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MS Environmental Biology Capstone Project

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MS ENVIRONMENTAL BIOLOGY
CAPSTONE PROJECT

by

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Table of Contents

CHAPTER 2, LIST OF TABLES

CHAPTER 2, LIST OF FIGURES

CHAPTER 3, LIST OF FIGURES

CHAPTER 1. LITERATURE REVIEW

Arthropod Utilization of Urban Green Spaces and Structures

Introduction

Arthropod population sizes and diversity have sharply declined since the 1950s, and continue to fall in the Anthropocene, with an estimated 40% population decline occurring in the last four decades (Wagner et al., 2021). One reason for these declines is that arthropod populations are vulnerable to anthropogenic stressors, such as habitat loss from urban expansion and development, the use of pesticides in agricultural environments, and the global effects of climate change (Wagner et al., 2021). Recognizing the strong effects of humans on arthropod communities, people, communities, and governments have begun devising strategies to counteract these human-driven declines. More projects and programs are made using these strategies as government interest in environmental practices grows. These programs propose that government action can lead to the re-greening of urban spaces and phasing out of systemic use of pesticides and fossil fuel.

To increase aesthetics, human satisfaction, and attainment of ecological benefits in cities, urban planners have begun adopting the practice of adding more green space as part of urban development and management plans (Bille et al.,2023; Heidt & Neef, 2008). In addition, some cities have begun to pass legislation that requires newly developed spaces to contain certain amounts of green space (Denver Green Roofs, 2018). Typically, green space is planned at ground-level; however, rooftop greenery has increased as well, especially in densely populated spaces with very limited ground-level spaces to convert into more green spaces. Building green space on rooftops may provide vegetation that supports arthropod communities, but a synthesis of the literature is needed to understand how the two green spaces differ in support of arthropod communities, and how these two types of green spaces may be used in tandem to complement one another.

Therefore, in this literature review, I aim to understand how urban green spaces on the ground and on roofs compare in their ability to support arthropod diversity in urban environments. Although both types of green spaces are found to be beneficial in supporting arthropod communities, they differ from each other in the taxa they can support. Overall, these differences can complement one another and support arthropod diversity. This indicates that the use of both green spaces within a management plan can help support arthropod communities further than one type of green space alone, and can help arthropods overcome dispersal barriers associated with connectivity and resource abundance.

Classification of Urban Spaces

In this review, I will distinguish three types of spaces within cities: urban-only environments, ground-level green spaces, and rooftop green spaces. Each space is defined by unique characteristics that depend on spatial and structural constraints, making each space distinctive in overall composition.

Urban-only spaces are not modified by "green planning" and are generally devoid of vegetation. While they may contain sporadically placed garden boxes or vegetation growing through built surfaces, these spaces are not typically designed to have vegetation included in them (Gardiner & Prajzner, 2013; Montes et al., 2022). This classification includes both ground-level spaces, such as strip malls and parking lots, and the rooftops of structures which are not engineered as green roofs. These spaces may seem devoid of life, but several species of arthropod can thrive in urban-only environments (Frankie & Ehler, 1978; Raupp & Herms, 2010), and provide an important point of reference from which to measure the effectiveness of green planning.

Ground-level green spaces include spaces such as parks, garden beds, and medians used as greenways along roads. These spaces are all found at ground level and do not have weight limits similar to those imposed on roof-top green spaces. However, they are often designed to be more aesthetically pleasing than environmentally beneficial (Gardiner & Prajzner, 2013). These spaces can support larger structured plants, a greater degree of landscape variation, and can include bodies of water (Gardiner & Prajzner, 2013; Montes et al., 2022).

Rooftop green spaces consist of low-growing shrubs, forbs, and other shallow-rooted plants on the tops of structures (Benedito et al., 2023). The rooftop green spaces have limitations inherent to their placement. These restrictions necessitate the selection of diminutively structured plants, as space is limited, and weight restrictions are imposed by structural integrity. This causes a need for weight-saving and space-saving measures in the forms of both general plant selection for size and water usage and shallow dirt beds that are well-draining to avoid excessive weight brought on by the planting materials and water storage (Giacamello, 2021).

Diversity Measures

Species diversity is broadly defined by three distinct measures: richness, evenness, and composition. Richness is the number of species present, whereas evenness measures how evenly total abundance is spread across all species. Composition, on the other hand, measures which particular species are present, and typically is measured by the relative abundance of specific species, families, or even orders. These three diversity indexes varied between the three spaces considerably when evaluating arthropod diversity

Differences in richness between ground-level green spaces and rooftop spaces show that ground-level green spaces are higher in overall species richness, while both are much higher than urban-only environments (Benedito et al., 2023; Bennett and Lovell, 2013; Dromgold et al., 2020). Spaces experiencing higher species richness were also spaces that stereotypically contained higher amounts of vegetation species richness, possibly leading to this disparity between the two spaces (Hunter & Hunter, 2008; Giacamello 2021).

