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# MS ENVIRONMENTAL BIOLOGY CAPSTONE PROJECT

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# MS ENVIRONMENTAL BIOLOGY
# CAPSTONE PROJECT

by

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A Project Presented in Partial Fulfillment
of the Requirements for the Degree
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# CHAPTER 1. LITERATURE REVIEW

## Urban nesters: Management implications of designing bird habitat on anthropogenic structures

### *Introduction*

Rampant urbanization via updating and adding to existing infrastructure contributes to the loss of the world's biodiversity and the homogenization of its biota (Aronson et al., 2014). The construction of bridges, electrical poles, roads, culverts, buildings, and dams, among others, can fragment habitat and degrade delicate ecosystems (Aronson et al., 2014). Although some of these anthropogenic structures are built with wildlife in mind, most project managers do not take into consideration how wildlife may use them beyond what their intended function should be. The spatial and temporal distribution of these anthropogenic structures can have varying effects on wildlife (De Lucas et al., 2008; Ferrer et al., 2012). Although most urbanization leads to a reduction of wildlife habitat, some anthropogenic structures may create new habitat for some highly adaptable species who are able to use these structures to their advantage (Lancaster & Rees, 1979; Mainwaring, 2015). Birds are particularly adaptive to the presence of man-made structures and use them for nesting and perching, and some highly adaptive species have filled the available niches in urban environments, thus preventing other bird species from thriving (Mainwaring, 2015). Implementing management strategies that examine the mechanisms that allow specific bird species to use these man-made structures is something that should be applied more broadly in the early planning stages of a project.

*Benefits of anthropogenic structures to birds*

Animals that use anthropogenic structures do so for many reasons including safe passage across or beneath highways, shelter from the elements, protection from predators, and to raise their young (Imlay, Nickerson, & Horn, 2018; Waller & Servheen, 2005). For birds, anthropogenic structures enhance the niches within that built environment (Lancaster & Rees, 1979). These structures provide an increased supply of holes, crevices, and ledges on which birds can nest and roost (Lancaster & Rees, 1979). Holes in telephone poles, gaps in houses, or even birdhouses are great options for cavity-nesting species like the Eastern bluebird (*Sialia sialis*), house sparrow (*Passer domesticus*), most woodpeckers, tits, and chickadees (Mayntz, 2021). Some cavity-nesting species, like the barn owl, use nest boxes during the breeding season, while other species use them during the non-breeding season when the nesting birds have vacated. Nest boxes increase the number of cavities available during the winter months, and birds that use them gain considerable thermal benefits and energy savings (Mainwaring, 2011). Cup nests, which are used by barn swallows (*Hirundo rustica*), ruby-throated hummingbirds (*Archilochus colubris*), yellow warblers (*Setophaga petechia*), and American robins (*Turdus migratorius*), can be positioned along tree branches, or may be nestled on ledges of buildings or even built beneath overpasses (Mayntz, 2021). Platform nests, which are built by many raptor species and large wading bird species, are relatively bulky and often built of larger twigs or sticks placed strategically on top of tall trees or telephone poles (Mayntz, 2021). Nesting opportunities for raptors are often enhanced through the modification of power-poles and by providing pre-built nesting platforms on the powerline structures (Kochert & Olendorff, 1999). Some raptors have even been known to nest on active construction equipment, locations that most other birds avoid (i.e. cranes; personal observation). All of these birds have adapted to the existence of certain anthropogenic structures, and some preferentially use them for nesting and roosting instead of their natural habitat.

### *Costs of anthropogenic structures to birds*

There are both direct and indirect negative effects (e.g. collisions and avoidance) associated with anthropogenic structure use by birds (Drewitt & Langston, 2008; Kuvlesky et al., 2007; Patten et al., 2005; Pruett, Patten & Wolfe, 2009). Fences, power lines, roads and wind turbines have all been associated with collision mortality in birds (Bevanger, 1998; Kociolek et al., 2011; Rioux, Savard & Gerick, 2013). Collision fatalities with anthropogenic structures are frequently implicated in biodiversity loss resulting from bird deaths, but indirect impacts such as fragmentation of habitat and disruption of migration corridors can also negatively affect bird populations (Waller & Servheen, 2005; Jenkins, Smallie & Diamond, 2010; Degregorio, Weatherhead & Sperry, 2014). Additionally, habitat fragmentation and disruption of migration corridors can alter how birds locate suitable nesting sites and can lead them to sites that are ecological traps.

### *Ecological Traps*

Ecological traps, or environmental cues that previously signaled a suitable habitat but leads an animal to use an unsuitable site, can decrease individual fitness and ultimately lead to population declines (Imlay, Nickerson, & Horn, 2018). No bird species is immune to the potential existence of ecological traps, but several studies have highlighted the problems that specific species have encountered because of them. Imlay, Nickerson, & Horn (2018) explored whether high nest temperatures and the physical properties of barns were associated with lower breeding success for a declining population of cliff swallows (*Petrochelidon pyrrhonota*). Cliff swallows are a cup-nesting species that has been known to build their mud nests along bridges, culverts and on buildings. The cliff swallows in Imlay, Nickerson, & Horn's (2018) study examined nestling fitness when nests were constructed on houses beneath wood or metal roofs. Cliff swallow survival and nestling mass was found to be lower when nests were constructed under metal roofs. Thus, as heat from the metal roofs increased, offspring fitness decreased (Imlay, Nickerson, & Horn, 2018; Savard & Falls, 1981). The researchers concluded that this was an example of an ecological trap, as sites that had previously been suitable, were no longer considered suitable due to high temperatures.

Another study explored the use of nest boxes by roosting birds during the non-breeding season (Mainwaring, 2011). The birds that use nest boxes during the non-breeding season are widely targeted by detrimental ectoparasites that thrive inside the nest boxes (Mainwaring, 2011). Because only some of the nest boxes have been infested, birds have no way of knowing which nest box to use, however variation in the quality of individual nest boxes as roosting sites, and competition between species resulted in larger and more dominant species roosting in preferred nest boxes that were not infested (Mainwaring, 2011). Thus, another example of an ecological trap.

Finally, Kochert & Olendorff (1999) explored how raptors benefit from the presence of power lines. Raptors that use power lines for perching have historically caused problems by disrupting power and can be electrocuted if they land on a wire that has not been fitted with the proper bird-safe protections (Kochert & Olendorff, 1999). Thus, this use of powerlines is considered an ecological trap for the raptors, as they have no way of discerning safe lines from unsafe lines. Despite the presence of ecological traps, many bird species continue to preferentially nest and roost on anthropogenic structures, and some have adapted to the point of dominating the few available niches in urban habitats (Lancaster & Rees, 1979).

### *Anthropophilic species and decreased diversity*

Although there can be an increased supply of holes, crevices, and ledges for nesting on anthropogenic structures, oftentimes, the few niches that are enhanced by the built environment are already occupied by a few highly adaptive species (Lancaster & Rees, 1979). This effect can often lead to homogeneity of urban bird communities. These highly adaptive species are sometimes referred to as “urban dominants” or anthropophilic species (Lancaster & Rees, 1979). Many of these “urban dominants” that use anthropogenic structures for nesting are cup, cavity, or platform nesters. Based on a global study of 54 cities, the most common species in cities globally included rock doves (i.e., rock pigeons) (*Columba livia),* house sparrows *(Passer domesticus),* European starlings *(Sturnus vulgaris),* and barn swallows (*Hirundo rustica)* (Aronson et al., 2014). Many of these species select anthropogenic structures due to their proximity to food, particularly in urban areas. These urban food subsidies can contribute to reduced species diversity while maintaining overall densities of favored species (Lancaster & Rees, 1979).

### *Management Implications*

Strategic management tactics can be implemented during the early stages of planning for structures that are known to be preferentially used by birds, either to deter unwanted species or attract desirable species. Many of the tactics that are currently used to deter unwanted species include the use of potentially harmful bird deterrents such as bird spikes and netting. Alternatively, landscape management implementations, such as planting less-desirable trees to deter species that detrimentally outcompete others, could lead to successful population control of the more dominant species and allow for further niche diversification. Overall, increasing bird diversity in urban habitats is an important aspect of management that should be applied more broadly among building planners. By investigating how birds may use a man-made structure once it is completed may allow for a more diverse group of species to use them successfully. More specifically, managers should explore how foliage height, disturbance level, and the creation of artificial nesting and roosting opportunities may serve to benefit birds that have otherwise been unable to successfully use man-made structures.

*Foliage Height*

Across an urban gradient, Lancaster and Rees (1979) found that as foliage height diversity increased, so did bird species diversity. This diversity in foliage height provides new, valuable niches for bird species that otherwise might be outcompeted by the “urban dominants”. Additionally, structural complexity of the habitat (as measured by the amount of foliage) was a good predictor of bird species diversity, regardless of which vegetation layer(s) predominated (Lancaster & Rees, 1979). House crows in Singapore, considered a “pest species”, selected nest sites in areas that were more open and were close to trash and food centers, thus managers planted less-desirable trees to deter the crows and encourage less-common species to nest in those areas instead (Soh et al., 2002). All of these circumstances provide evidence that building planners and managers should investigate how foliage may contribute to the success or failure of bird establishment in urban areas.

*Level of Disturbance*

For some species, the level of disturbance near anthropogenic structures was more important determinant of species presence than was habitat structure. The house crows in Singapore selected nest sites in areas that were more urbanized with higher disturbance (Soh et al., 2002). Alternatively, barn owls abandon their territories following the disappearance of anthropogenic structures (nest boxes), the depletion of edges and ditches, the expansion of road networks, and persecution (i.e., highly disturbed habitat) (Martínez & Zuberogoitia, 2004). Some researchers speculated that birds may be more likely to nest higher in areas that are considered more disturbed, however, level of disturbance associated with urban habitat was not found to be a principal factor in explaining the higher nesting height of birds when compared with natural habitat (Savard & Falls, 1981). Results like these demonstrate why building managers should explore how the level of disturbance, both spatially and temporally, might impact how birds use man-made structures.

