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MS ENVIRONMENTAL BIOLOGY
CAPSTONE PROJECT

by

Marley T. Borham

A Project Presented in Partial Fulfillment
of the Requirements for the Degree
Masters of Science
in Environmental Biology

REGIS UNIVERSITY
May, 2020

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CHAPTER 1. LITERATURE REVIEW

Effects of Logging on Bats in the Pacific Northwest

Introduction

Bats are one of many species that function as indicators of environmental health or habitat quality. They are used around the world as an indicator because they are specialists and are impacted greatly by disturbances. Bats have specific temperature requirements, roosting preferences, and foraging behaviors that are often analyzed to evaluate changes in an ecosystem because any slight change in these roosting or foraging preferences can have significant impacts on their survival. Therefore, it is beneficial to utilize bats when analyzing disturbance effects on an ecosystem's health. The Pacific Northwest, specifically Washington, Oregon and, Northern California, contains a wide variety of bat species, 9 of which are considered either threatened or endangered (Hayes & Wiles, 2013). Logging in this area has massively disrupted forests, destroying habitat and displacing animals, including bats.

Logging is the main driver behind the extinction of cavity-roosting bats in the Pacific Northwest, indicating a decrease in ecosystem health. Converting to more sustainable forestry methods will help conserve these cavity-roosting bat populations and the health of the forest ecosystem. A significant amount of research has been done on the effects of logging in the tropics. However, the literature is lacking evidence that logging is also affecting bat populations in non-tropical regions, like the Pacific Northwest. Not enough information exists to determine the effects of logging in temperate regions, and which methods of sustainable logging will most effectively sustain these already threatened or endangered species and conserve forest ecosystems.

Bat Species Diversity & Roosting

All bats belong to the order Chiroptera, one of the largest and most widespread orders of mammals in the world. Bats have adapted the ability to fly and sustain flight naturally with forelimbs that have been modified into wings, making them unique to all other mammals (Mlakar & Zupan, 2011). Bats can live in nearly every habitat type, with the majority of all bat species centered around the tropics (Figure 1). In the Pacific Northwest, there are 15 species of bats, all of which are insectivores, and many of which are cavity-roosting (Mlakar & Zupan, 2011). Roosts provide safe and secure locations for bats to reproduce, raise young, and hibernate (Campbell, Hallett, & O'Connell, 1996). Cavity-roosting bats prefer large-diameter trees, with rotting tree centers, and warm-protected areas (Crampton & Barclay, 1998). Most preferred roosting trees are found in old-growth forests, which can be used as roosts while alive or as snags.

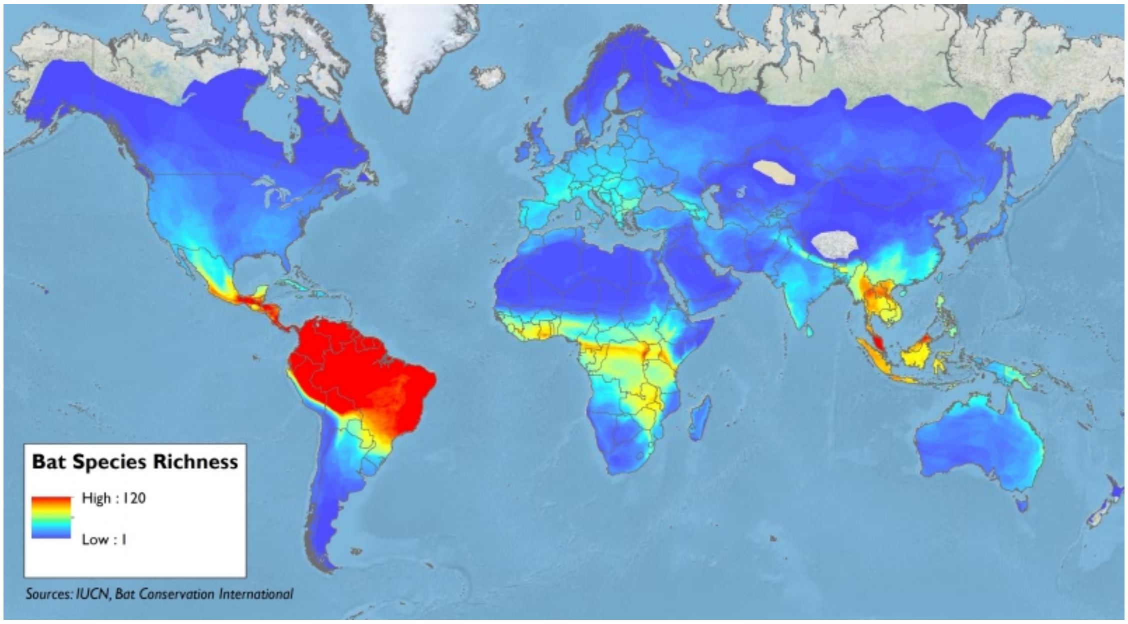

Figure 1: Bat Species Richness. Areas shaded with red, orange, or yellow contain somewhat high species richness. Areas shaded in green or blue contain low species richness (Bat Conservation International).

Dead standing trees (snags) are an important ecological feature supporting a variety of wildlife, including bats. Currently, in the Pacific Northwest, snag removal regulations have been implemented without trying to understand the ecological impact of their removal. There is not enough information on the regulations and management guidelines that directly alter snags, especially in old-growth forests. There should be more research focused on regulations from an ecological context, connecting the effects of each regulation to biological results to fully understand how they are affecting the ecosystem (Kroll, Lacki, & Arnett, 2012). Snags are essential for many roosting species, and their removal may have consequences to the ecosystem's overall function.

Logging & Habitat Loss

Logging is an important piece of the regional Pacific Northwest economy because of its use for timber harvest and clearing land for agriculture or economic development. With growing human populations, timber and agricultural demands are increasing, expanding logged land. Although logging is deemed necessary by many stakeholders for population and economic growth, it reduces habitat for many species. In the Pacific Northwest, logging has increased exponentially over the past 20 years; lacking soils able to support agriculture, the timber industry is able to thrive as a leading economic driver for the region (Peterson & Anderson, 2009; Strittholt, Dellasala, & Jiang, 2006). The Pacific Northwest contains many bat species due to the large percentage of old-growth forests compared to many other areas of the United States. For humans, bats are essential to old-growth forests because of their value as indicator species, with specific temperature requirements, roosting preferences, and foraging behaviors. With such specific needs, any disturbance to bat ecosystems will likely have significant impacts on their health that are simple to assess, which is why they are such good indicator species.

Ideal roosting sites, for many bat species, require specific temperature and moisture levels that are not preserved in logged or managed forests, because they lack the dead and decaying snags that offer preferred roosting site requirements. Bats prefer large-diameter trees such as the Douglas fir, which is one of the main trees harvested for timber in the Pacific Northwest (Oliver, Larson, & Oliver, 1990). Additionally, many forests are converted into young forests with cyclical logging: cutting down trees for harvest, and allowing them to regrow for a set number of years afterward. Cyclical logging is causing tree species such as the white pine and ponderosa pine, which are not typically logged, to become preferential roosting sites because of their large size compared to the new younger trees (Campbell et al., 1996). This change in roost site preference, caused by the lack of large trees which would typically be preferred roosting sites, is not affecting the abundance of bats, though it is changing the survival rates of several species that have particular roosting requirements (Law, Chidel, & Law, 2018). For example, Law et al. (2018) found that the survival rates of the Eastern forest bat (*Vespadelus pumilus*) significantly decreased from 41% in unlogged sites to 30% in logged sites.

Clear-fell logging is the logging method that most disrupts ecosystems in the Pacific Northwest. This method wipes out all trees in an area, including trees not needed for timber production. Clear-fell logging leads to fewer roosts overall with remaining roosts closer to each other than they were before (Borkin, O'Donnell, & Parsons, 2011). Bat species in the Pacific Northwest, such as the California myotis (*Myotis californicus*), require geographically distinct areas for roosting and do not use other bat species' roosts or form social groups (Borkin et al., 2011; Hayes & Wiles, 2013). These requirements cause *Myotis californicus* and other species to relocate to different roosting sites, which, depending on the area, can be far away. Traveling great distances can expel massive amounts of energy, making it a perilous task for bats and can decrease survival in groups of otherwise healthy bats (Cisneros, Fagan, & Willig, 2015).

Clear-fell logging severely reduces bat habitat, shrinking the pool of roosts available to each bat or bat social group (Borkin et al., 2011). In New Zealand, on average, 20% of all roosting sites are destroyed every year, approximately 70% of which are lost to logging operations while only 30% are lost to natural tree falls (Borkin et al., 2011). This vast majority of roosting sites lost to logging reveals how devastating logging is to habitats. Non-sustainable methods of logging, such as clear-fell logging, are destroying bat habitats causing bat species to become threatened or completely endangered. The loss of these habitats indicates a decline in ecosystem health that could be better managed with other methods of logging.

Sustainable Logging Methods & Forest Management

Sustainable forestry methods may help alleviate the damage being done by logging and should be implemented in all old-growth forests. One sustainable forestry method currently used in Trinidad is the period block system, which is a selective logging method with a harvest rotation of 30 years (Clarke, Rostant, & Racey, 2005). To evaluate how sustainable period block system is, Clarke et al. (2005) examined bat populations in primary forests as well as period block system logged forests to determine overall ecological health. Period block system did not influence bat species diversity but did significantly affect community structure; frugivores and insectivores were found in primary forests, and carnivorous bat species were pushed into the newer, more disturbed areas. Clarke et al. (2005) argue that more sustainable forestry methods like period block system should be evaluated because it is essential to understand the impacts of logging disturbance on wildlife. This logging method may serve as a blueprint for managing forests in the least harmful way (Clarke et al., 2005).

Although period block system and other sustainable methods have higher habitat conservation rates than non-sustainable methods, they do significantly change forest structure as well as plant and animal community composition (Clarke et al., 2005). In contrast, the absence of any logging activity increases bat species heterogeneity and population density over time, and overall bat community composition remains functional (Gaoue et al., 2015). Other studies have observed a decrease in bat species richness in logged sites 10 years following the disturbance, which has led researchers to suggest that forest recovery of logged sites does not offset the losses from disturbance (Peters, Malcolm, & Zimmerman, 2006). Additionally, short-term tree harvest, harvesting specific tree species and then allowing them to regrow at high intensity, significantly impacts the understory plant community composition. This harvesting method has negative impacts on the quality of available habitat that trees provide in these young stands, causing the habitat quality of many trees to decrease and no longer be up to the standard of old non-disturbed forests (Peterson & Anderson, 2009). Without logging, forests can grow successionally with minimal disturbance and provide preferential habitat for bats and other species.

