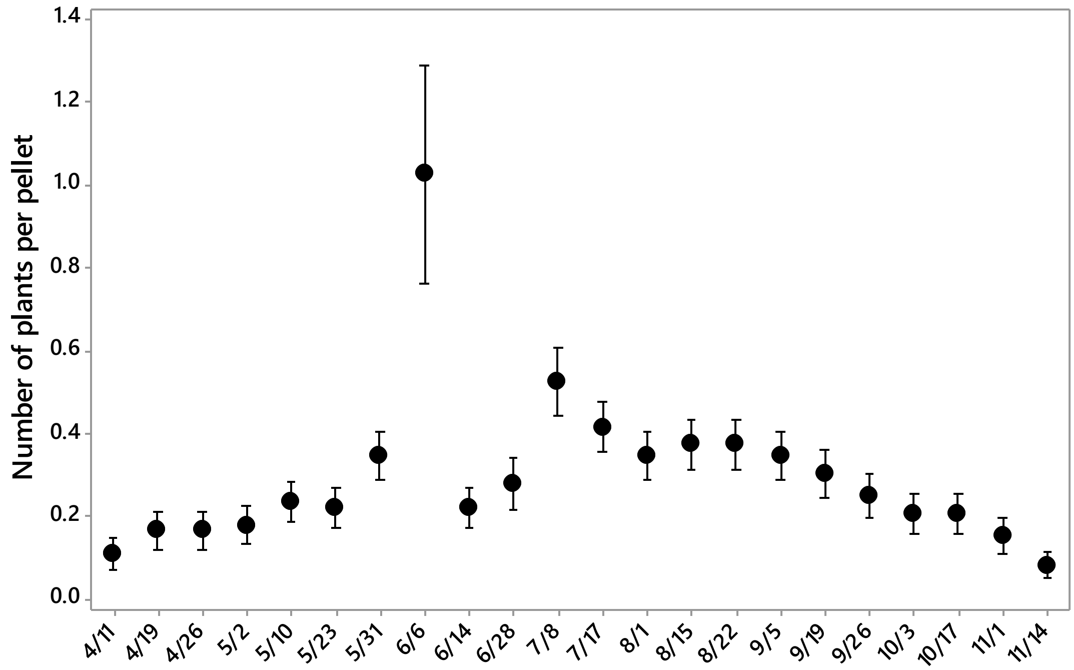


Figure 6. Mean number of plants ±1 standard deviation (N = 72 pellets per time period) from an individual fecal pellet over the course of the study. Number of plants reflects probability of a randomly chosen deer or elk pellet producing 1 or more germinant.