### *Artificial Nesting and Roosting Opportunities*

Another management tactic that could be widely implemented is explicitly creating nesting and roosting opportunities for birds. In a study in Spain, barn owls preferred areas with a high availability of cavities, mainly in anthropogenic structures (nest boxes), and high percentages of edges and ditches (Martínez & Zuberogoitia, 2004). As previously stated, power poles can be modified to allow for additional nesting and roosting sites for raptors (Kochert & Olendorff, 1999). In rural areas, the creation of eco-bridges is an idea that has been implemented in countries like South Korea and Canada with great success (Huh et al., 2015). These structures, however, are aimed more specifically toward large mammals and other terrestrial species, and there is little data on how they are used by birds. Future studies should examine this relationship to better assess whether eco-bridges provide suitable habitat for birds or are simply being used as they were intended (as animal crossings).

## *Conclusions*

In the more intensely developed areas, urban niches are restricted to ledge-, cavity-, and platform-nesting species (Lancaster & Rees, 1979). However, anthropogenic structures do provide suitable nesting sites for a range of threatened bird species globally, which suggests that building managers could use such structures as tools to aid in the conservation of endangered birds much more than they do at present (Mainwaring, 2015). Specifically, managers should explore how foliage height, disturbance level, and the creation of artificial nesting and roosting opportunities may serve to benefit less-common species of birds and aid in their success in urban habitats. Researchers speculate that without opportunity for further niche diversification, it is unlikely that other species will adapt or evolve to compete successfully with the established urban dominants (Lancaster & Rees, 1979). Thus, through careful planning and research, anthropogenic structures built in the future could allow for further niche diversification and provide suitable habitat for more species of birds.

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# CHAPTER 2. GRANT PROPOSAL

## Management implications of niche dominance by anthropophilic bird species in Denver, CO

### *Section 1. Abstract*

Niche dominance by anthropophilic bird species prevents less-common species from persisting in urban habitats. These less-common species are often considered threatened because of their inability to adapt to urbanization. Dominance by anthropophilic bird species leads to homogenization of urban bird communities. Although management tactics exist to deter “urban dominant” bird species, building planners rarely plan for bird usage of anthropogenic structures in the early stages of projects. This prevents managers from taking a proactive approach toward creating niches for less-common birds and deterring urban dominants, thus preventing managers from aiding in conservation efforts by increasing local bird diversity. Oftentimes, building planners have no knowledge of the bird species found in their project site, nor any of the habitat characteristics of the area being urbanized. I plan to bridge this knowledge gap by conducting an urban bird community and urban habitat study. The GIS portion of this study will aim to define vegetative and structural habitat characteristics within 11 districts in Denver, Colorado. The bird census aspect of this study aims to understand the current bird community composition and diversity within the 11 districts and aims to quantify the relationship between habitat diversity and bird species diversity within these urban areas. This improved knowledge will allow building managers to diversify the available niches located on anthropogenic structures to enhance the diversity of birds in the urban area.

## *Section 2. Anticipated Value, Literature Review, Objectives, & Hypotheses*

### *Anticipated Value*

This study will inform bird conservation efforts by identifying how building managers can plan for bird use of anthropogenic structures through the diversification of niches. To give an accurate description of the bird populations that occupy these niches, I will measure species richness, diversity, and abundance of birds that are observed nesting and/or roosting on anthropogenic structures. I will also measure foliage height, level of disturbance, and the presence of artificial nesting and roosting opportunities (i.e., nesting boxes/platforms) within the study areas to determine bird habitat suitability. Historically, management tactics used to control urban dominant bird populations have focused solely on deterring them, rather than focusing on methods to attract more diverse bird communities through niche diversification. The information from this study will fill knowledge gaps on which species currently occupy the available urban niches on anthropogenic structures, thus providing building managers with the tools to promote bird diversity and control urban dominant species.

### *Literature Review*

#### *Urban Dominants*

Urbanization typically leads to reduction of wildlife habitat; however, some anthropogenic structures may create new habitat for highly adaptable species who are able to use these structures to their advantage (Lancaster & Rees, 1979; Mainwaring, 2015). Birds are particularly adaptive to the presence of man-made structures, which provide an increased supply of holes, crevices, and ledges for nesting. However, the few niches that are enhanced by the built environment are quickly occupied by a few highly adaptive species, sometimes referred to as “urban dominants”, or anthropophilic species (Lancaster & Rees, 1979). Niche dominance by anthropophilic species can homogenize urban bird communities, with less adapted species being unable to outcompete the dominant species (Lancaster & Rees, 1979). Historically, management tactics used to control urban dominant bird populations have focused solely on deterring them, rather than focusing on methods to attract more diverse bird community through niche diversification.

*Nesting Types*

In urbanized areas, urban niches are restricted to cavity-, ledge-, and platform-nesting species, thus, many of the urban dominants also fit into these nesting categories (Aronson et al., 2014; Lancaster & Rees, 1979). Holes in telephone poles, gaps in houses, or even birdhouses are great options for cavity-nesting species like the Eastern bluebird (*Sialia sialis*), house sparrow (*Passer domesticus*), most woodpeckers, tits, and chickadees (Mayntz, 2021). Some cavity-nesting species, like the barn owl, use nest boxes during the breeding season, while other species use them during the non-breeding season when the nesting birds have vacated. Nest boxes increase the number of cavities available during the winter months, and birds that use them gain considerable thermal benefits and energy savings (Mainwaring, 2011). Cup nests, which are used by barn swallows (*Hirundo rustica*), ruby-throated hummingbirds (*Archilochus colubris*), yellow warblers (*Setophaga petechia*), and American robins (*Turdus migratorius*), can be positioned along tree branches, or may be nestled on ledges of buildings or even built beneath overpasses (Mayntz, 2021). Platform nests, which are built by many raptor species and large wading bird species, are relatively bulky and often built of larger twigs or sticks placed strategically on top of tall trees or telephone poles (Mayntz, 2021). Based on a global study of 54 cities, the most common species in cities globally included cavity nesters like the rock dove (i.e., rock pigeon) (*Columba livia),* house sparrows *(Passer domesticus),* and European starlings *(Sturnus vulgaris),* and cup nesters like barn swallows (*Hirundo rustica)* (Aronson et al., 2014). Despite these nesting types being the most common in urban habitats, urban dominant bird species tend to displace less-common species of the same nesting type.

*Habitat Requirements of Anthropophilic Bird Species*

Birds require very specific habitat characteristics when using anthropogenic structures, and this can influence their success in urban habitats. Some important requirements include foliage height, level of disturbance, and the creation of artificial nesting and roosting opportunities. Across an urban gradient, Lancaster and Rees (1979) found that as foliage height diversity increased, so did bird species diversity. This diversity in foliage height provides new, valuable niches for bird species that otherwise might be outcompeted by the "urban dominants". Additionally, structural complexity of the habitat (as measured by the amount of foliage) was a good predictor of bird species diversity, regardless of which vegetation layer(s) predominated (Lancaster & Rees, 1979). For some species, the level of disturbance near anthropogenic structures was a more important determinant of species presence than was habitat structure. House crows in Singapore selected nest sites in areas that had a higher level of disturbance but were more open and were close to trash and food centers (Soh et al., 2002). Oftentimes, these urban food subsidies alone, can contribute to reduced species diversity, while maintaining overall densities of urban dominant species (Lancaster & Rees, 1979). Alternatively, barn owls abandon their territories following the disappearance of anthropogenic structures, the depletion of edges and ditches, the expansion of road networks, and persecution (i.e., highly disturbed habitat) (Martínez & Zuberogoitia, 2004). Finally, the presence of artificial nesting and roosting opportunities can play an important role in the diversification of niches. Nesting opportunities for raptors are often enhanced through the modification of power-poles and by providing pre-built nesting platforms on the powerline structures (Kochert & Olendorff, 1999).

*Deterrents & Opportunities*

Opportunities exist to enhance avian diversity in urban environments through careful planning and management. Anthropogenic structures provide suitable nesting sites for a range of threatened bird species globally, which suggests that building managers could use such structures as tools to aid in the conservation of endangered birds (Mainwaring, 2015). Strategic management tactics to deter unwanted species and/or attract desirable species can be implemented during the early stages of planning for structures that are known to be preferentially used by birds. Many of the tactics that are currently used to deter unwanted species include the use of potentially harmful bird deterrents such as bird spikes, netting, and even electric shock (Seamans & Blackwell, 2011). Alternatively, landscape management implementations, such as planting species of trees to deter urban dominants, could lead to successful population control of the more dominant species and allow for further niche diversification (Soh et al., 2002). However, rather than focusing solely on deterring species that dominate urban niches, managers should also aim to diversify niches in the planning stages of projects to attract more diverse species. Investigating how birds may use a man-made structure once it is completed may allow for modifications that will allow more species to successfully utilize the structure and surrounding vegetation for nesting and roosting. More specifically, managers should explore how foliage height, disturbance level, and the creation of artificial nesting and roosting opportunities may serve to benefit birds that have otherwise been unable to successfully use man-made structures (Mainwaring, 2015). Through careful planning and research, anthropogenic structures built in the future could provide opportunities for further niche diversification and thus provide suitable habitat for more species of birds. Managers need a prior understanding of the habitat structure and the presence or absence of rare and dominant bird species in the area they are planning to develop.

*Objectives*

This study will provide baseline data on bird use of anthropogenic structures in an urban environment. Data will be collected on bird species diversity, bird species dominance, and urban habitat characteristics, particularly foliage height diversity. These data will provide building managers/planners with critical knowledge on current urban bird species diversity, and the bird species currently absent within the urban habitat. These data will be valuable for suppressing the abundance of known urban dominants and allowing for the persistence of the species they out-compete through the diversification of the existing urban niches.

*Questions & Hypotheses*

Table 1. Questions and hypotheses.

| | |
|---|---|
| **Q1**: What are the dominant bird species in the city of Denver, CO? | **Q2**: What is the relationship between foliage height diversity and bird diversity in Denver, CO? |
| **H1**: Rock doves (i.e., rock pigeons) (*Columba livia*), house sparrows (*Passer domesticus*), European starlings (*Sturnus vulgaris*), and barn swallows (*Hirundo rustica*) are the most dominant species in Denver, CO. | **H2**: Areas in Denver, CO with higher foliage height diversity will also have higher bird diversity. |

*Section 3. Methods*

*Plot Selection & Census Methods*

To quantify bird abundance and diversity, I will randomly select 5 ~130-ha study plots from within each of the 11 council districts in Denver, CO, USA (see Appendix). Following plot selection, 5 points will be randomly selected within each plot. These points will serve as centroids for radial point counts during bird censuses. Birds will be counted during the breeding season (early May- late August) and census counts will occur between 0.5 and 3.5 hours after sunrise. For each census, an observer will conduct 5 ~200-yard radius point-counts per plot to estimate species abundance (González-Oreja et al., 2018). Centroids for radial point counts will be randomly selected. I will use the incidence of each species at each habitat type as a proxy for its local abundance (González-Oreja et al., 2018). Species, location, and activity of all birds (adults and fledglings) seen or heard will be recorded on census map-sheets.