Another proposed forestry method is to implement policies that may assist logging companies in embracing sustainable harvesting techniques. Kilgore and Blinn (2004) found that both technical and educational programs have been implemented around the country to encourage loggers how to appropriately apply sustainable guidelines and the importance of doing so (Kilgore & Blinn, 2004). These policies can be implemented in many ways; for example, in Oklahoma, a few timber companies are beginning to encourage policy implementation by providing price premiums to loggers who follow policy guidelines (Kilgore & Blinn, 2004). Considerable research on the effectiveness of these programs, or how logging companies have implemented them, does not exist, but the current literature on these programs may begin to promote a switch from traditional logging methods to more sustainable methods.

Conclusion

Bats are indicators of habitat and environmental health (Mlakar & Zupan, 2011), making them useful in analyzing logging effects on forest ecosystems. In the Pacific Northwest, logging is increasingly destructive to wildlife habitats, including those of bats. The specific requirements many forest-dwelling bats have for their roosting sites allow researchers to examine the direct effects logging has on forests. The current literature on the negative effects of logging, specifically in the Pacific Northwest, is lacking, allowing the logging industry to continue at full force. More research is needed to comprehend the devastation logging has on forest habitats. The focus on logging effects on bats in the tropics gives researchers and sustainable logging advocates some specific blueprints for how they may apply tested methods to places like the Pacific Northwest. Sustainable methods used in the tropics may affect bats in the Pacific Northwest completely differently, but they may lead to the beginnings of more a sustainable logging industry. Logging is driving the destruction of bat and other wildlife habitats, leading to increased extinction rates of bats (Borkin, O'Donnell, & Parsons, 2011). There is a need for more research on how logging affects bats in the Pacific Northwest, and how sustainable methods such as period block system may be implemented in the Pacific Northwest region as a whole.

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CHAPTER 2. GRANT PROPOSAL

Restore waterflow and natural channel characteristics through salt cedar (*Tamarix* spp.) control methods around South St. Vrain Creek

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Section 1: Abstract

Invasive species have been introduced throughout the United States, negatively impacting many ecosystems. In Colorado, salt cedar (*Tamarix spp.*) has begun to invade disturbed riparian zones, negatively affecting plant communities and surrounding soil compositions. By drawing up salts from deep down in the soil and secreting them into the topsoil, salt cedar increases the overall salinity of soils, decreasing the ability of native species to germinate. Currently, Boulder County Parks and Open Space (BCPOS) is being invaded by salt cedar and is looking for a way to control its harmful effects. I will determine what areas of BCPOS are at highest risk of salt cedar invasion by conducting vegetation surveys. I will then evaluate three different invasive species control methods: mechanical removal, chemical treatments, and biocontrol treatment. The data collected in this assessment will provide BCPOS managers with information necessary for managing and preparing for salt cedar invasion.

Section 2: Objectives, Goals, Literature Review, and Anticipated Value

I will establish the highest priority areas for restoration in BCPOS by quantifying the amount of existing salt cedar (*Tamarisk* spp.) within a 10-meter region and determining how large the risk of seed dispersal may be. I will then determine the most effective salt cedar control method and how each method impacts waterflow and channel characteristics in the riparian areas around South St. Vrain Creek. This study will examine the effectiveness of mechanical control, chemical control and biocontrol of invasive salt cedar. Effectiveness will be determined by how much salt cedar is removed and the amount remaining after regeneration; the most successful method will cost-effectively remove salt cedar and minimize the amount of regeneration. My results will provide information to help land managers successfully remove salt cedar and understand the environmental impacts of their removal on factors such as soil erosion, soil salinity, and water availability of streams or rivers and their surrounding riparian zones.

Specific Goals

Goal #1: Determine which areas of South St. Vrain Creek are high priority for restoration/at highest risk for salt cedar invasion.

Goal #2: Determine which method of salt cedar control is most effective at restoring function to South St. Vrain Creek.

Literature Review

In the Southwestern United States including parts of Colorado, salt cedar has begun to invade quickly, taking over riparian zones by out competing the willows, cat tails and other native, non-invasive riparian species (Di Tomaso, 1998). Salt cedar is native to the Mediterranean region but can establish on disturbed land such as agricultural, urbanized, and other altered lands in the United States (Brock, 1994). As an invasive species, salt cedar is very competitive because it draws up salts from soil and excretes them from its leaves, increasing the soil salinity and suppressing germination of other species (Di Tomaso, 1998). Salt cedar not only changes the salinity of the soils around them, they also affect the salinity and water levels in the surrounding streams or rivers. Friederici (1995), found that one large salt cedar tree can absorb up to 760 liters of water a day. Its salt output can run off into waters and increase the salinity of the water and sequentially impact the biotic factors within the waters (Di Tomaso, 1998). As the salinity of both the water and soils increases many plant species are unable to grow or reproduce and slowly the function of the ecosystem is changes altogether.

Management of salt cedar is accomplished by mechanical control, chemical control, or biocontrol treatments. Mechanical control can take the form of hand cutting, mowing, ploughing, or chainsaw cutting. Chemical control is accomplished through herbicide application, and biological control agents for salt cedar take form in the tamarisk beetle (*Diorhabda carinulata*). There is a lack of information on the relative effectiveness of each method of salt cedar invasion control (Brock, 1994; Bateman et al., 2010). Mechanical treatments are usually done with the goal of removing all top growth but in some cases include the removal of root systems as well; the removal of root systems may disrupt nearby species, negatively impacting the ecosystem (Brock, 1994). Chemical treatments in the form of herbicide application have been used to treat salt cedar for decades but the best herbicide with the lowest ecological and economic costs has yet to be found (Douglass, Nissen, & Hart, 2013); with chemical control there is also the risk of water contamination depending on the chemical used. Chemical treatments often need a bit of mechanical control before application leading to more time and money being spent on the treatment than only using one or the other (Brock, 1994; Harms, & Hiebert, 2006). Lastly, biocontrol treatments are often used when there is a pest known for preying on an invasive species. Biocontrols can be dangerous because they place another alien species into an environment without always how they may impact the surrounding environment (Bateman et al., 2010). Tamarisk leaf beetles (*Diorhabda elongate)* are pests that forage on the leaves of salt cedar and are thought to increase salt cedar mortality up to 40% (Hultine et al., 2010). Although they have been used as a control method in other areas of the United States in the past, they have not been studied enough to fully understand their potential widespread impacts (Hultine et al., 2010). All invasive species control methods are feasible and have been done but their effectiveness and efficiency have not been properly analyzed. More information on each method is needed to create proper management protocols for salt cedar control.

Anticipated Value

Removing salt cedar in zones that have been completely invaded or have the possibility of destructive invasion will restore or maintain the function of the ecosystem. Boulder County Parks and Open Space has begun to see the invasion of salt cedar and knowing how to properly deal with it is important for maintaining the heath of the Boulder County Parks and Open Space riparian ecosystems. To properly remove or control salt cedar, it is important to fully understand the benefits and costs of each management technique before applying them. The literature is currently lacking the information needed to understand how each method of control will impact an ecosystem. This study will provide land managers and governments with the information to create an effective protocol for controlling salt cedar.

Section 3: Methods

Study Site: This study will be conducted along South St. Vrain creek in the area managed by Boulder County Parks and Open Space where salt cedar has been recorded (Fig. 1). The total length of the study site is 1.5 miles on each side of the creek which is just a small portion of the nearly 33-mile-long creek. This creek drains part of the foothills north of Boulder.

Goal #1: Build a map of South St. Vrain Creek that locates areas of high restoration priority

To identify areas with high salt cedar I will conduct a baseline vegetation survey along both sides of South St. Vrain Creek across the entire 1.5 miles of Boulder County Parks and Open Space managed land (Fig 1). Thirty 10mX10m plots will be selected randomly along transects on both sides of the creek, using ArcGIS. I will navigate to each plot using a GPS device with the randomly selected plots predownloaded onto it. During this baseline survey I will record total species richness and percent cover of salt cedar, cottonwood, and willow, which are the main competitors of salt cedar. Areas with high percent cover (above 20 percent) of salt cedar and low species richness (fewer than 5 total species) will be considered high-risk areas. Other high-risk areas may have low species richness and low percent cover (below 10 percent) of salt cedar but are in close proximity (within 10 meters) to areas with high percent cover of salt cedar areas, making them susceptible to invasion. I will repeat this survey technique twice prior to applying the control methods to confirm the presence or lack of salt cedar. Following the completion of the surveys, I will use ArcGIS to create a map of the collected data which indicates which areas are considered high risk.

Goal #2a: Evaluate different salt cedar control methods

After completion of both baseline vegetation surveys, I will select thirty 10mX10m plots along both sides of South St. Vrain Creek that fall within areas I determined to be high priority, 15 plots on each side of the creek. I will randomly select the plots using a map of the study site on ArcGIS. All plots will be at least 10m apart from one another to avoid any overlap of vegetation. I will then assign ten plots to each of the three salt cedar control methods. Ten plots will be chain sawed, mowed, and plowed as a mechanical treatment (Bay & Sher, 2008; Belote et al., 2010), ten plots will be chain sawed and treated with an Arsenal and glyphosate herbicide mix on the cut stumps as a chemical treatment (McDaniel & Taylor, 2003), and the last ten plots will be treated with the release of tamarisk leaf beetles as a biocontrol (Nagler et al., 2018). After completion of each treatment I will survey the entire study site, as in goal #1. I will repeat the same survey technique again once the growing season has ended to quantify the regeneration of salt cedar.

Goal #2b: Cost-benefit analysis of each salt cedar control method

After the completion of all surveys and treatments of plots, I will perform a cost-benefit analysis of each treatment method. I will compare the actual monetary costs of supplies used for each method, costs of labor, and environmental costs discovered in the post-treatment surveys associated with each treatment method to the benefits to the ecosystem that each treatment method provides.

Data Analysis

I will conduct a before/after, control/impact (BACI) assessment on the effects of each control method described above. This will compare the results of the pre-management surveys to the results after applying each control method. The BACI design will compare the sites conditions in the time before any treatments have been applied and the time after the treatments have been applied to each plot to estimate the magnitude to effects (Palmer, Zedler & Falk, 2016). To complete the BACI analysis I will use R Studio to compare models from the survey data collected either before or after the treatments are applied.