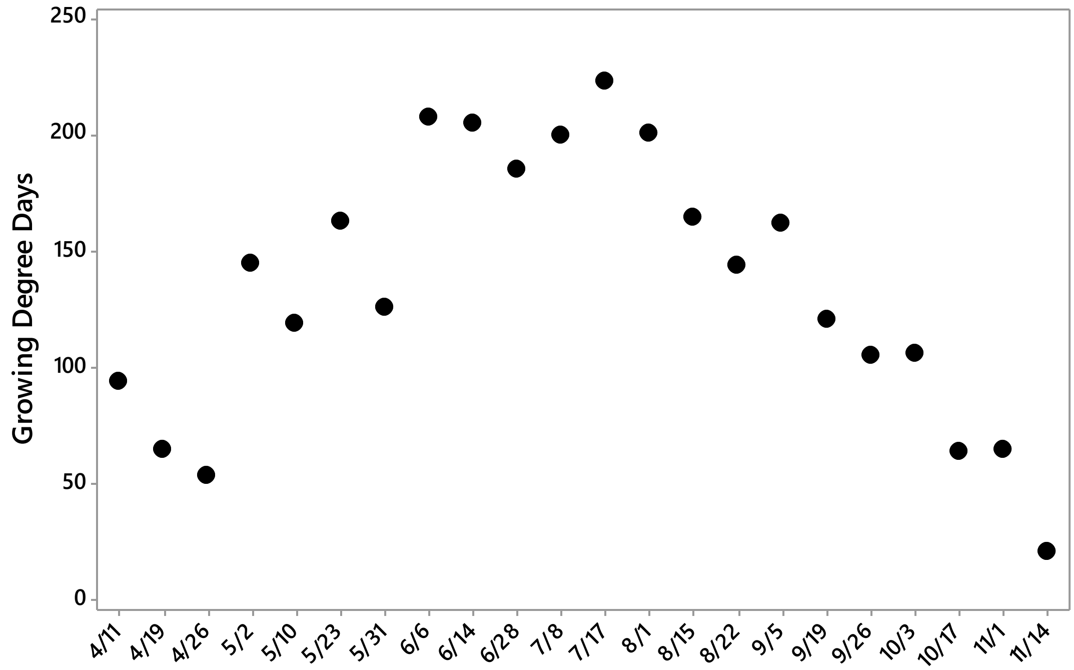
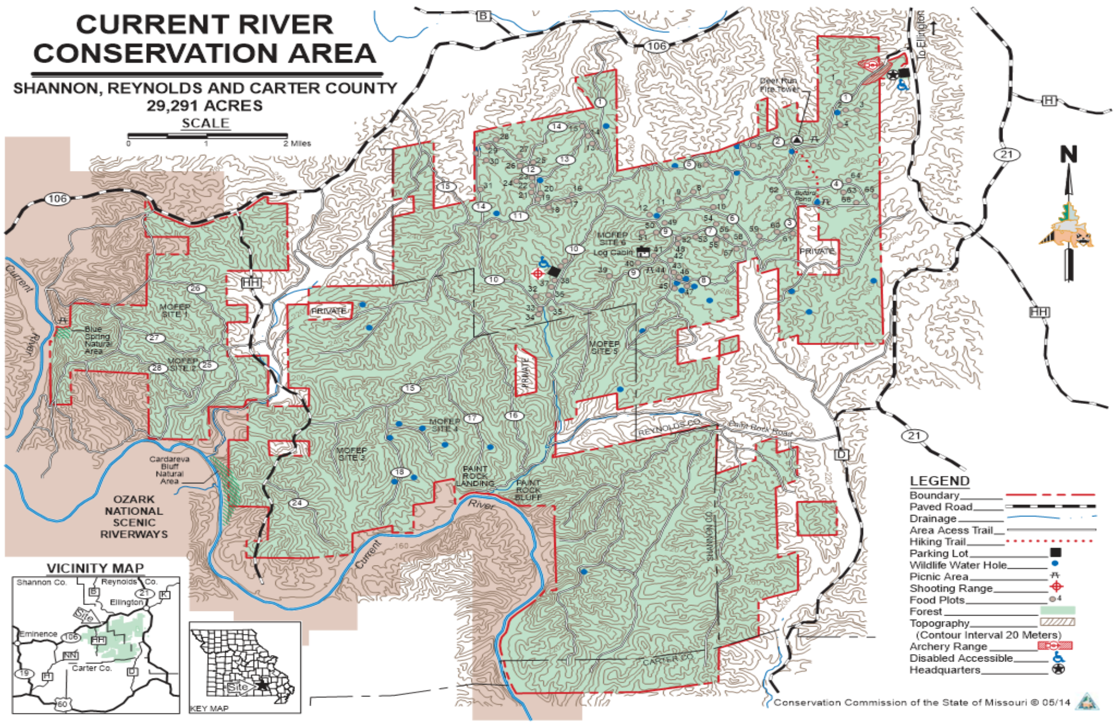


Figure 7. Weekly total Growing Degree Days (GDD, base 50°Farenheit) throughout the study. Used mainly in agricultural systems to determine when different stages of growth will occur, GDD was used here as a similar metric to show germination opportunity throughout the study. Average daily temperature minus 50°F produced a daily GDD, which was used for the weekly total. Weekly GDD was used to indicate conditions that pellets would have experienced after being deposited in the field.

APPENDIX

Appendix A

Map of the Current River Conservation area in southeastern Missouri. This section of the Ozark Mountains – Salem Plateau, part of the U.S. Interior Highlands is located southwest of Ellington, Missouri. Food plot collection locations were in the northeastern corner of the conservation area.



Appendix B

Food plot collection locations (shown by enlarged circle) within the Current River Conservation Area. 9 food plots were randomly selected from more than 60 that range throughout the northeastern and north-central regions of the conservation area. Ease of collection and increases in animal traffic were the bases for food plots being chosen as collection sites.