*Habitat Description*

To quantify habitat diversity, Leaf Area Index (LAI) will be calculated for all trees within each plot using a PARBar ceptometer, which uses the photosynthetically active radiation (PAR) inversion technique for calculating LAI (Salter et al., 2019). The PARBar uses a modified version of the canopy light transmission and scattering model, in which LAI is estimated using the amount of light energy transmitted by a plant canopy, wherein a very dense canopy will absorb more light than a sparse canopy (Salter et al., 2019). Additionally, canopy height will be measured for each tree within the plots using a Nikon Forestry Pro II rangefinder in “Height Mode”. Finally, nesting/roosting height will be measured for any birds noted perching on any vegetation or anthropogenic structures within each plot.

*Data Analysis*

To address my first hypothesis, I will summarize census results as number of species per square kilometer and determine the mean density of each species and the total bird community in each plot. I will then divide these data into nest type categories (i.e., cup, cavity, or platform nester) to determine the relative abundance of each nest type within each plot. I then will calculate bird species diversity and bird species richness for each plot in each nest type category.

To address my second hypothesis, foliage height diversity (FHD) will be calculated from the LAI using the *leafR* package in R (R Core Team, 2021). Relationships between characteristics of bird communities and FHD will be examined statistically using analysis of variance (ANOVA). I will examine variation in mean density of each bird species, bird species diversity, bird species richness and FHD between plots and nesting types to determine the best fitting model. I will include the presence of anthropogenic structures as a random effect.

*Negative Consequences*

Any negative impacts should be minimal when conducting this study. There will be no handling of birds or nests during data collection, as this study is observational. There will be minimal disturbances to the environment during fieldwork. Observers will maintain a minimum distance of 10 feet from the birds to minimize the amount of disturbance.

*Project Schedule*

| **Date** | **Activity** | **Deliverables** |
|---|---|---|
| Mid-March 2022-mid-April 2022 | Determine suitable survey sites | GPS of suitable sites |
| Late-April 2022-late-May 2022 | Collect aerial photos of spring vegetation at sites | Use ArcGIS and existing habitat polygons to display site boundaries and varying vegetative heights. |
| Early-May 2022-late-August 2022 | Conduct bird surveys and collect habitat data | Excel spreadsheet of bird species, percent cover and structure characteristics by plot |
| Early-Sept. 2022-Late Dec. 2022 | Analyze field data. | Monthly status reports on data analyses. |
| Early-Jan. 2023-late-Feb. 2023 | Draft, edit, and complete report | Final Report |

*Section 4. Budget*

| Item | Justification | Cost per Unit | Quantity | Total |
|---|---|---|---|---|
| Gosky Updated 20-60x60 HD Spotting Scope with Tripod, Carrying case and Smartphone Adapter | For field surveys conducted at a distance >1000 yards. | $179.98 | 3 | $539.94 |
| Adasion 12x42 HD Binoculars with phone adapter | For field surveys conducted at a distance <1000 yards. | $149.99 | 3 | $449.97 |
| Garmin Oregon GPSMAP 64sx | To reach points/map locations | $349.99 | 2 | $699.98 |
| Rite in the Rain mini-stapled weatherproof notebooks (3 pack) | For field notes | $8.95 | 2 | $17.90 |
| ArcGIS/Collector (1-year subscription) | To manage GIS datasets/polygons/rasters | $500 | 1 | $500 |
| Nikon Forestry Pro II rangefinder | To measure vegetation/structure height within plots. | $499 | 2 | $998 |
| Stipends | Payment to research assistants for field work May-August (3 assistants) | $2,000.00 | 3 | $6,000 |
| Total Resource Expenditures | | | | $9,205.79 |

*Appendix*

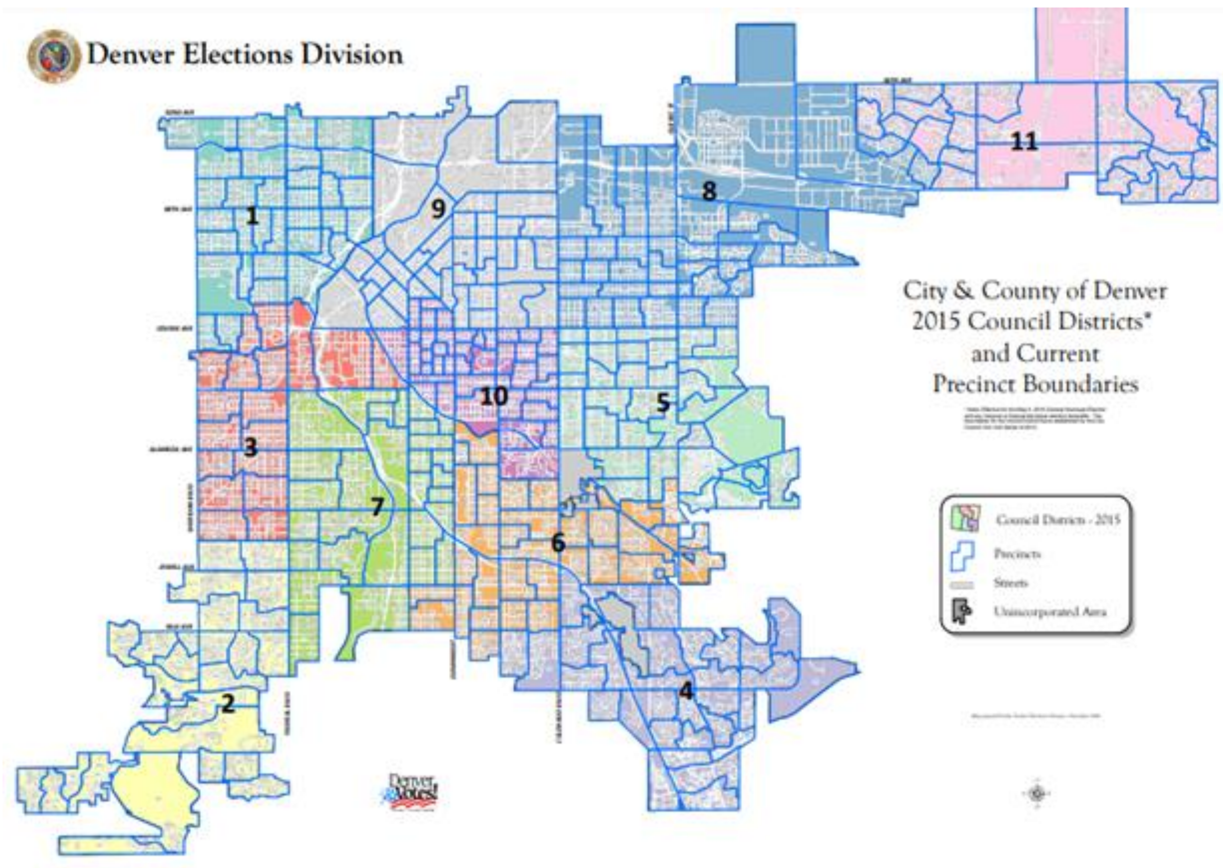


Figure 1. City and County of Denver (2015) Council Districts and Precinct Boundaries (City of Denver, 2021).

# Samantha Kathleen Ortega

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## Education

- **M.S. Environmental Biology (expected graduation May 2022)**

Regis University
Graduate Student Council Member

- **B.A., Biology with a Minor in Environmental Studies, *Magna Cum Laude,* 2020**

Regis University
Dean's List – Fall 2019, Spring 2020; Member of Alpha Sigma Lambda - Regis Chapter

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## Research Experience

- **Croke Reservoir Environmental Assessment –** *Regis University & Croke Reservoir Subcommittee* **August 2020-present**

Quantified potential environmental impacts of public misuse of the Croke Reservoir and surrounding nature area in Northglenn, Colorado. Completed an Environmental Assessment (EA) per NEPA regulations and determined a series of proposed actions to mitigate the creation of desired paths along the shoreline, bank destabilization and erosion, and unregulated camping and fishing. Participated in two public scoping meetings to date.

- **Denver Mountain Parks (DMP) Bison Project –** *Regis University* **August 2020-present**

Collected and analyzed plant, dung beetle, and soil samples to quantify how bison and dung beetles impact biotic and abiotic factors in high-altitude shortgrass prairie. Determined the baseline productivity of the grassland with high levels of grazing activity. Presented findings and herd management recommendations to Denver Mountain Park stakeholders in the spring 2021. Project is ongoing.

- **"Defining forest edge in fragmented primate habitat in Costa Rican rainforests" August-December 2019 Undergraduate Research –** *Regis University*

Analyzed how anthropogenic edges impact primate populations in a fragmented rainforest in Costa Rica. Collected literature about habitat fragmentation, habitat patches, deforestation, anthropogenic edges and edge effects as it pertains to species of New World monkeys. Working to determine a data-based definition of forest "edge" using data on monkey sightings and their distance to anthropogenic edges. Paper is in progress.

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## Job Experience

- **Biologist (seasonal), Great Plains Region, Colorado May 2018-present**

Pinyon Environmental, Inc.
3222 S. Vance St, Unit 200 Lakewood, CO 80227

**Responsibilities:** Responsible for all technical aspects of Migratory Bird Treaty Act (MBTA) compliance on Colorado Department of Transportation (CDOT) projects in Adams, Clear Creek, Jefferson, and Douglas Counties. Also performed wetland delineations, clear and grub surveys, collected and managed field data, utilized photographic documentation, and worked directly with contractors to work most effectively around protected birds.