Negative Impacts

The negative effects of completing this study are dependent on the treatment method. Treatment using mechanical control may have consequences such as trampling of vegetation, increased erosion along South St. Vrain Creek, or unintended removal of other species. The potential negative impacts of chemical treatments include contamination of water through herbicide run-off and unintentional trampling of surrounding vegetation. Both chemical and mechanical methods have negative impacts that depend on the experience of field technicians whereas the potential negative impacts of biocontrol as a treatment are dependent on the pest used. Biocontrol treatment can have negative effects on surrounding vegetation and wildlife depending on the life history of the pest; in this case it is unknown the exact effects tamarisk beetles may have on the South St. Vrain Creek ecosystem. While these negative effects are possible, if the treatments are all completed following the protocol, which will include steps to minimize impacts such as the proper way to spray herbicide by only applying it to the targeted plants, by trained technicians, the impacts will not be detrimental. If there are considerable negative effects, remediation of the sites may be considered.

Project Schedule

Dates	**Activities**	**Deliverables**
April 2020 – May 2020	▪ Conduct initial vegetation surveys	▪ Map of high-risk areas
June 2020 – August 2020	▪ Set up plots for study ▪ Apply treatment methods to each plot	▪ Data on each control method
November 2020	▪ Complete survey of treated plots	▪ Map of how high-risk areas have changed
December 2020	▪ Analyze data through cost-benefit analysis ▪ Write up report of all findings	▪ Cost-benefit analysis of each method ▪ Which method is the most effective and efficient ▪ Complete report with the final results

Section 4: Budget

Item	**Justification**	**Cost**	**Quantity**	**Total Cost**
Chain saw	To mechanically remove salt cedar	$159 (homedepot.com)	1	$159
Mower	To mechanically remove salt cedar	$329 (homedepot.com)	1	$329
Herbicide	To chemically remove salt cedar	$30/ gallon	1	$30
Sprayer	To chemically remove salt cedar	$125 (ULINE.com)	1	$125

Gas	For travel to and from the site	$0.535/ mile 45mi = $$24.08	10 trips	$270.80
GPS	For locating the treatment plots	$299.99 (garmin)	1	$299.99
Flags	To mark treatment plots	$7.97/ per 100 pack	1	$7.97
iPad	For data collection in the field	$138.89	1	$138.89
Student Field Tech	To conduct the treatment of the plots	$1000 stipend	2	$2,000

Total Request: $3,360.65

Section 5: Qualification of Researcher

Marley T. Borham

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Telephone: **(708) 822-8065**

Email: **mborham@regis.edu**

Education

M.S. in Environmental Biology, May 2020, Regis University (Denver, CO)

B.A in Environmental Studies, December 2018, Marquette University (Milwaukee, WI)

Relevant experience

June 2018 - August 2018 **Land Stewardship Intern (Urban Ecology Center) – Milwaukee, WI**

- Organized and led the volunteer land stewardship program at Riverside Park multiple times weekly
- Planted a variety of native plant species throughout the parks
- Assisted in overseeing and maintaining a plant nursery containing a wide range of native plant species
- Conducted multiple vegetation surveys in all three of the parks (Riverside Park, Menomonee Valley, Washington Park)
- Assisted with seed collection throughout the growing season at surrounding natural areas

January 2018 – May 2018 Land Stewardship Intern (Riveredge Nature Center) – Saukville, WI

- Worked in a team to map and remove a variety of invasive species using a Garmin GPS system.
- Assisted in leading Riveredge Nature Center's volunteer land stewardship program with volunteers of all ages and environmental knowledge
- Organized and maintained an inventory of equipment and supplies

April 2017 – December 2018 Laboratory Assistant – Gamble Lab (Marquette University)

- Upheld the livelihood of an assortment of gecko species with different feeding regimens, sterilizing enclosures, and temperature regulation.
- Performed a variety of safety procedures to certify reliable data collection in the laboratory

August 2017 – January 2018 Biology Teaching Assistant (Marquette University)

- Graded case studies, quizzes, exams and short papers
- Administered exams and monitored students as a test proctor
- Tutored students on a variety of biological concepts weekly and by appointment

Relevant course work (B.A., Marquette University)

Advanced Ecology, Environmental & Natural Resource Economics, Tropical Ecology in Panama, Food, Water & Society, Plant Biology, Material Cultures: Environmental Protection

Relevant course work (M.S., Regis University)

Forest & Vegetation Ecology, Aquatic Ecology, Advanced Behavioral Ecology, Biostatistics & Research Design, Conservation & Restoration Seminar, Environmental Biology Colloquium & Grant Writing, Field Ecology, Environmental Regulation & Impact Assessment (NEPA), ArcGIS

Appendix:

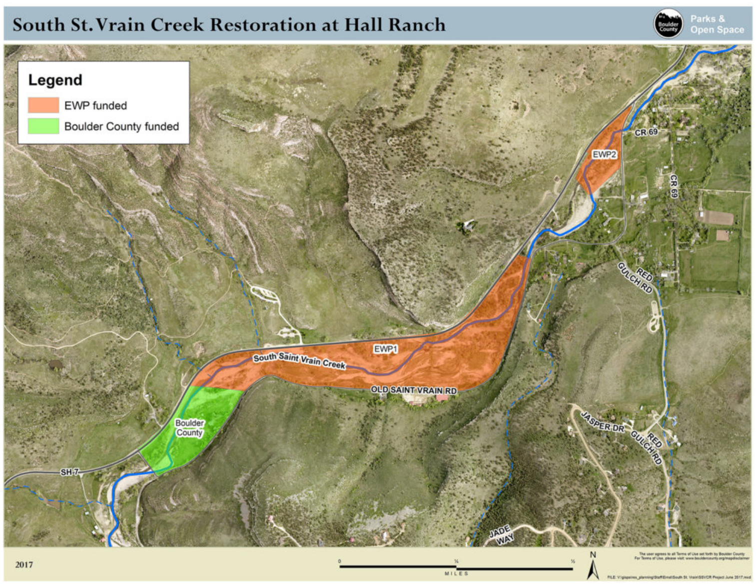

__Figure 2__: Map shows South St. Vrain Creek, areas highlighted green are managed by Boulder County Parks and Open Space and orange highlighted areas are managed by EWP (https://www.bouldercounty.org/open-space/management/south-st-vrain-creek-restoration/).

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CHAPTER 3: JOURNAL MANUSCRIPT

Analysis of population growth rate of *Penstemon degeneri* in Colorado's Arkansas River Valley indicate no significant trends over three years

Abstract

Penstemon degeneri is a rare and endemic species of flowering plant found in Colorado, USA. As a rare and endemic species, *P. degeneri* has never before been studied or monitored in the field. The Bureau of Land Management (BLM) Royal Gorge Field Office has begun a monitoring study to determine the status of this species, its life history characteristics, and its growth rate. The study began in 2017 with monitoring of *P. degeneri* populations at four sites across south-central Colorado. I examined the population count data of *P. degeneri* that has been collected over the past 3 years using Bayesian statistical methods to determine if there are any changes in growth rate so far. I hypothesized that growth rates at the four sites will differ due to varying environmental factors that have not yet been recorded and found that there is not enough data to obtain significant trends in growth rate at three of the four sites. One site, Table Mountain, did show a significant positive trend in growth which may be due to this site having little disturbance history. More population data on *P. degeneri* needs to be collected to further investigate the changes in population growth rates, and to determine any additional life history traits.

Introduction

Currently, the world as we know it is changing physically due to increased anthropogenic disturbance from growing human populations. These changes have physical impacts on our environment, such as increased habitat loss. Changes like habitat loss are leading to the extinction of thousands of species worldwide every year (Dirnböck, Essl & Rabitsch, 2011; Thomson, 2005). Some species are at higher risk of extinction from habitat loss because of their small geographic ranges and low populations; these species are known as endemic species (Isik, 2011). Endemic species are similar to rare species but have some differing characteristics.

Species may be considered rare and/or endemic when they can be characterized in one or more of the following ways. The first and best-known characteristic for endemic species is that they have a narrow geographic range (Isik, 2011). Depending on how narrow the geographic range, species may be considered locally, regionally, nationally, or continentally endemic (Isik, 2011). Having a relatively small geographic range causes a lot of endemic species to have small population sizes and low genetic variability. Because of their narrow geographic range and small population sizes, rare and endemic species may be hard to study and a lack of data on these species makes them harder to conserve (Thomson, 2005). Along with their narrow range, low genetic variability decreases a species ability to combat change in climate, habitat, and disease risk (Isik, 2011). With low genetic variability and low ability to fight off disease, many endemic species have only a few populations remaining and may display declines in population size (Dirnböck, Essl & Rabitsch, 2011; Isik, 2011; Thomson, 2005). These species also may have specialized niche demands that are being impacted by changing climate and anthropogenic disturbances (Dirnböck, Essl & Rabitsch, 2011; Isik, 2011; Cañadas et al., 2014). Climate change and varying environmental gradients have been shown to have a significant impact on endemic species richness and range (Cañadas et al., 2014). These characteristics make endemic species vulnerable and can help explain the extinction rates from habitat loss we see worldwide.

Many species exhibit more than one of the above characteristics, which may lead them to be listed as a threatened species.