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## Key Skills

- Research/data collection, statistical analyses (using R), wetland delineation, avian/raptor surveys, Colorado species knowledge, field surveys, transects, GIS, community/population/species demographics, MBTA compliance, laboratory skills.
- Excellent problem solving, communication and organizational skills.
- Computer skills- R/RStudio, ArcPro, Uniprot, UCSC Genome Browser, GTEX, QGIS, iDigBio, GBIF, DarwinCore, NetLogo
- Teambuilding/Training/Supervision

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## Professional References

- Karin McShea – Pinyon Environmental, Inc. – mcshea@pinyon-env.com
- Dr. Kristofor Voss – Regis University M.S. Environmental Biology Program Director – kvoss@regis.edu
- Dr. Amy Schreier – Regis University Associate Professor – aschreier@regis.edu

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# CHAPTER 3. JOURNAL MANUSCRIPT

## Musth impacts bull Asian elephant (*Elephas maximus*) behavior at Denver Zoo.

*Abstract*

Musth, a period of heightened testosterone, affects a suite of bull elephant behaviors. For this reason, captive bull elephants are often housed alone. To better evaluate captive bull elephant welfare, it is important to understand their activity budget when they are in musth compared to when they are not in musth. We assessed the activity budgets of three bull Asian elephants at Denver Zoo during periods of both musth and non-musth to understand how musth influences captive elephant behavior. We hypothesized that behaviors exhibited by bulls at Denver Zoo would be different during musth compared to non-musth periods. We conducted instantaneous scan sampling of each individual elephant both in and out of musth, recording each bull's activity every minute across 30-minute samples. We used generalized linear models to compare activity budgets across musth and non-musth periods, and by individual. As predicted, across individuals, musth bulls spent significantly greater percentages of scans locomoting and significantly fewer scans resting and feeding compared to non-musth periods. The bulls spent a higher percentage of scans engaging in stereotypy during periods of musth, however, this difference was not significant. As for individual differences, two bulls spent significantly less time resting during musth, while the third individual spent significantly more time resting during musth compared to non-musth periods. Our study highlights the importance of systematically observing elephant behavior and emphasizes how individual differences in behavior should play a role in determining bull elephant management during musth periods.

Keywords: musth; elephant welfare; activity budgets; resting; locomotion; feeding; stereotypy

## *Introduction*

Originally thought to be solitary in the wild, bull Asian elephants (*Elephas maximus*) have mostly been housed alone in zoo settings (Hartley et al., 2019; Srinivasaiah, 2020). However, recent studies demonstrate that bull elephants frequently spend much of their time socializing in large groups of either mixed-sex or all-male cohorts (Chiyo et al., 2011; Keerthipriya et al., 2020). This can be challenging for zoos that house bull elephants, as many are not equipped to support their specific social needs (Thevarajah et al., 2021). The most challenging aspect of housing bull elephants is when they enter their natural hormonal change called musth.

Musth is a multimodal sexual selection signal that results in competitive advantages for male elephants through eliciting physiologic and behavioral changes (LaDue et al., 2021; Keerthipriya et al., 2020). Physiologically, musth is induced when heightened levels of seral androgens, namely testosterone, are released and is at least partially regulated by the thyroid (Chave et al., 2019; Duer, Tomasi, & Abrahamson, 2016; LaDue et al., 2021). The signaling of musth is multimodal, meaning the elephants use numerous sensory methods to indicate their heightened reproductive state including urine dribbling, temporal gland secretion and even specific low frequency calls which have been observed in African elephants (LaDue et al., 2021; Poole, 1999). Musth generally lasts 15-90 days (Ananth, 2000), and though like a seasonal rut observed in many large ungulates (Martin et al., 2014), musth generally occurs asynchronously from other elephants. This asynchronous timing of musth allows smaller musth males in poor condition to dominate larger, normally higher-ranking, non-musth males in good condition resulting in varying levels of reproductive success among bulls, and constantly shifting dominance hierarchies (Hollister-Smith et al., 2007; Poole, 1989). Each individual's musth initiation, duration, and intensity is influenced by a number of factors, such as social rank and health status; however, age also plays an important role in establishing dominance and influencing a musth male's reproductive success (Hollister-Smith et al., 2007; LaDue et al., 2021).

Dominance status among musth bulls is most influenced by the age of the musth male (Hollister-Smith et al., 2007). Males continue to grow throughout their life span, and older, larger males typically have the highest dominance rank among bulls (Hollister-Smith et al., 2007; Poole, 1989). Because of this increased dominance rank, older males have elevated paternity success compared with younger males (Hollister-Smith et al., 2007; Poole, 1989). Size inequalities among reproductively mature males can be great, such that a 40-year-old male can be two times heavier and 30% taller than a 20-year-old male (Hollister-Smith et al., 2008). Among males in musth, paternity success increases significantly with age until the very oldest age classes, when it modestly declines (Hollister-Smith et al., 2007). Despite massive shifts in dominance hierarchies, little research has explored how age of captive musth males affects their behavior.

Males experience stark and sometimes unpredictable changes in behavior during musth. When a bull is in musth, they show heightened aggression towards other bulls, and have also attacked humans, both in the wild and in captivity (Gore et al., 2006; Sukumar, 2006). Thus, male elephants housed in captivity need specialized attention to ensure the safety of the animal, staff, and other elephants (Hartley, Wood & Yon, 2019). It is typically recommended that male elephants in musth be housed separately during the duration of their hormonal period (Duer, Tomasi & Abramson, 2016). However, social isolation and restriction from reproductive opportunities, paired with the behavioral changes inherent in musth, may affect captive bull activity budgets, both at night and during the day. These effects may also be enhanced with increased age, as periods of musth become more established. Changes in a musth bull's time spent resting, moving, feeding, and engaging in stereotypic behavior all impact captive bull elephant welfare and are valuable areas of study.

Rest is an integral part of the health and well-being of elephants (Holdgate et al., 2016; Walsh, 2017). Elephants can sleep standing up or in a recumbent, or laying, position and prefer resting on sandy substrate rather than cement or harder substrates (Holdgate et al., 2016; Walsh, 2017). Juvenile elephants rest at night for an average of 5 hours and 8 minutes in captivity and the amount of time spent resting at night decreases with age (Walsh, 2017). In zoos, established elephant social groups tend to rest for longer durations compared to newly integrated groups (Thevarajah et al., 2021). Further, elephants that sleep in close proximity (within two body lengths) to conspecifics sleep for longer durations than when conspecifics were not present (Williams et al., 2015). There is a lack of data on the resting behavior of elephants who are housed alone, and research on resting behavior of captive musth elephants is often limited to instances when the bull is tranquilized and/or restrained (i.e., chained; Talukdar & Deori, 2020).

Roving, or an animal's natural tendency to roam widely in the wild, is concerning for some species kept in captivity (Clubb & Mason, 2003). In the wild, Asian elephants have home ranges that are between ~34–232 $km^2$ (Fernando et al., 2008). In bull elephants, musth is employed as a roving strategy to maximize reproductive success while reducing high energy activity such as fighting (Keerthipriya et al., 2020). For African elephants, musth periods result in an increase in the daily mean travel speed and distance for males over 35 (Taylor et al., 2020). Believed to prevent competition among bulls, male elephants in India demonstrate locational dispersal, in which males not only disperse from their natal clans but also from their natal home ranges to new locations (Keerthipriya et al., 2020). For Asian elephants in Sri Lanka, males in musth expanded their range by ~30% as they searched for mates, however these ranges were estimations and were likely under-estimated (Fernando et al., 2008). There is little data on the movement patterns of captive males in musth, however research into this topic would be valuable given the limited space provided by zoos.

As wild bull elephants in musth travel in search of mates, they will often forego food (Keerthipriya et al., 2020). Asian elephants are megaherbivores that spend 12-18 hours per day feeding in the wild, during which they can consume up to 10% of their body mass (Sukumar, 2006). By not eating as much during musth, wild bull elephants send messages to other elephants through chemical changes that result from a lack of food (Ananth, 2000). This self-induced reduced food intake, sometimes to the point of starvation, alters their metabolism and changes the chemistry of the temporal secretions, releasing more volatile compounds, sending an olfactory message to conspecifics indicating that the elephant is in full musth (Ananth, 2000). There is a lack of data on the feeding behaviors of captive elephants in musth, which highlights the need for additional research to improve captive bull elephant welfare.

Stereotypy is repetitive, largely invariant behavior that serves no obvious goal or function, often attributed to stress or boredom (Fernandez, 2021). The patterns of repeated behavior have been observed in numerous species of captive animals including giant pandas (*Ailuropoda melanoleuca*), polar bears (*Ursus maritimus*) and Bengal tigers (*Panthera tigris*) (Fernandez, 2021; Liu, Duan, & Wang, 2017; Vaz et al., 2017). Captive animals with a large natural home range have higher rates of stereotypy and higher infant mortality rates than those that are naturally sedentary or have smaller ranges (Clubb & Mason, 2003). Asian elephants display stereotypic behaviors that can be categorized into four main groups: stationary whole body, locomotor, oral, and self-directed (Greco et al., 2017). Social interaction, both during the day and at night, and spending more time in enclosures with both indoor and outdoor spaces were the best indicators for reduced stereotypy in elephants (Greco et al., 2016; Readyhough et al., in press). These data indicate the importance of social contact in elephants for the well-being of the animal, however, social interaction may be complicated with the onset of musth in male elephants and only some zoos have been able to accommodate multiple bull elephants.

Denver Zoo, as of 2018, is currently one of three certified Association of Zoos and Aquariums (AZA) facilities that routinely houses bull elephants together, and with positive results (Schreier et al., 2021; Thevarajah et al., 2021). They house a group of five bull Asian elephants; three elephants are adults, and the other two are nearing maturity. Until recently, when the mature bulls at Denver Zoo go through their musth period, they are housed alone both during the day and at night to prevent aggression and injury towards conspecifics. Understanding how captive elephant behavior may differ between musth and non-musth periods will be advantageous in creating new standards for welfare.

To better understand how musth affects the behavior of the bull Asian elephants housed at Denver Zoo, this study addresses two main questions: does musth impact the amount of time Asian elephants at Denver Zoo spend engaging in rest, locomotion, feeding, and stereotypy during the day and at night, and does musth elephant's age also impact the frequency of these behaviors? We hypothesized that time spent engaging in each of the behaviors would differ across musth and non-musth periods. Wild elephants employ musth as a roving strategy and travel far outside their territories, foregoing feeding, in search of females in estrus; thus, we predicted that the elephants at Denver Zoo would spend less time resting and feeding, and more time locomoting and engaging in stereotypy during periods of musth (Keerthipriya et al., 2020;

LaDue et al., 2021; Poole, 1987). We also hypothesized that age would impact musth behavior and predicted that differences in behavior between musth and non musth will be more pronounced in older males than younger bulls, as older elephants in musth have less time to maximize their reproductive potential (Keerthipriya et al., 2020).

## *Methods*

### *Study Site & Study Subjects*

Denver Zoo's elephant enclosure, Toyota Elephant Passage, is a multi-yard, rotational exhibit that was built to support the specific needs of a bachelor elephant group and features two miles of interconnected trails on 10 acres of varied terrain ("Exhibits," 2021; Thevarajah et al., 2021). The exhibit boasts mud wallows, scratching trees, shade structures and more than a million gallons of water for swimming and bathing ("Exhibits," 2021). Elephants are housed indoors or outdoors depending on time of year. Elephants in musth are typically housed alone in their own separate enclosure at Toyota Elephant Passage.

This study includes three of Denver Zoo's bull Asian elephants. At the beginning of this study (August 2018), Individual 1 was 11 years old and was going through "moto-musth's" periodically throughout the year as he reached puberty. Individual 2 was 14 years old and went through an annual musth period in the summer months. Individual 3, the largest elephant in this study, was 49 years old and went through an annual musth period in late-autumn/early-winter.

### *Data Collection*

To address our hypotheses regarding bull Asian elephant behaviors, we conducted instantaneous sampling of individual elephants over 30-minute periods, recording the behavior of each elephant every minute (Altmann, 1974). We coded elephant behaviors as resting, locomotion, feeding, and stereotypy (Table 1). As all elephants were housed alone during musth, we did not record social behaviors. Daytime data were collected at Denver Zoo between 9:30 h - 11:30 h and 13:30 h - 15:30 h from August 2018 - January 2020. We collected ~186 hours of daytime elephant behavioral data for musth bulls. Nighttime data were collected using video footage recorded between 18:00 h and 6:00 h from February 2019 - January 2020. We collected ~72 hours of nighttime elephant behavioral data for musth bulls. We aimed to analyze similar amounts of data on each elephant during periods when they were in musth and periods when they were not in musth. To address our hypotheses regarding how elephant behaviors (resting, locomotion, feeding, and stereotypy) varied between musth and non-musth periods, we analyzed behavioral data from periods when elephants were in musth compared to those from periods when elephants were not in musth. We recorded behavioral data using Zoomonitor® (Lincoln Park Zoo, Chicago IL, and Zier Niemann Consulting). We calculated inter-observer reliability by calculating the number of scans in agreement across observers by the total number of scans, and data collection began once researchers reached 95% correspondence.

*Ethogram*

Table 1. Ethogram of behaviors for bachelor group of five bull Asian elephants at Denver Zoo.

| Behavior | Definition |
|---|---|
| Resting | Actor sleeps while remaining within two body lengths of original position without performing any other behavior; can be either recumbent or standing. |
| Stereotypy | Actor performs stereotypic behavior. |
| Locomotion | Actor moves directionally along a horizontal surface (not while feeding); can include slow or fast walking or running. |
| Feeding | Actor ingests presented diet items; includes manipulating food items. |
| Out of View | Actor cannot be seen or cannot be distinguished from other elephants. |
| Other | Actor performs any other behavior not on ethogram. |

*Data Analysis*

To statistically assess the difference in observed behaviors between periods in musth and periods when not in musth, we calculated binomial proportions for each of our behaviors (resting, locomotion, feeding, and stereotypy) and whether the focal animal was in musth and whether the behavior occurred during the day or at night. Behaviors were coded as 1 (behavior occurred) or 0 (behavior did not occur), nighttime data were coded as 1 and daytime data were coded as 0, and if the focal animal was in musth at the time of data collection, it was coded as 1, and if the focal animal was not in musth at the time of data collection, it was coded as 0 (Table

2). We then conducted a generalized linear model (GLM), with access to inside/outside/both and total area they have access to as random effects, and musth status and focal animal as fixed effects. The models were fit separately with each type of behavior as its own binomial response. We used the *anova()* command in R (R Core Team, 2019) to perform a drop-in-deviance test on the GLM model objects to compare reduced models to a full model and select the best model for each behavior (Table 3).

*Individual Differences*

To statistically assess differences in observed behaviors between individual elephants, we subset the data by individual elephant using the *dplyr()* package in R (R Core Team, 2019; Wickham et al., 2021), then conducted a GLM with access to inside/outside/both and total area they have access to as random effects, and musth status as a fixed effect. The models were fit separately with each type of behavior as its own binomial response. We again performed a drop-in-deviance test on the GLM models to compare reduced models to a full model and select the best model for each behavior.

## *Results*

As expected, the bulls spent a lower percentage of scans resting during periods of musth (13.6%; 95% CI: 8.41%-18.77%; Figure 1) when compared to periods when not in musth (17.1%; 95% CI: 12.8%-21.4%; Figure 1). When controlling for other variables that might impact activity (i.e., the fixed effects in our models: focal animal), the odds of resting decreased by 56.8% (95% CI: -4.3% - 82.1%) when the focal elephant was in musth, however, this difference was only marginally significant (p=0.06; Figure 1; Table 4). Also as predicted, the percentage of time spent locomoting increased during musth: the bulls spent 24.23% of scans locomoting during musth (95% CI: 17.75%-30.7%; Figure 1) compared to 17% during periods when they were not in musth (95% CI: 12.7%-21.3%; Figure 1) representing a marginally significant 59.8% increase in the odds of locomoting during musth when controlling for other variables (95% CI: -3% - 163%; p=0.06; Figure 1; Table 4). Furthermore, the frequency of feeding also significantly decreased during musth. The bulls spent 14.2% of scans feeding during musth (95% CI: 8.92%-18.77%; Figure 1), compared to 28.88% when they were not musth (95% CI: 23.7%-34.1%; Figure 1), a significant 60.8% decrease in the odds of feeding during musth when controlling for other variables (95% CI: 33.2%-77%; p=0.0005; Figure 1; Table 5). Overall, the elephants engaged in very little stereotypic behavior; however, during musth, the bulls spent a higher percentage of scans engaging in stereotypy (10.53%; 95% CI: 5.9%-15.2%; Figure 1) compared to periods when they were not in musth (7.33%; 95% CI: 4.35%-10.32%; Figure 1). This represents a 64.8% increase in the odds of the elephants engaging in stereotypy when controlling for other variables, however, this difference was not significant (95% CI: -17%-227%; p=0.15; Figure 1; Table 5).

*Individual Differences*

There were notable behavior differences across individual bulls. During his moto-musth periods, Individual 1 spent a lower percentage of scans resting (5%; 95% CI: -0.64%-10.72%), representing a significant 86.6% decrease in the odds that he was resting when in musth compared to when he was not in musth (95% CI: 30.2%-97.5%; p=0.017; Figure 2A). Individual 1 also spent a lower percentage of scans feeding (20.1%; 95% CI: 9.70%-30.50%), and instances of locomotion were higher compared to when not in musth (33.7%; 95% CI: 21.45%-46.00%), however, neither of these differences were significant (feeding, p=0.1574; locomotion, p=0.246; Figure 2A). Though extremely rare to be observed in Individual 1, instances of stereotypic behavior were slightly higher when in musth compared to when not in musth (6.2%; 95% CI: 0.06%-12.46%) though again, these differences were not significant (p= 0.238; Figure 2A).

Individual 2 also spent a lower percentage of scans feeding when he was in musth (10%; 95% CI: 2.63%-17.31%; Figure 2B), representing a significant 69.3% decrease in the odds of him feeding when he was in musth compared to when he was not in musth (95% CI: 14%-89%; p=0.0244; Figure 2B). The percentage of scans that Individual 2 spent locomoting (23%; 95% CI: 12.71%-33.34%) and engaging in stereotypy (12.3%; 95% CI: 4.24%-20.33%) were both slightly higher when in musth, however, these differences were not significant (locomoting, p=0.685; stereotypy, p=0.684; Figure 2B). He also spent a lower percentage of scans resting during periods of musth (5.6%; 95% CI: -0.02%-11.27%) representing a significant 82.4% decrease in the odds of Individual 2 resting while he was in musth (95% CI: 30.2%-97.4%; p=0.013; Figure 2B).

Like the other two individuals, Individual 3, the oldest of the three bulls, spent a lower percentage of scans feeding (12.8%; 95% CI: 3.26%-22.37%), with the odds of feeding significantly decreasing by 69.8% when he was in musth compared to when he was not in musth (95% CI: 7%-90%; p=0.0365; Figure 2C). Unlike the other two individuals, Individual 3 spent a higher percentage of scans resting when he was in musth (34.8%; 95% CI: 21.20%-48.44%) representing a significant 181.7% increase in the odds that Individual 3 would be resting when he was in musth compared to when he was not in musth (95% CI: 13%-601%; p=0.026; Figure 2C). Individual 3 also spent a slightly higher percentage of scans locomoting (14.4%; 95% CI: 4.34%-24.40%) and engaging in stereotypy when he was in musth (13.4%; 95% CI: 3.65%-23.11%) compared to when he was not in musth (locomoting= 14.4%; 95% CI: 4.3%-24.4%; stereotypy=

13.4%; 95% CI: 3.7%-23.1%); however, like the other two, these differences were not significant (locomoting, p=0.411; stereotypy, p=0.347; Figure 2C).