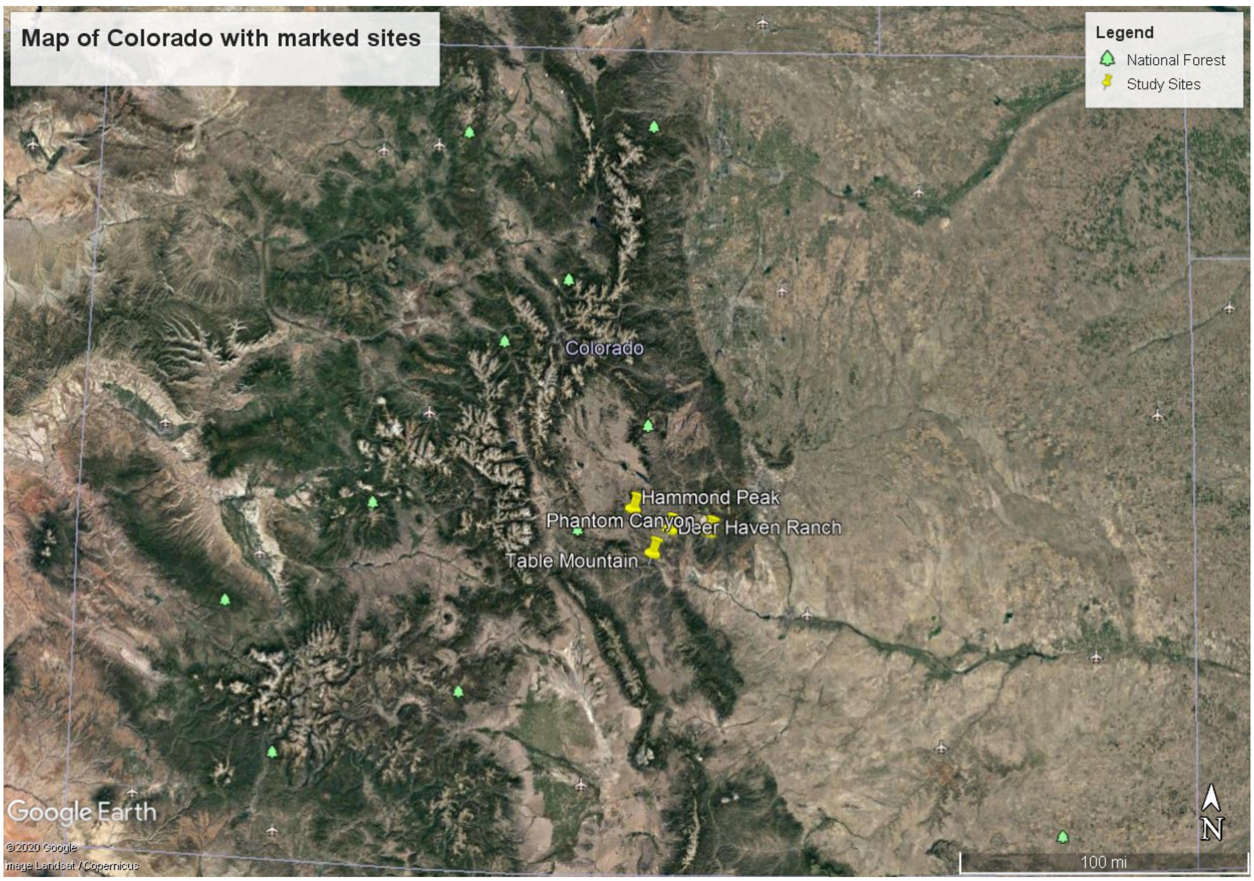
P. degeneri is a rare and endemic perennial herb that is part of the Plantaginaceae family, and is found at elevations from 1830 to 2896 meters in south-central Colorado (Beatty, Jennings & Rawlinson, 2004; Meyer, 2008). *P. degeneri* is distinguished from other *Penstemon* species by the size of its anther sacs, its unique yellow petal color, the density of the hairs on its petals, and its relatively small geographic range (Beatty, Jennings & Rawlinson, 2004). In south-central Colorado, *P. degeneri* is found in pinyon-juniper woodlands, ponderosa pine forests, and the montane meadows of the Arkansas River Valley (O'Kane, 1988). Within these habitats, *P. degeneri* inhabits rocky areas, cracks of rock slabs, pine-needle duff, oak brush, grassy meadows, and the areas between meadow and forests (Beatty, Jennings & Rawlinson, 2004).

The Bureau of Land Management-Royal Gorge Field Office is undertaking the monitoring of this endemic species to establish both population and landscape-scale trends, understand the species responses to changing environmental conditions, and to identify its important life-history traits. Four permanent trend-monitoring plots were established in 2017 where known populations of *P. degeneri* existed. Sites were selected for sampling based on surface management, accessibility, and size of population at location of occurrence. Sampling locations are distributed across the known range of the species. An analysis of population growth trends at disjunct populations will allow for an understanding of the overall viability of the species. Monitoring sites are located at Sommerville Table (Table Mountain), Hammond Peak, Deer Haven Ranch, and Phantom Canyon populations. With natural and anthropogenic disturbances affecting all four sites, it is expected that there will be differences in population trends, growth rate, and ability to reproduce between the four *P. degeneri* populations. I focused on the population growth rate using Bayesian statistic methods which incorporates conditional probabilities with the existing data that will give the BLM a more rounded estimate of what their future populations may look like. This statistical method was chosen as a baseline to begin to understand the changes in population growth as monitoring continues annually. With a flat prior, I hypothesize that the population growth rate of *P. degeneri* with differ significantly across the four sites because of varying environmental factors.

Methods

Study Site

The first site established in 2017 as a site containing a population of *P. degeneri* is Table Mountain. Historically, Table Mountain has been relatively undisturbed (Table 1). Located on the north rim of the Arkansas River Valley, high above Cañon City, it had native grasses but minimal water availability (Rustand, 2019). Small numbers of cattle grazed the area sporadically, but the area could never support large numbers of livestock for very long without a water source. Therefore, unlike many montane grasslands in Colorado, the species composition of parry oat grass, mountain muhly, junegrass, western wheatgrass, slender wheatgrass, blue grama, and others at High Mesa has changed little since the late 1800s (Rustand, 2019). The second site is Hammond Peak, which was established in 2017 as a site containing a population of *P. degeneri* (Table 1). Hammond Peak had been intensively logged as the first homesteaders built a mill along its north slope (Rustand, 2019). *P. degeneri* occurs along peaks ridgeline as it transitions from grassland along the south slope to mixed conifer on the north slope. The third site established in 2017 containing a population of *P. degeneri* is Deer Haven Ranch (Table 1). This location has been intensively managed by the forestry and fuel program (Rustand, 2019). Within the population occurrence area, ponderosa pine thinning and several controlled burns have taken place, creating a stand that contains mature trees with a grassy understory. The fourth and final site containing a population of *P. degeneri* is called Phantom Canyon and was again established in 2017 (Table 1). This last site occurs along historic stagecoach road and railroad line that connected Florence, Colorado, to Cripple Creek, Colorado which is now a part of the Gold Belt Scenic Byway (Rustand, 2019). Due to this area's history and little management action, the site where the plant occurs today is heavily disturbed (Rustand, 2019).



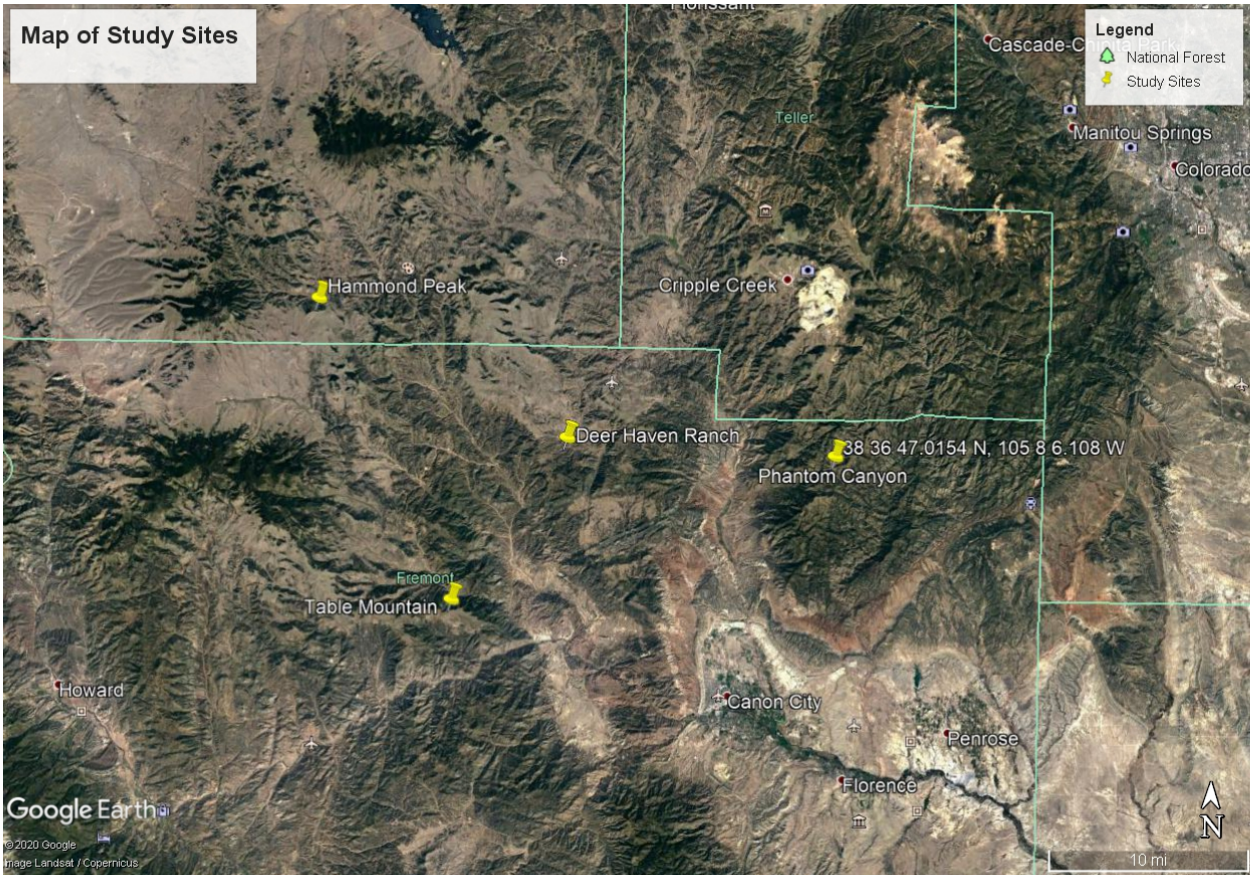


Table 1: Sampling sites with a summary of descriptive features (Google Earth)

Sampling Site	GPS Location Plot (0,0)	Elevation	Average Slope	Aspect	Disturbance History
Table Mountain	13S 458005 4262173	~8800ft	0.0%	Flat	Little grazing
Hammond Peak	13S 447301 4285734	~9700ft	7.6%	NE	Logged

Deer Haven Ranch	13S 467020 4275045	~8000ft	0.0%	Flat	Burned and grazed
Phantom Canyon	13S 488244 4273848	~8200 ft	1.6%	SW	Railway and road

Data Collection

We established rectangular macro plots at each monitoring site within areas of species occurrence with plot dimension chosen based on population size and structure. We selected transect locations within each macroplot using a restricted random method to maximize the detection of variability within the sampling location (Figures 1-4). We placed permanent stakes at both ends of each transect to be read yearly. To determine mean plant density, we recorded all occurrences of *P. degeneri* within the transect belt, notes were taken on life stage and phenology documenting if individuals were flowering, fruiting, or damaged as well.

Data Analysis

I used the program WinBUGS alongside the R Studio (version 1.2.5033) package R2WinBUGS to create a Bayesian state-space model which works well for analyzing population count data (RStudio Team, 2015). Running the Bayesian state-space model for each of the four populations over three years gave figures which show the true, observed, and estimated values of population size. The model estimated true and observed values based on the initial counts of *P.* degeneri in 2017, the mean population growth rate across all three years of data collection, and the temporal variation of the growth rate. The estimated values are the result of running the state-space model with a flat prior. These estimated values come from a Markov chain Monte Carlo (MCMC) algorithm, which creates a probability distribution. Along with the Bayesian model, I performed t-tests to compare population counts of *P. degeneri* between 2017-2019 at each of the four sites. These t-tests gave a little more insight into the current population trends of *P.* degeneri, as the Bayesian model only projects into the future.

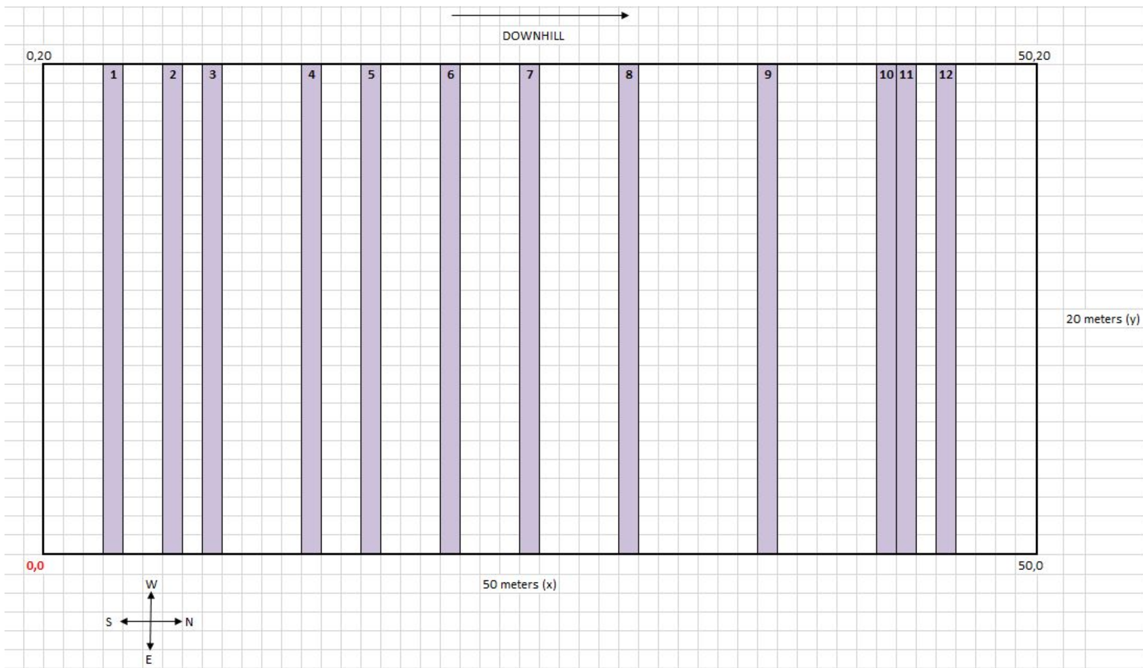


Figure 3: Table Mountain plot with 12 transects

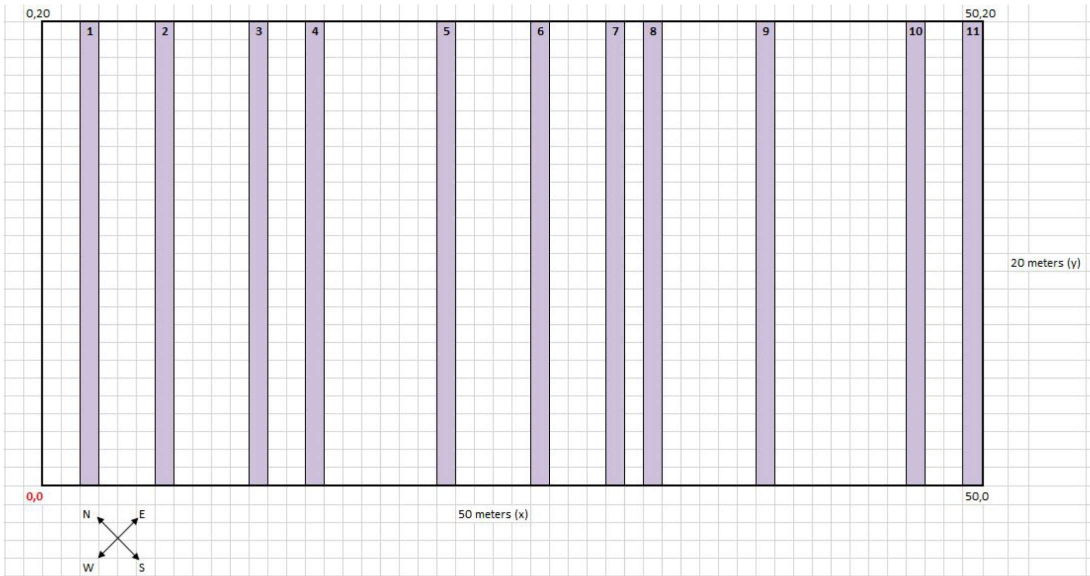


Figure 4: Hammond Peak plot with 11 transects

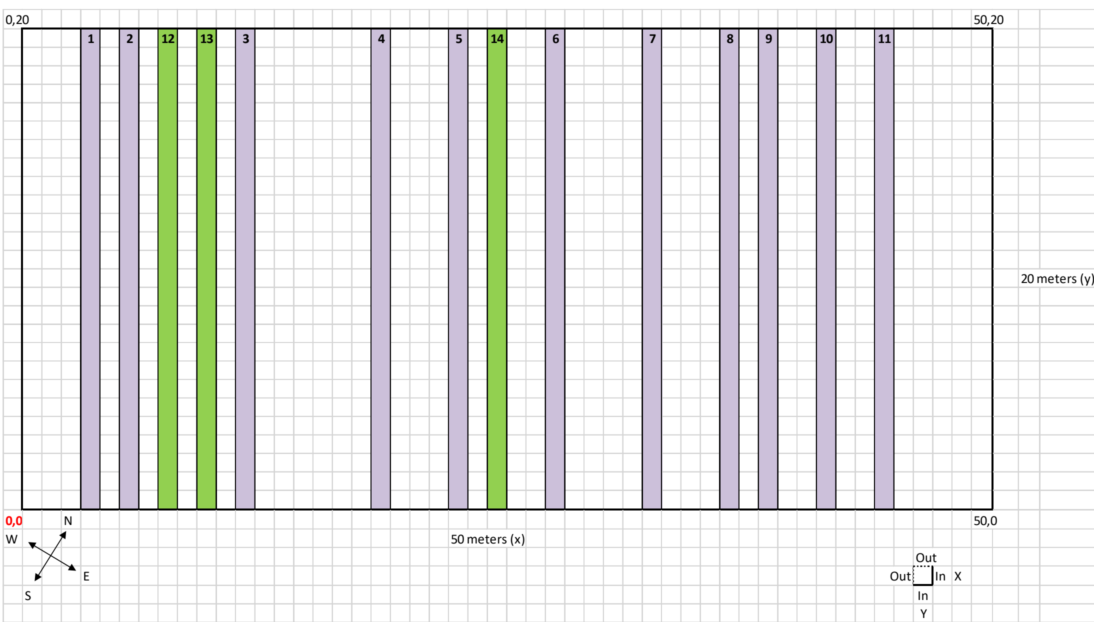


Figure 5: Deer Haven Ranch plot with 11 initial transects and 3 added transects

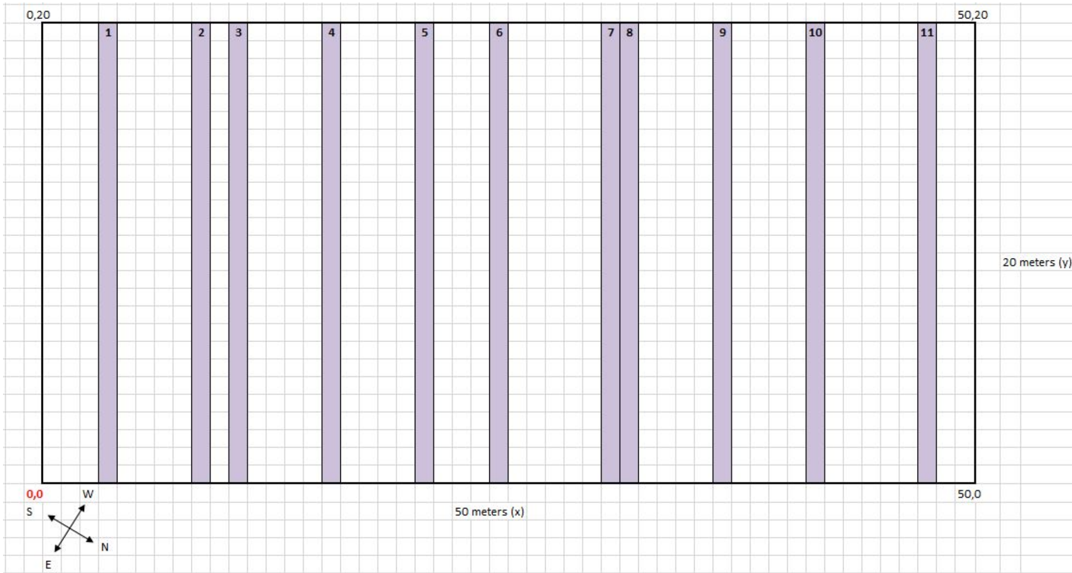


Figure 6: Phantom Canyon plot with 11 transects

Results

The resulting graphs of the state-space model (Fig. 5) for each of the 4 populations show that the true, observed, and estimated values do not differ significantly as the model has only 3 years of data to work from. The results of running t-tests of population sizes from 2017, 2018, and 2019 showed slight trends in population size across all four sites but yielded no significant results for all of the sites but Table Mountain where an upward trend in population growth was detected (p-value: 0.005) (Fig. 6-9). The results of percent flowering and vegetative growth mirrored the growth of population represented by the t-tests.