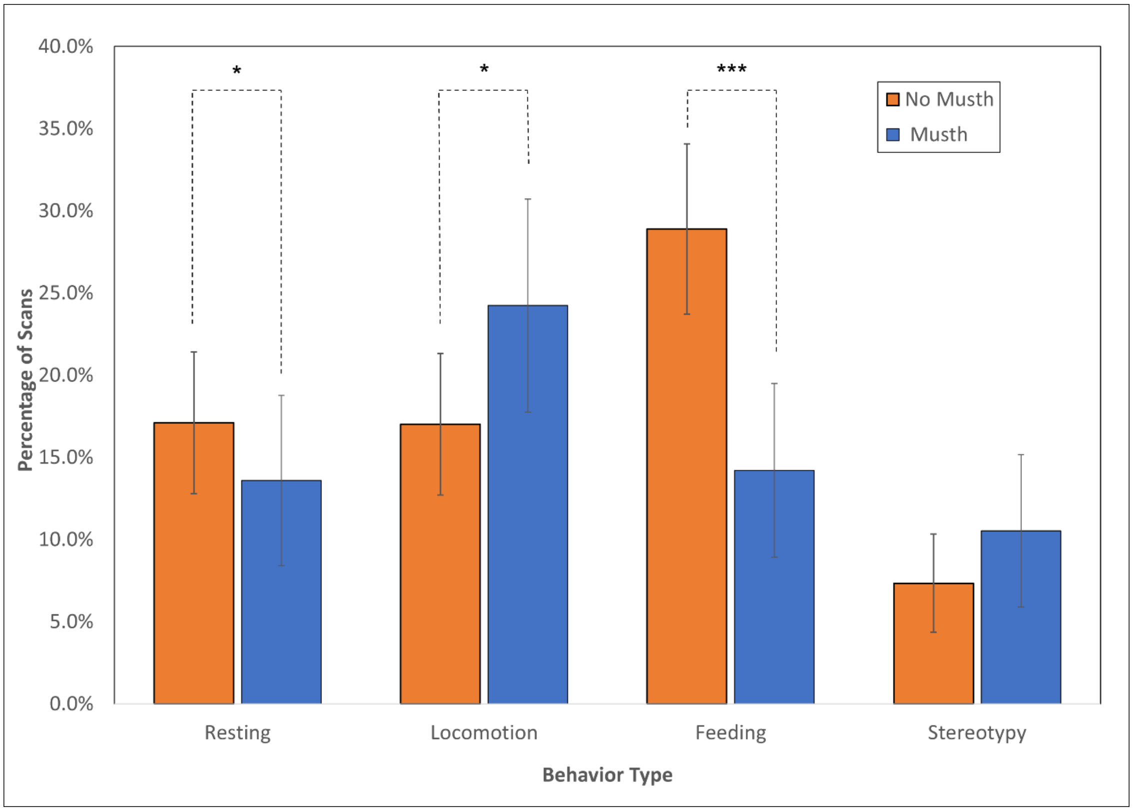


Figure 1. Percentage of scans bulls engaged in resting, locomotion, feeding, and stereotypic behaviors when in musth compared to not in musth. Error bars represent 95% confidence intervals. *indicates p$\leq$0.060; ***indicates p<0.050

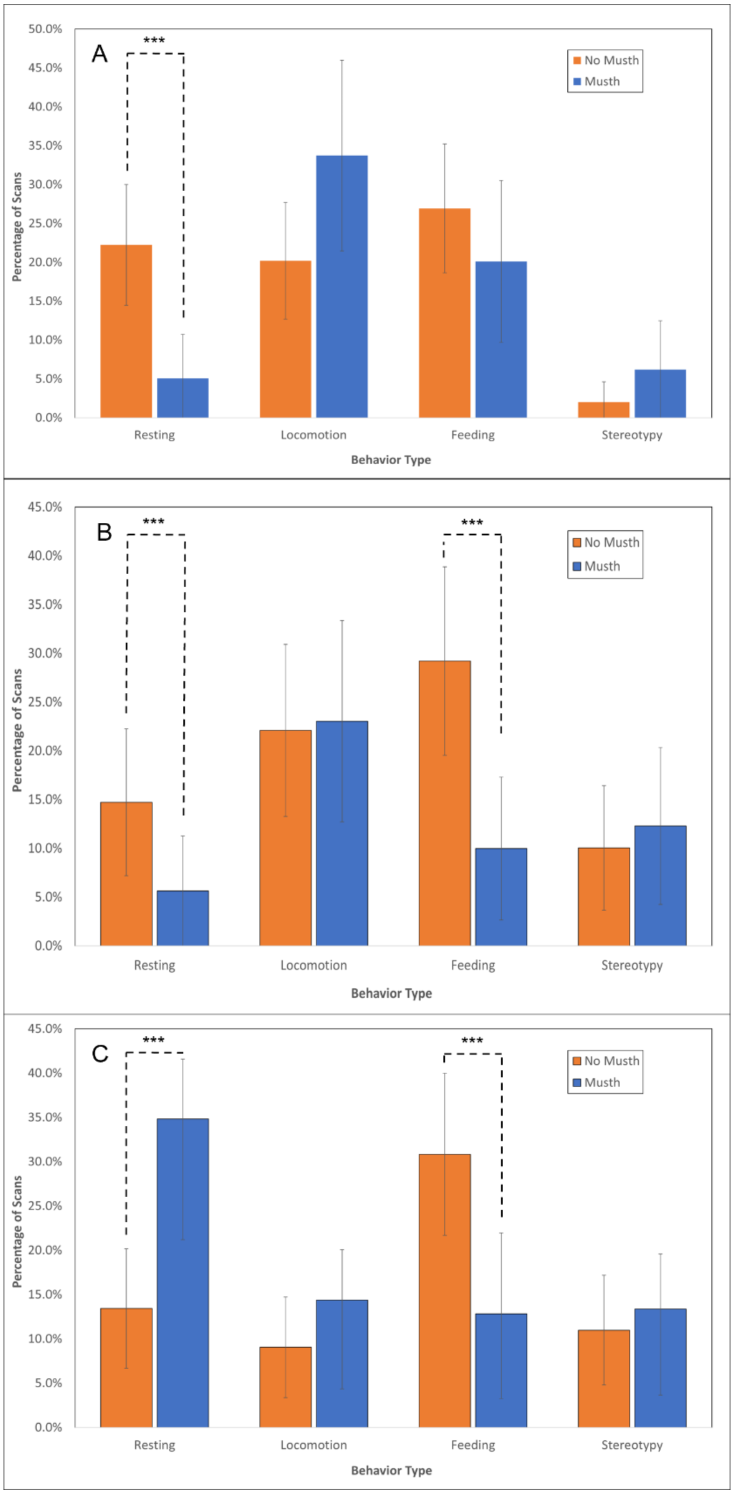


Figure 2. Percentage of scans that Individual 1 (A), Individual 2 (B), and Individual 3 (C) engaged in resting, locomotion, feeding, and stereotypic behaviors when in musth compared to when not in musth. Error bars represent 95% confidence intervals. ***indicates p<0.050

Table 2. Description of variables considered in our Generalized Linear Models (GLM).

| **Variable** | **Description** | **Reference Level** |
|---|---|---|
| *FocalMusth* | Binary variable indicating if the focal animal was in musth (1) or not (0) during the time of the observation session | No musth (0) |
| *AccessArea* | Continuous variable indicating the size of the area that the focal animal had access to (per 1,000 $ft^2$); 2.00-47.37 | 2,000 $ft^2$ |
| *InOutAccess* | Categorical variable indicating if focal animal had access inside (in), outside (out), or both (both) | Both |
| *DayNight* | Binary variable indicating if observations took place in the day (1) or night (0) | Night (0) |
| *InOutAccess*AccessArea* | Interaction term between InOutAccess (in, out, both) and AccessArea (2.00-47.37) | Both:AccessArea |
| *FocalName* | Categorical variable indicating whether the focal animal was Individual 1, Individual 2, or Individual 3. | Individual 1 |

Table 3. Model comparison table for GLMs that included all elephant data. Bold indicates the final model. Associated p-values from comparison of reduced models to full model with drop-in-deviance test using *anova()*.

| Model | AIC | Parameters | p-value |
|---|---|---|---|
| **Resting** | | | |
| ***FocalMusth + DayNight + InOutAccess + AccessArea + (InOutAccess * AccessArea) + FocalName*** | **210.012** | **10** | **-** |
| **Locomotion** | | | |
| *FocalMusth + DayNight + InOutAccess + AccessArea + FocalName + (InOutAccess * AccessArea)* | 288.1865 | 10 | - |
| *FocalMusth + DayNight + AccessArea + FocalName + InOutAccess* | 284.3194 | 8 | 0.9522 |
| *FocalMusth + DayNight + AccessArea + FocalName* | 282.2505 | 6 | 0.97 |
| ***FocalMusth + DayNight + FocalName*** | **281.1632** | **5** | **0.9398** |
| **Feeding** | | | |
| *FocalMusth + DayNight + InOutAccess + AccessArea + FocalName + (InOutAccess * AccessArea)* | 410.4715 | 10 | - |
| *FocalMusth + DayNight + InOutAccess + AccessArea + FocalName* | 405.9832 | 8 | 0.8955 |
| *FocalMusth + DayNight + AccessArea + FocalName* | 402.8763 | 6 | 0.8706 |
| *FocalMusth + DayNight + FocalName* | 402.9589 | 5 | 0.8813 |
| ***FocalMusth + DayNight*** | **398.6838** | **3** | **0.9281** |
| **Stereotypy** | | | |
| *FocalMusth + DayNight + InOutAccess + AccessArea + FocalName + (InOutAccess * AccessArea)* | 213.9083 | 10 | - |
| *FocalMusth + DayNight + InOutAccess + AccessArea + FocalName* | 211.1742 | 8 | 0.8714 |
| *FocalMusth + DayNight + AccessArea + FocalName* | 206.9511 | 6 | 0.9769 |
| ***FocalMusth + DayNight + FocalName*** | **204.9667** | **5** | **0.9908** |

Table 4. GLM model parameter estimates for all data (resting and locomotion). Generalized linear model results of associations between predictor variables (fixed effects) and behavioral response variables. Odds Ratio = indicates the change in odds of a behavior being observed given the constraints of a model; ß = Beta coefficients from model outputs: positive values indicate an increase in odds compared to the reference level while negative values indicate a decrease in odds compared to reference level; z-value = test-statistic for the Wald-test where the parameter is 0; p = p-value from Wald test. * indicates reference level. Bold signifies statistical significance ($p<0.05$)

| | | Resting | | | | Locomotion | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Predictor** | **Level** | **Odds Ratio** | **β** | **z-value** | **P** | **Odds Ratio** | **β** | **z-value** | **P** |
| *FocalMusth* | No Musth | - | - | - | - | - | - | - | - |
| | Musth | 0.5678705 | -0.83903 | -1.866 | 0.06198 | 0.597916 | 0.4687 | 1.844 | 0.065141 |
| *AccessArea* | | 0.0186146 | -0.01879 | -0.117 | 0.9071 | - | - | - | - |
| *InOutAccess* | Both | - | - | - | - | - | - | - | - |
| | Inside | **332.1024** | **5.80845** | **2.122** | **0.03384** | - | - | - | - |
| | Outside | 0.794686 | 0.58483 | 0.241 | 0.80942 | - | - | - | - |
| *DayNight* | Day | - | - | - | - | - | - | - | - |
| | Night | **20.22437** | **3.05515** | **5.245** | **1.56E-07** | **0.868783** | **-2.0309** | **-4.542** | **5.58E-06** |
| *InOutAccess*AccessArea* | Both:AccessArea | - | - | - | - | - | - | - | - |
| | In:AccessArea | **0.8710383** | **-2.04824** | **-3.284** | **0.00103** | - | - | - | - |
| | Out:AccessArea | 0.046593 | 0.04554 | 0.286 | 0.77488 | - | - | - | - |
| *FocalName* | Individual 1* | 0.9889327 | -4.50376 | -1.884 | 0.05953 | **0.576923** | **-0.8602** | **-3.904** | **9.48E-05** |
| | Individual 2 | 0.2397135 | -0.27406 | -0.645 | 0.51916 | 0.160291 | -0.1747 | -0.623 | 0.53315 |
| | Individual 3 | **4.51273** | **1.70706** | **3.228** | **0.00125** | **0.687703** | **-1.1638** | **-3.452** | **0.000556** |