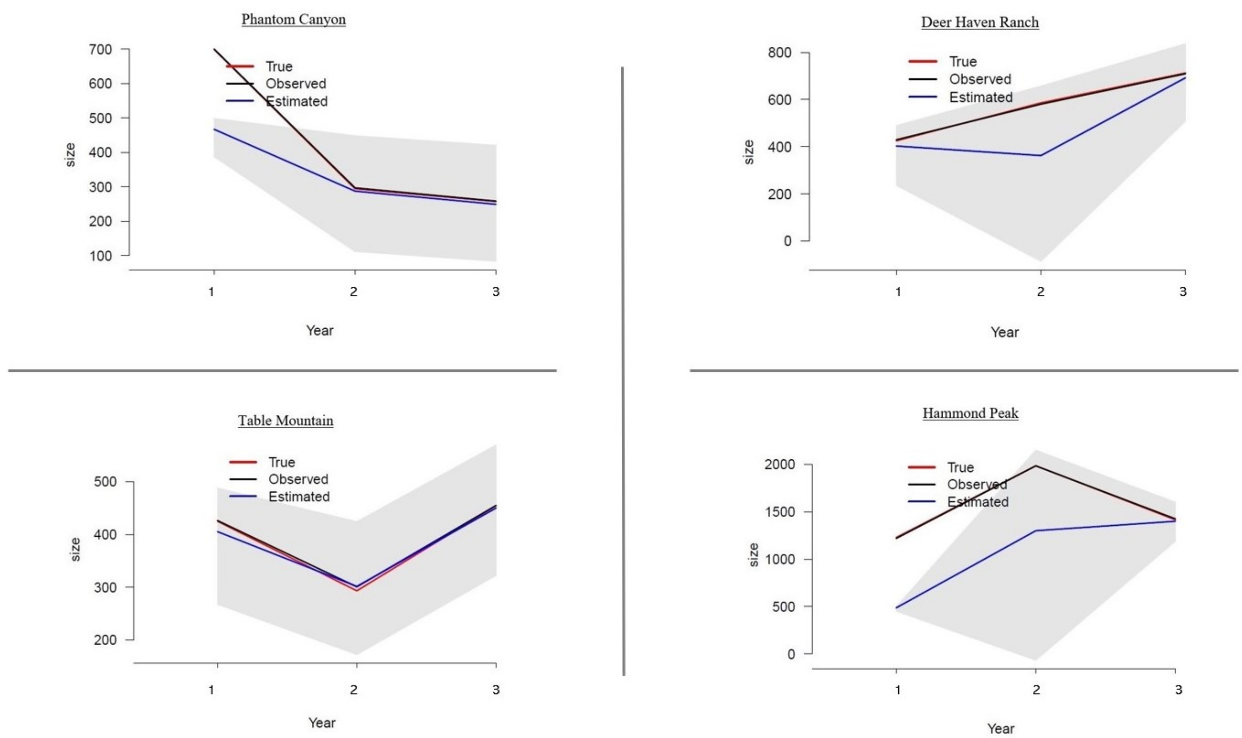


Figure 5: This figure shows how the Bayesian model models the estimated and observed population sizes. The true value shows how the population has decreased over the first year and then slowly began to increase in the second year. The true, observed, and estimated values vary across all four sites because of their differing initial population sizes and mean annual growth rates.

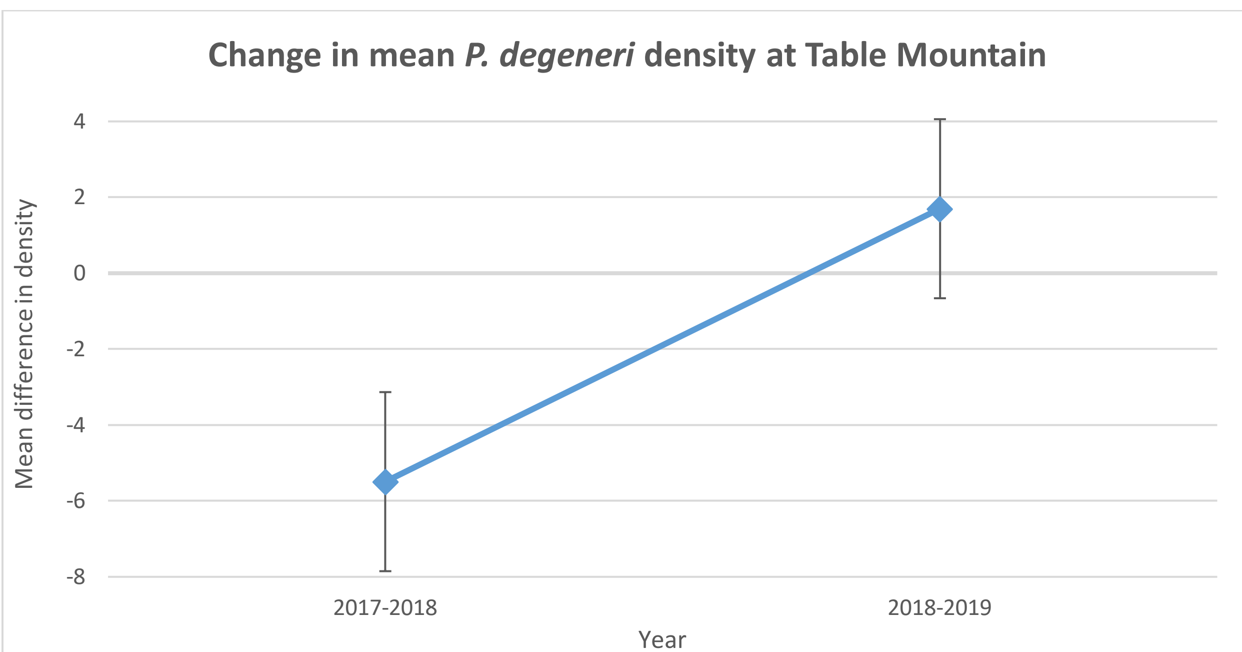


Figure 6: Difference in population size of P. degeneri between 2017-2019 at Table Mountain (p-value:0.005; 95% CI: 1.30-2.36).

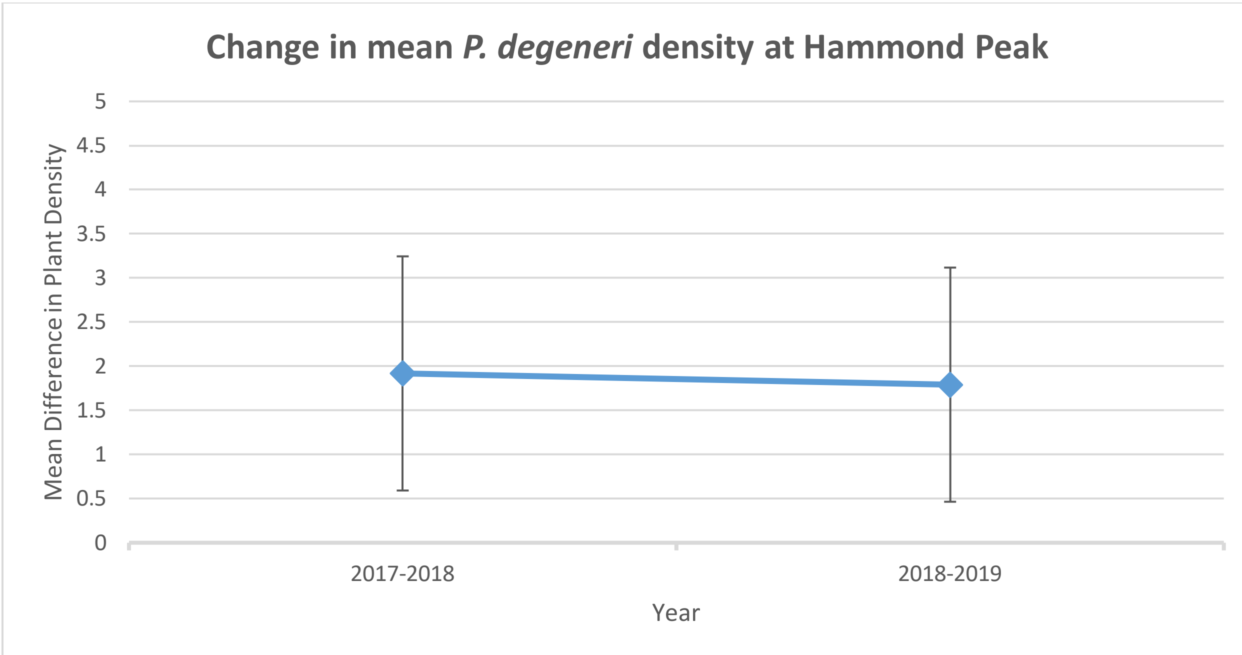


Figure 7: Difference in population size of P. degeneri between 2017-2019 at Hammond Peak (p-value: 0.924; 95% CI: 1.326-1.906).