Table 5. GLM model parameter estimates for all data (feeding and stereotypy). Generalized linear model results of associations between predictor variables (fixed effects) and behavioral response variables. Odds Ratio = indicates the change in the odds of a behavior being observed given the constraints of a model; ß = Beta coefficients from model outputs: positive values indicate an increase in odds compared to the reference level while negative values indicate a decrease in odds compared to reference level; z-value = test-statistic for the Wald-test where the parameter is 0; p = p-value from Wald test. * indicates reference level. Bold signifies statistical significance ($p<0.05$)

| | | Feeding | | | | Stereotypy | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Predictor** | **Level** | **Odds Ratio** | **β** | **z-value** | **P** | **Odds Ratio** | **β** | **z-value** | **P** |
| *FocalMusth* | No Musth | - | - | - | - | - | - | - | - |
| | Musth | **0.6082377** | **-0.9371** | **-3.472** | **0.000517** | 0.648392 | 0.4998 | 1.43 | 0.15265 |
| *AccessArea* | | - | - | - | - | - | - | - | - |
| *InOutAccess* | Both | - | - | - | - | - | - | - | - |
| | Inside | - | - | - | - | - | - | - | - |
| | Outside | - | - | - | - | - | - | - | - |
| *DayNight* | Day | - | - | - | - | - | - | - | - |
| | Night | **0.8339722** | **-1.7956** | **-4.523** | **6.09E-06** | 0.558422 | -0.8174 | -1.686 | 0.09188 |
| *InOutAccess*AccessArea* | Both:AccessArea | - | - | - | - | - | - | - | - |
| | In:AccessArea | - | - | - | - | - | - | - | - |
| | Out:AccessArea | - | - | - | - | - | - | - | - |
| *FocalName* | Individual 1* | **0.4318103** | **-0.5653** | **-4.01** | **6.07E-05** | **0.963963** | **-3.3232** | **-7.18** | **6.95E-13** |
| | Individual 2 | - | - | - | - | **2.369283** | **1.2147** | **2.418** | **0.01561** |
| | Individual 3 | - | - | - | - | **2.818662** | **1.3399** | **2.659** | **0.00784** |

## *Discussion*

We explored differences in resting, feeding, locomoting, and stereotypy in three captive bull Asian elephants at Denver Zoo during periods of musth compared to periods when not in musth. The behavior of the bulls significantly differed across musth and non-musth periods. As predicted, bulls spent less time resting and feeding, and more time locomoting and engaging in stereotypy during periods in musth when compared to periods when not in musth. The odds of the bulls feeding while in musth decreased significantly when compared to non-musth periods. Likewise, the odds of them resting during musth also decreased, while the odds of them locomoting during musth increased, however both were only moderately significant. Though generally rare, the odds of them engaging in stereotypy during musth increased slightly, however this change in behavior was not significant. The behavior of bull Asian elephants at Denver Zoo also significantly differed across individuals. Individual 1, the youngest elephant in this study, spent less time resting and feeding, and more time locomoting and engaging in stereotypy during periods in musth when compared to periods when not in musth, with the odds of resting during musth decreasing significantly across musth and non-musth periods. Individual 2 also spent less time resting and feeding, and more time locomoting and engaging in stereotypy during periods in musth when compared to periods when not in musth, with the odds of both resting and feeding during musth decreasing significantly across musth and non-musth periods. Like the other two elephants, Individual 3, the oldest elephant in this study, also spent less time feeding, and more time locomoting and engaging in stereotypy during periods in musth when compared to periods when not in musth, with the odds of feeding during musth decreasing significantly when compared to non-musth periods. However, contrary to our prediction, Individual 3 spent more time resting during periods of musth compared to periods when not in musth, with the odds of him resting during musth also increasing significantly.

Our results suggest that there is a decrease in resting behavior during musth in captive Asian bull elephants, induced by the physiologic changes inherent to this multimodal sexual signaling strategy and made worse by confinement (Keerthipriya et al., 2020; Greco et al., 2016; Meehan et al., 2016). The lack of rest due to musth has the potential to decrease the health of captive elephants, as sleep is an integral part of their regulatory function (Holdgate et al., 2016). However, contrary to our predictions, Individual 3, the oldest elephant included in this study, rested significantly more when he was in musth. Previous studies have found that elephants sleep less as they get older, with the amount of sleep decreasing further during musth, however in captivity this may be more on a case-by-case basis (Walsh, 2017). Little research has investigated the resting behaviors of captive bulls in the oldest age classes, therefore focusing on age differences of captive bulls would be an ideal opportunity for future studies.

Our results suggest there is an increase in locomoting during musth in captive bull Asian elephants, which aligns with previous studies. In the wild, Asian elephants have large home ranges that extend further during musth to maximize a bull’s reproductive success (Fernando et al., 2008; Keerthipriya et al., 2020). Many captive elephants in musth are confined to small areas with limited ability to release the energy created by the increase in testosterone, however, our research highlights the need for additional space that allow elephants in musth to roam (Hartley et al., 2019).

One of our most striking findings suggest that there is a significant decrease in feeding during musth in captive bull Asian elephants. In the wild, elephants will forego food as they roam in search of mates, which changes the chemistry of their temporal secretions, sending an olfactory message to conspecifics indicating that the elephant is in full musth (Ananth, 2000; Keerthipriya et al., 2020). However, little research has been done on the feeding behavior of captive elephants in musth, and these results highlight a very large gap in knowledge.

Additionally, our results show an increase in stereotypic behavior during musth, though these results were not statistically significant. Due largely to space constraints and being housed alone, captive bull elephants are unable to employ musth as they typically would in the wild, potentially creating stressful situations for these animals, which is a key factor in inducing stereotypic behaviors (Clubb & Mason, 2003; Fernandez, 2021; Greco et al., 2016). Greco et al. (2016) found that stereotypy increases with more time spent indoors and less social interaction. Though musth was not incorporated into their study, it shows that elephants in more confined spaces display higher levels of stereotypic behavior. Thus, when adding musth as a variable, and limiting their ability to use musth as a roving strategy, an increase in bull stereotypy can be expected (Greco et al., 2016). Many captive elephants in musth are confined to small areas, with limited ability to release the energy created by the increase in testosterone, further explaining this phenomenon (Hartley et al., 2019). Additionally, the inability of the elephants to utilize both indoor and outdoor areas may have impacted the frequency of stereotypy (Readyhough et al., in press). Our results highlight the need for increased research into stereotypy in captivity during periods of musth in bull elephants.

There were limitations to the study that may have influenced the results. First, the camera footage was often blurry or had challenging lighting, which made it difficult to distinguish individual elephants and the behaviors they were exhibiting. Similarly, the camera footage rotated between different areas of the exhibit, making it difficult to find the individuals and increasing the likelihood that the elephant would be out of view in the sample. Additionally, there were more than ten researchers coding data, which increased the potential for inconsistent documentation of behaviors. Errors in data entry were largely resolved prior to analyses and despite these limitations, we believe that our results accurately represent the phenomena that we observed.

Understanding the relationship between Asian bull elephant musth, and key behaviors such as rest, feeding, locomotion, and stereotypy are increasingly important for zoos looking to improve the health and well-being of their bull elephant herds. Examining the response of musth elephants with limited contact to non-musth elephants by monitoring the levels of agnostic and affiliative behavior can provide insights into the sociality of bull elephants in musth. Future research should explore the social responses of captive bull elephants in musth to other bulls to determine if introducing dyads would be appropriate. Previous studies have shown that bull elephants are more social than previously thought and that social opportunities increase the amount of rest and decrease stereotypy (Greco et al., 2016; Schreier et al., 2021; Thevarajah et al., 2021). Examining how behaviors shift when musth elephants are in contact with non-musth elephants will provide more understanding of the sociality of these animals and could be a potential solution for decreasing stereotypy exhibited when musth elephants are housed alone.

Our research offers zookeepers and zoo managers better knowledge of the behaviors that captive bull elephants exhibit when in musth. To date, literature on the behaviors of captive bull elephants in musth is lacking, thus we aimed to illuminate the importance of understanding all aspects of bull elephant behavioral ecology with this study. Awareness of the behavioral differences in musth bulls allows managers to better accommodate musth elephants and improve welfare, and with the implementation of our recommendations, investigating these effects becomes more feasible. With this information zoo managers will be able to make better decisions regarding musth and behavior management, thus improving the overall health of captive bull elephant herds.

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# CHAPTER 4.

## Northern Bobwhite recovery at Bridgestone-Firestone Centennial Wilderness Area, White County, Tennessee

### *Introduction*

The Tennessee Wildlife Resources Agency (TWRA) announced a plan in October 2021 to cut down approximately 2000 acres of hardwood forest in phases over the next three years. The plan aims to create grassy habitat for the Northern Bobwhite, a species of quail, whose population has plummeted in Tennessee in recent decades. The wilderness area, located in White County about halfway between Nashville and Knoxville, is a popular, publicly owned hunting and recreation destination. The land was gifted to the state in 1998 by the Bridgestone Corporation with the requirement that the land be maintained as a wilderness area. The Tennessee Wildlife Federation claims that the TWRA would comply with this requirement by creating habitat for the quail. Those opposed to the plan to cut down the forest include the White County Board of Commissioners, local business owners, some local hunters, and environmental groups. Local businesses serve tourists, hikers, kayakers, and other visitors who stay in local accommodations and visit local coffee shops all drawn to the wilderness area. White County officials, environmental groups, and local hunters claim there are other adjacent areas for potential habitat that would not involve cutting down the forest. My solution is to discontinue the proposed forest clearing of the area to the north, and instead focus on Phases 2 and 3 of the proposed forest clearing of the area to the south. This solution will provide suitable habitat for the Northern Bobwhite while retaining the protection status of the conservation area.