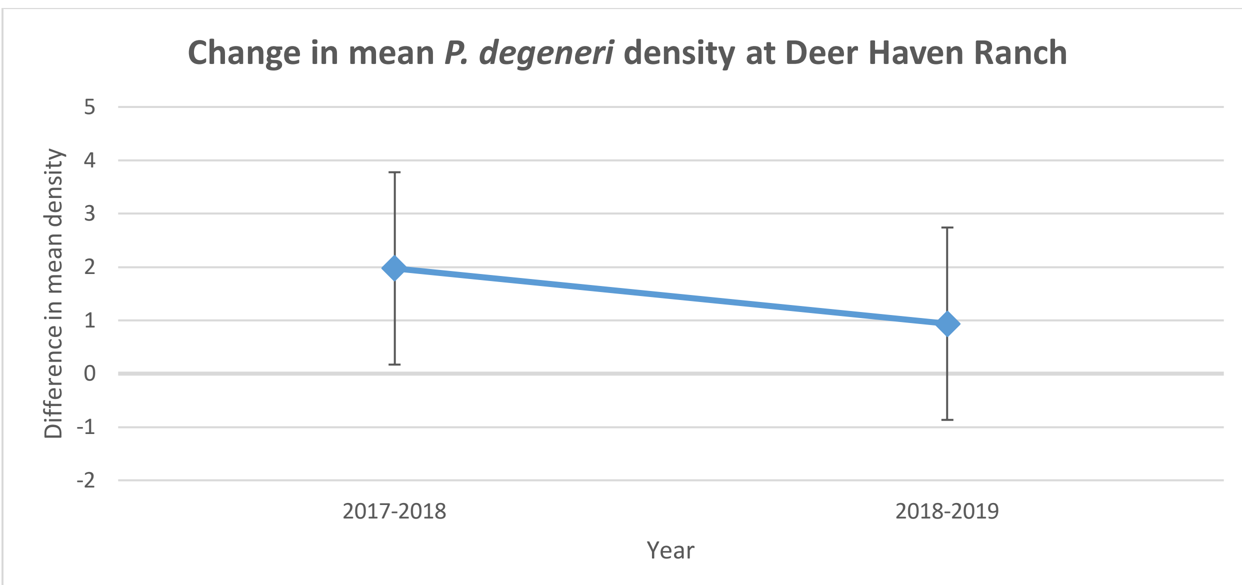


Figure 8: Difference in population size of P. degeneri between 2017-2019 at Deer Haven Ranch (p-value: 0.379; 95% CI: 0.773-1.803).

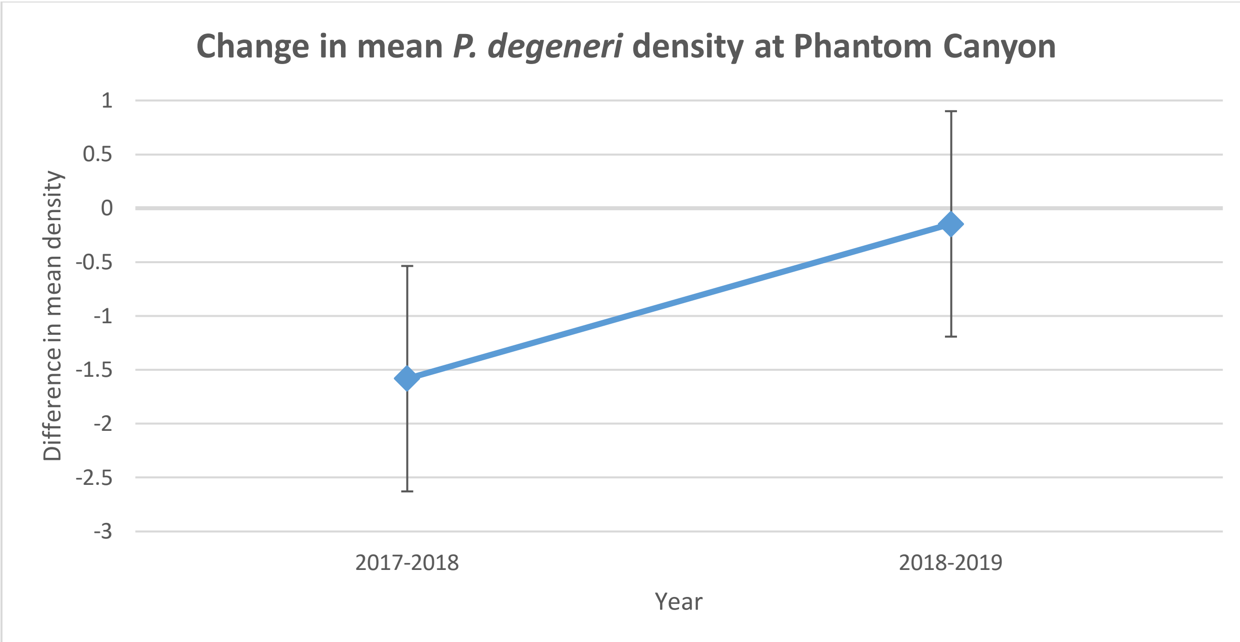


Figure 9: Difference in population size of P. degeneri between 2017-2019 at Phantom Canyon (p-value:0.140; 95% CI: 0.896-1.041).

Discussion

A model of this kind is designed for data collected over many years which is why the resulting graphs do not signify any specific trends. It was chosen for this study because it provides baseline information that can be built up as more data is collected annually. Looking at the first few years of monitoring data is important to determine how much data needs to be collected and how often (Phillips-Mao et al., 2016). As the results of this analysis don't show any significant results, we can expect that the model needs more data to determine any changes in population growth rates (Pico et al., 2008). T-tests were used to give a better insight into the changes in population growth rate at each site over the past 3 years, and it is anticipated that in the future t-tests will only confirm what is shown in the Bayesian model. As the monitoring of *P*. degeneri continues over the years the model will become more accurate and the estimate will be more informative. The results of this *P. degeneri* population growth monitoring has not shown any significant results. Therefore, the results do not support my hypothesis that the growth rates will vary across sites due to possible differing environmental variables at the different locations. This could be due to a variety of factors, the main being a lack of adequate data as the monitoring has only taken place once a year for three years. With only three years of data significant trends are not seen and it is recommended that monitoring data consist of at least 5-7 years to analyze annual population growth rates (Pico et al., 2008). Other factors that may have had a role in non-significant results could be sampling error and monitoring design. Each of the four sites currently have between 11-13 transects each, which in this case may not be enough to properly analyze the populations of *P. degeneri*. Another factor that could account for the lack of significant results could be the geographic location of the four sites, all four sites are in south-central Colorado. The close proximity of the sites with similarity in weather and elevation across all four sites could lead to populations that grow comparably (Table 1).

Although the results are currently not significant and only show minor changes, tracking the growth rate of *P. degeneri* remains important. Due to the endemic nature and lack of literature on this species it is essential to track the known populations so that it may be protected if it becomes threatened or endangered. The BLM has the resources and is able to monitor species like *P. degeneri* so that if the population reaches a level they consider to be at risk of extinction they can recommend of petition that it be added to the U.S. Fish and Wildlife service to be listed as threatened or endangered (Elzinga & Salzer, 1998). Doing so will give the species protection against things such as habitat destruction or seed collection. Additionally, because of the endemic nature of *P. degeneri* it is important for the BLM to monitor its populations as it is only found in Colorado and if the populations disappear there are no other populations that can be used to try and save the species (O'Kane, 1988).

In order to continue the monitoring of *P. degeneri* in a way that will ensure that the BLM as all the knowledge they need to make proper recommendations for this species, there are some changes that could improve the protocol and overall methodology of the study. The first piece being that the monitoring should focus on the life history of this species. As the life history traits are currently unknown for this species it is important that the BLM monitors in a way that will make these traits known. Life history traits such as its dispersal processes and rates are important for understanding how the species is able to grow its populations (Pico et al. Elzinga & Salzer, 1998; Hutchings, 1991) Some species may have dispersal methods that are dependent on the environment where others may disperse their seeds on their own (Elzinga & Salzer, 1998). Other traits that are useful to know and understand are its reproduction strategies, plant growth rates, and survivorship techniques (Hutchings, 1991; Elzinga & Salzer, 1998). Each of these life history traits tells managers and scientists why and how the populations grow in the ways they do and for the BLM these are important traits that should be examined for the good of the species (Picó et al., 2008; Usher, 1991). If *P. degeneri* populations start to decline knowing traits such as their dispersal methods will be important to try and conserve the species.

We know that plants can either reproduce sexually or asexually which determines whether an individual plant is reliant on other individuals and environmental conditions or is able to reproduce on its own (Chasan & Walbot, 1993). Plants that reproduce sexually are at a higher risk of extinction because of the way they rely on outside conditions to produce seeds (Sosa et al., 1998; Chasan & Walbot, 1993). Understanding the reproduction strategies of *P. degeneri* will help determine the need for conservation which is important because of the endemic nature of this species (Adsersen, 1989). Plants that reproduce sexually often do better when the population is large because the opportunity for reproduction is higher which is one reason why knowing the growth rate of plant populations is important. If a particular plant species has a high population growth rate, the probability of that species going extinct is lower than a sexually reproducing species with a low population growth rate (Sosa et al., 1998). We know that *P*. degeneri flowers and is likely a species that reproduces sexually so determining the growth rate of its known populations will tell us how likely it is to go extinct.

Creating a monitoring project for a rare and endemic species like *P. degeneri* where life history traits are unknown is a hard task to take-on but in doing so the BLM can gain valuable knowledge on how to conserve species of this kind that can be shared with other management groups. Refining monitoring protocols and discovering the best methods of statistical analysis will be crucial to the BLM in continuing to monitor rare and endemic species. With the information they will gain the BLM can help other land managers best monitor their land for species like *P*. *degeneri* and maintain biodiversity across the state of Colorado.

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CHAPTER 4

Increased Hunting and Education to Counteract White-Tailed Deer Overpopulation in Wisconsin

Introduction

In the Midwest, white-tailed deer (*Odocoileus virginianus*) have consistently expanded their range and increased in population size. Populations of deer in the Midwest US have increased in size because of changes in both top-down and bottom-up controls. Anthropogenic control of rivers by way of damming, channelization, stabilization, and diversion promoted the establishment of forest cover in riparian zones, prime habitat for white-tailed deer because they provide cover and vegetation for food (VerCauteren & Hygnstrom, 2011; Jodie et al., 2017). The stabilization of many rivers and streams throughout the Midwest resulted in more consistent flow and protection against erosion which promote the growth of vegetation on the banks (Odgaard, 2015). Similarly, the creation of irrigation systems throughout the Midwest permitted an increase in production of crops such as corn, alfalfa, and soybeans, all of which are prime food sources for deer as well (VerCauteren & Hygnstrom, 2011). The enhancement of these bottom-up controls occurred at the same time as the loss of top predators. Eradication of native wolves throughout the Midwest starting in the late 1800s decreased predation on white-tailed deer thereby releasing deer populations from top-down control (U.S. Fish and Wildlife Service, 2019). The expanded range of white-tailed deer initiated by the enhancement of bottom-up controls in conjunction with the loss of top-down control continues to plague the entire Midwest. Consequently, some states have begun efforts to decrease deer populations in order to prevent the damage they cause to ecosystems. For instance, the state of Wisconsin has seen many negative impacts brought about by the overwhelming white-tailed deer population and is beginning to debate the best way to combat the issue.

In Wisconsin, white-tailed deer have been an important part of the culture and ecosystem for hundreds of years (Lewis, 1998). Along with fishing, camping, and hiking, hunting is one of the main pastimes of Wisconsinites. Until the late 1990's, 46% of the state's households had at least one hunter (Lewis, 1998). Hunting is a unifying tradition passed down from one generation to the next within many Wisconsin families. Unfortunately, this passion for hunting is beginning to crumble because most individuals of younger generations move towards the cities and away from the hunting country. This decline in hunting interest further intensifies deer population growth because it further diminishes top-down control on deer populations. Increase in size of deer population is causing damage to agricultural land, private property, state land, and is even increasing danger for drivers (Devitt, 2019). The overpopulation of white-tailed deer across the Midwest and Wisconsin has impacts on many stakeholder groups, many of which disagree on the best solution to deer overpopulation. In order to effectively manage exploding deer populations, I argue that Wisconsin's government needs to expand awareness on the issue of deer overpopulation by introducing citizens to conservation efforts such as wolf reintroduction and promoting financial support of the DNR. The government should additionally develop an education program to promote hunting in younger generations in both cities and rural communities. The Wisconsin DNR can use some of the profits from hunting to promote education and awareness on this issue, support local farmers so that they may lease their land for hunting, and extend hunting season, because they are the stakeholder group who tracks deer populations and have the financial resources and workforce connections to support outreach programs.

Stakeholders

Farmers

Many farmers in Wisconsin whose farms fall victim to deer herbivory believe that deer are a nuisance that bring them few, if any, benefits. Although farmers have always dealt with deer eating their crops, the population of deer has grown so large that farmers are now seeing damage that is negatively impacting their revenue (VerCauteren & Hygnstrom, 2011). Not only do deer eat and trample crops, but they also spread disease to livestock. With denser deer populations around the state, there is a higher probability that diseased or infected deer encountering livestock farms and subsequently infect livestock with diseases they may not have otherwise been exposed to (VerCauteren & Hygnstrom, 2011). Farmers, therefore, consider white-tailed deer a nuisance species because of the revenue lost to crop damage or livestock illness. Consequently, most farmers would like to see deer populations effectively controlled. The Wisconsin Department of Natural Resources (WDNR) has aimed to solve this problem by encouraging farmers to lease their land to hunters. Leasing farmland to hunters gives hunters a private area to hunt where deer are often found and easy to see and it gives farmers an opportunity to gain extra income (VerCauteren & Hygnstrom, 2011). Depending on the farmers needs, leasing their land may make up for the income lost due to destruction from the overpopulation of deer. Not only would leasing their farmland help farmers make money but it can also help lower the deer density in their area and decrease the damage to their crops.

Conservationists

There are many conservation groups throughout Wisconsin that, depending on their location, deal with overpopulation of deer in the forests and prairie lands they are trying to protect. One of the most prominent conservation groups in Wisconsin is the Aldo Leopold

Foundation, this group has a mission to foster the care of land and community (Eco-USA, 2019). Many of the other groups of conservationists are local to nature centers, schools, and counties across the state (Eco-USA, 2019). Many of these groups encourage members to be stewards of the land, like Aldo Leopold. Being a steward for the land is to take in every part of the ecosystem, understand how it works and promote the lands overall health (Aldo Leopold Nature Center, 2019). With an overpopulation of deer in Wisconsin, the land that many of these groups or individual conservationists tend is being negatively impacted.

Although white-tailed deer are important to forest food web and help structure forest communities, these ecosystems cannot sustain large densities (Jodie et al., 2017; Revkin, 2012). White-tailed deer destroy the understory of Wisconsin's forests by eating shrubs and tree saplings and by breaking young trees when they rub trees to mark them (Jodie et al., 2017). Physical damage wrought by white-tailed deer also disrupts insect communities, especially those of pollinators (Jodie et al., 2017). Insects such as butterflies, bees, and moths rely on many understory plants for habitat, reproduction, and food; these plants in turn rely on insects for pollination. When large populations of deer roam the forest and destroy vegetation, plant-pollinator relationships are disrupted because the vegetation that attracts the pollinators is lost (Sakata & Yamasaki, 2015). Not only do deer destroy forests through physical damage, but they indirectly influence plant community structure by encouraging the growth of invasive plant species. Deer can be selective in what they consume and often avoid invasive species such as garlic mustard which can spread quickly in Wisconsin's forests (Jodie et al., 2017; Pursell, 2019). These large deer populations also travel much of the day and may carry seeds of these non-native species to other areas that could have otherwise avoided invasion (Sakata & Yamasaki, 2015). Denser deer populations means that more deer travelling through the forest resulting in greater spread of invasive plant species. As stated by the naturalist and author Aldo Leopold, “I now suspect that just as a deer herd lives in mortal fear of its wolves, so does a mountain live in mortal fear of its deer.” (Jodie et al., 2017; Pursell, 2019; Leopold & Schwartz, 1966).

Recreationalists

In Wisconsin, camping and hiking are pastimes of many Wisconsinites who have differing views on the effects of deer overpopulation. Many of these recreationalists value the time they can spend away from cities out in the wilderness. Campers often look at their time away from home as a way to relax and escape from stress (Houghton, 2018). Wisconsin has thousands of campsites statewide, both private and public, which make getting away from home easier since campers can travel shorts distances to find a campsite that fits their needs (Houghton,2018). Hikers, similar to campers, often take time to enjoy nature away from the hustle and bustle of city living. Recreationalists typically include individuals who are fond of nature’s aesthetics and enjoy the biodiversity they see when taking a trip. Overpopulation of deer increases top-down control on many species which may lead to a decrease in the biodiversity which many recreationalists seek.

Unfortunately, there are conflicts between this group and the hunters in the state because the proposed solution of expanding hunting season to combat deer overpopulation (VerCauteren & Hygnstrom, 2011). A longer hunting season would mean a shorter camping season in some areas, making finding a peaceful campsite more difficult for some campers. In the areas where camping and hunting are permitted at the same time of the year hunting can disrupt the blissfulness many campers seek when going out into the wilderness. Hunting can cause loud sporadic noise which not only disturbs campers and hikers but also, they wildlife they may be trying to view.

Department of Natural Resources

The WDNR is a statewide agency that tracks and monitors wildlife, plants, and natural resources, and sells permits for hunting to create revenue that supports wildlife conservation programs. With the mission of protecting and enhancing our natural lands and the resources they provide, the WDNR is interested in supporting every level of the ecosystem. To protect the integrity of Wisconsin's forest and their natural resources, it is important for the WDNR to monitor environmental conditions, wildlife, plants and how they all intereact. Because the WDNR earns revenue from each hunting permit sold, the agency would hope to reverse recent declines in hunting licenses purchased (Devitt, 2019). The WDNR researches and monitors species across the state including white-tailed deer (Wisconsin Department of Natural Resources, 2019). By tracking and monitoring deer populations across the state, the WDNR can sell the number of permits needed to control the deer population without bringing them to dangerously low levels. With an overpopulation of deer, the WDNR can sell more permits and allow hunters to take home more deer per permit (Devitt, 2019). WDNR can help control deer overpopulation by selling additional permits for hunting. By doing so, the WDNR will also, earn more revenue that can be used for additional wildlife conservation efforts and for creating an education program that teaches the importance of hunting in Wisconsin.

Hunters

Although hunting activity has declined in recent years, if it experiences a resurgence, deer populations can be better controlled. Research has shown that when given the opportunity to harvest 2 more antlerless deer than originally allowed, the deer populations in upstate New York were still considered too high, the problem was with the low number of hunters registered (Brown et al., 2000). Hunting in Wisconsin has been a form of recreation for hundreds of years; it is important in many communities and families for meat or outdoor enjoyment. However, deer hunting has declined in recent decades because hunting isn't as popular for younger generations or people living closer to large cities (Devitt, 2019). Due to decreasing popularity, the number of hunters and permits sold in Wisconsin is steadily dropping (Devitt, 2019). The drop in hunting has negatively impacted revenue from permit sales, which Governor Walker sought to reverse by enacting legislation to eliminate the minimum hunting age (Kaeding, 2018). Unfortunately, the number of young hunters who signed up was not enough to offset the decreased sales of permits (Kaeding, 2018). Although there have been actions to promote hunting in younger generations, the outreach that the state government has attempted has not been as wide-spread and inclusive as it should be. The governor tried to lower the age requirement for hunting to allow more younger children to partake in hunting but the focus on only younger children was not enough to significantly increase the number of hunters. If the state government wants to promote hunting potential hunters need to be incentivized to hunt. A longer hunting season and educational campaigns that align with conservationists' goals of promoting healthy forests may incentivize people such as campers, hikers, and conservationists to buy hunting permits and partake in deer hunting.

Solution

The best solution when considering the opinions of the stakeholders is to expand education on white-tailed deer's significance in Wisconsin and the importance of hunting, to encourage farm owners to lease their land to hunters, and to relax hunting regulations by expanding hunting season. Creating an education program throughout the state that teaches the importance of white-tailed deer in Wisconsin's forests and how controlling populations through hunting will promote healthier forests will benefit citizens who are uneducated on the issue at hand and the options they have to help solve the problem. The solution of increasing education on white-tailed deer and hunting as an option for control could bring hunting numbers up as it would promote hunting in a way that is beneficial to many groups and doesn't negatively impact others. Educational initiatives could extend to states surrounding Wisconsin to bring in out-of-state hunters as a way to increase the number of hunters and increase WDNR's revenue, which could then be put towards conservation of natural resources. Along with promoting education on the issue to increase top-down control of deer, the state of Wisconsin should also create a program that works hand-in-hand with farmers to determine how they may go about leasing farmland to hunters in a way that will adequately and safely control deer populations. Leasing farmland will promote good relations between hunters and farmers and can decrease deer populations to numbers that no longer negatively impact farmers but still allows hunters to enjoy their pastime. In addition, expanding both the time that hunters are may hunt and where they can hunt should be pursued by the WDNR in a way that doesn't effectively limit other recreationalists who enjoy the outdoor spaces WDNR For example, WDNR might explore extending hunting season in farmlands that do not serve the broader public, but maintain current restrictions in public hiking and camping areas. The combination of an education program, a farmland leasing program, and a carefully managed extended hunting season is the best way to combat the overpopulation of white-tailed deer in Wisconsin that would result in the greatest benefit for stakeholders.

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