*Background Information*

*Northern Bobwhite (Colinus virginianus)*

The Northern Bobwhite is a ground-dwelling bird (TWRA, 2022b). Males have a bold black-and-white face pattern, while the females have a buff face, with a dull brown body (TWRA, 2022b). These birds are native to grasslands interspersed with thickets of shrubs and briars near deciduous or coniferous forests of the southeastern United States and are often found along farm field edges (TWRA, 2022b). Northern Bobwhites form mated pairs between late April – July and can raise multiple broods in a season (TWRA, 2022b). The pair chooses a nest site on the ground in dense brush, and both help build a shallow depression, lined with grass and leaves, with an arch built over the nest resulting in a well-hidden entrance (TWRA, 2022b). Clutches can range from 5 to 24 eggs and both sexes incubate the eggs for about 1 month, and within a day or two of hatching the young fledge, although the parents continue to tend to them (TWRA, 2022b).

The Northern Bobwhite is a permanent resident across Tennessee occurring in all but the highest elevations of eastern Tennessee (TWRA, 2022b). Their numbers are declining in the state due to the succession of young forests to mature stands, reforestation of farmlands, and modern agricultural practices, including the conversion of native pasture to exotic fescue for cattle, which yields little food for Bobwhites and is unsuitable nesting habitat (TWRA, 2022b).

*Bridgestone-Firestone Centennial Wilderness Area*

The Bridgestone-Firestone Centennial Wilderness Area (BFCWA) is a 10,000-acre area that includes a wide variety of habitats including a 700-acre tract of native warm-season grass, which is burned on a rotation to provide continuous habitat for grassland species, second-growth hardwood forests, and 2,000 acres of early succession pine plantation (TWRA, 2022a). Hiking trails are open to the public and camping is available at primitive camping sites (TWRA, 2022a). Deer and wild turkeys are commonly spotted in the area (TWRA, 2022a). The warm-season grass fields support some nesting Northern Bobwhite, Dickcissel, Blue Grosbeak, Red-winged Blackbirds, and many Neotropical migratory songbirds nest in the deciduous forests including Black-throated Green Warbler, Red-eyed Vireo, Worm-eating Warbler, and Ovenbird (TWRA, 2022a). The Bridgestone company donated the land to the state of Tennessee under certain conditions, or covenants, including that it be preserved as a wilderness area (Wadhwani, 2022a). The covenants cite more than 30 species of plants and animals that are of state and federal concern, including at least six species listed on the Endangered Species Act (ESA) (Wadhwani, 2022a). Nearly 99% of all historical native grassland areas in the southeastern U.S. have been urbanized and converted for agriculture, including those on the Cumberland Plateau (Simms, 2022). By creating savannas, grasslands, and shrublands, the TWRA argues that the native grasslands can be restored (Simms, 2022). As of February 2022, the TWRA halted their plans to clearcut the northern portion of the property, known as “The Farm,” but are moving forward with cuts on a large portion of the southern tip of the property, known as “Big Bottom” (Figure 1) (Wadhwani, 2022a). At this time, the total acreage of forested land slated for clearcutting is unknown (Wadhwani, 2022a).

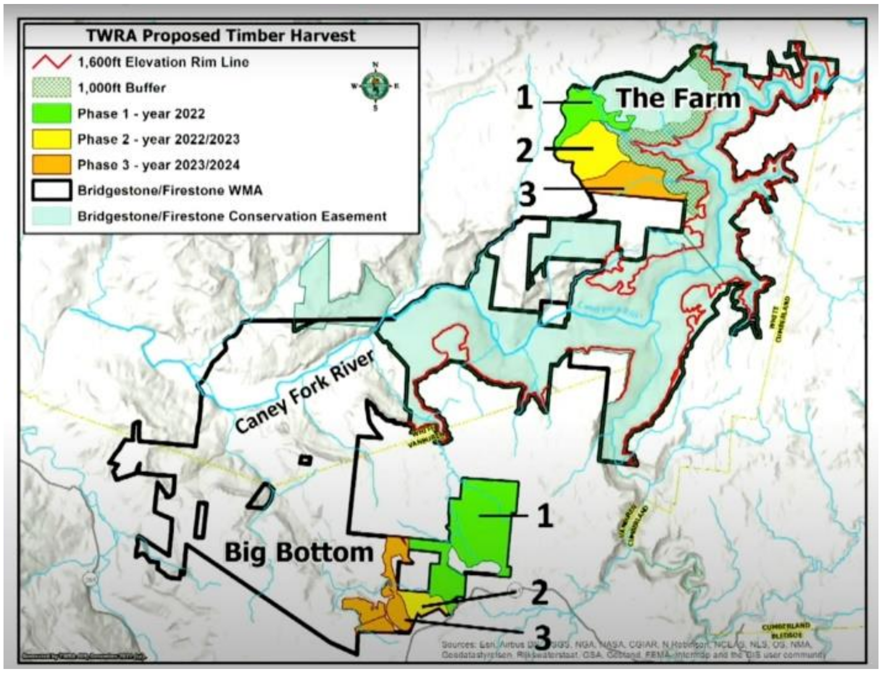


Figure 1. A December 2021 map showing the phases of TWRA's plan to harvest ~2000 acres of timber in the Bridgestone Firestone Centennial Wilderness Area (Wadhwani, 2022).

## *Stakeholders*

### *Tennessee Wildlife Resources Agency (TWRA) and Quail Hunters*

The TWRA values the quail and its grassland habitat for its own sake as well as for its economic and recreational value. The TWRA claims that the estimated revenue on the timber harvest that would result from this proposal is between $80,000-$120,000 which would be invested back into the Bridgestone Firestone WMA within a year for to support further wildlife conservation and management ("TWRA Defends Land Management at Bridgestone Firestone Centennial Wilderness Area", 2021). Thus, this stakeholder also values the forest for its timber value and announced that they would put the clearcutting of the Bridgestone lands out for bid to timber companies in February 2022 (Wadhwani, 2022a). The TWRA is unique among state agencies in keeping the proceeds of sales of public resources within its budget, instead of transferring them to the state's general fund (Wadhwani, 2022a). Other stakeholders want to move forward with the proposal because they place value in the recreation opportunities created by increasing the Northern Bobwhite population. Local hunters use the forest for hunting deer and other species of quail, however, the TWRA argues that reducing overgrown forest acreage will greatly enhance nesting and brooding cover for wild turkeys and will provide food sources and nutritional requirements for deer antler growth and development during the spring and summer months (“TWRA Defends Land Management at Bridgestone Firestone Centennial Wilderness Area”, 2021). The TWRA also claims that deer, turkey, Prairie Warbler, Field Sparrow, Loggerhead Shrike, Yellow-breasted Chat, Indigo Bunting, Blue Grosbeak, eastern cottontail, Dickcissel, quail, and numerous unnamed endangered plants would benefit from the creation of grassland and early successional habitat (“TWRA Defends Land Management at Bridgestone Firestone Centennial Wilderness Area”, 2021). Some hunting enthusiasts support the felling, including members of Quail Forever, a quail hunting organization. According to the Quail Forever 2021 Quail Hunting Forecast, “some of the best quail hunting right now in Tennessee can be found on the wildlife areas in the middle section of the state”, particularly in grassland habitats (Hartner, 2021).

*Local Governmental Agencies, Business Owners, and Environmentalists*

The White County Board of Commissioners has argued that the land remains a wilderness and that no hardwood trees are cut down. White County’s legislative body consists of 14 county commissioners elected to four-year terms by the people of their respective districts and each district has two commissioners (WC, 2022). Speaking for their county and the rising concern voiced by community members, the Board has moved forward with several lawsuits over the proposal, the most recent citing the Bridgestone company’s covenants. More specifically, the recent lawsuit describes at least six species listed in the covenants that are protected by the Endangered Species Act (ESA) (Wadhwani, 2022a). Other members of the public have raised concerns about how the felling would interfere with the viewshed for the nearby Virgin Falls Wilderness Area (Mays, 2022). Local business owners have also voiced concern over the loss of business following the conversion of the forest (Wadhwani, 2022b). Many businesses rely on the tourism and recreation opportunities provided by the conservation area, and its conversion could be detrimental to small businesses that have already taken a hit during the COVID-19 pandemic. Finally, environmental groups have shared their concerns about how the proposed project is essentially destroying one habitat to make room for another, and instead argue that the forest should remain intact and minimally disturbed to protect the approximately 30 endangered species that occur in the area (Mays, 2022; Wadhwani, 2022a).

### *Proposed Solution*

To support a Northern Bobwhite population in White County, certain habitat requirements would have to be met. Bobwhite abundance is often determined by the composition and size of herbaceous and woody shrub patches; thus, Bobwhites are most abundant where native grasses, forbs (broadleaf plants, weeds), legumes, and shrubs are closely arranged (Elmore et al., 2014). Through the removal of hardwood forests, it could potentially be years before the subsequent grassland habitat would meet the Bobwhite's habitat requirements (Elmore et al., 2014). However, once the grasslands meet the requirements, translocation of wild Bobwhites could potentially ensure future population persistence in White County (Terhune et al., 2006).

An effective solution to this issue involves many steps to satisfy all stakeholders and ensure both the continued protection of the conservation area and the species therein, and the creation of new grassland habitat for the Northern Bobwhite. The goal of this solution is to implement only Phases 2 and 3 of TWRA's proposed action for the area to the south known as

“Big Bottom”, which will create grassland habitat that will allow Northern Bobwhite populations to recover in White County, TN, but on a smaller scale than the current TWRA plan. The area to the north known as “The Farm”, which is within the BFCWA conservation easement, will not be considered for modification into grassland habitat so that it may continue to protect the species noted in the Bridgestone covenants.

By utilizing the two areas of the smallest phases, this proposed solution aims to prevent the unnecessary conversion of large swaths of old-growth hardwood forests into grasslands, and rather focus on the smaller, desirable, areas. This would still provide translocated Bobwhite populations with suitable habitat, and it would do so more quickly than it would through the removal and modification of larger forest areas (Elmore et al., 2014; Terhune et al., 2006). This would decrease the amount of visible felled trees and maintain the views of Virgin Falls Wilderness Area. What's more, by creating the grasslands on sites within the current proposed phases, the grassland habitat would back up to the forest and provide additional means of protection, as the birds would be able to use both habitat types (Elmore et al., 2014). Finally, this proposed solution would continue in phases, with the first phase completed in 1-2 years, and the subsequent phase completed in the following year until project completion.

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