When compared to urban-only environments, both rooftop and ground-level spaces have higher evenness, but evenness tends to be higher in rooftop green spaces than ground-level green spaces (Benedito et a., 2023, Dromgold et al., 2020). Rooftops were shown to have a lower richness, and as such, the total abundance is more evenly spread across those species than in ground-level green spaces, which had a higher number of species, but many of which were rare (Braaker et al., 2017; Dromgold et al., 2020). Urban-only environments had fewer numbers of species present total abundance in general.

Arthropod composition varied considerably across all three types of urban spaces with different orders dominating in each. Rooftop units were found to have more Hymenoptera and fewer Coleoptera and Diptera overall, while ground-level green spaces favored Diptera and Coleoptera (Bennett & Lovell, 2013; Benedito et al., 2023, Braaker et al., 2017). Urban-only environments mostly contained non-native Coleoptera (specifically Carabidae), Blattodea, Lepidoptera, and Hymenoptera, that were subsidized by anthropogenic food sources (e.g., trash, effluent, improperly stored food) (Buenrostro & Hufbauer, 2022; Frankie & Ehler, 1978).

Explanations for Observed Differences in Diversity

Diversity among these systems can be attributed to differences in the systems themselves. Although the diversity measures are different, the reasons for differences in diversity are interconnected. Increases in richness, evenness, and community compositions are heavily dependent on vegetation selection, structure, and spatial limitations.

Richness increases in both types of green spaces compared to urban-only spaces are likely driven by the higher cover and diversity of vegetation in these spaces (Braaker et al., 2017; Dromgold et al., 2020; Bennet and Lovell et al., 2013; Montes et al., 2022). Rooftop spaces are limited to shallow growing plants, as the soil bed on roofs needs to be thin to avoid weight that might lead to structural collapse (Giacomello 2021). In addition, the soil needs to be a porous soil that avoids retention of water, and therefore weight. This leads to rooftop green spaces having shorter growing plants that require drier soils, which results in less ground cover overall (Dromgold et al., 2020; Salman & Blaustein 2018), potentially preventing many arthropod species from living in the area, as the resources required are not present because of these limitations. The lack of vegetative ground cover may also increase soil temperature, preventing many soil-borne insects from laying eggs and propagating on rooftop spaces (Dromgold et al., 2020; Salman & Blaustein 2018).

Differences in evenness can be attributed to the green spaces' ability to host species that become more represented than others. Areas devoid of species variation in vegetation can allow for certain arthropods species to become more abundant, which causes the community to become less even (Hunter & Hunter, 2008; Bennett and Lovell, 2013; Buenrostro & Hufbauer, 2022; Raupp & Herms, 2010). Ground-level green spaces are also spatially constrained by existing infrastructure and other design constraints such as aesthetics that may be required for funding their construction (Bille et al., 2023; Hunter & Hunter 2008). These constraints can lead to certain plant species being excluded, which decreases arthropod diversity below an area's potential if there were no such constraints. Urban-only spaces face these challenges to an even greater degree, as they lack proper habitat and resources for most arthropods (Hunter & Hunter, 2008; Sanchez et al., 2020); species that are supported rely heavily on anthropogenic subsidies (Frankie & Ehler 1978) and may not be native to the area. The result is a fairly depauperate arthropod community.

Changes in arthropod community can result from the presence of suitable habitat and variation in resources availability. Ground-level and rooftop green spaces contained higher resources than urban-only areas, allowing for higher amounts of species to find suitable habitats within them (Benedito et al., 2023; Bennett and Lovell, 2013; Dromgold et al., 2020). However, the species richness in both rooftop green spaces and ground-level green spaces differ seasonally, as resources in both environments change throughout the year (Montes et al., 2022; Bennett and Lovell, 2013). These differences can especially be seen in turf-style ground-level green spaces (spaces seeded with typically non-native, cool-season grasses) that border more naturalistic prairie-style green spaces (spaces with native grasses and other vegetation), as the prairie spaces have more diverse and abundant resources in later seasons (Bennett & Lovell, 2013). This also helps demonstrate the need for more careful consideration of plant species selection when designing green spaces to help support native species.

The vertical location of each of these spaces can create barrier for dispersal, as well. Both horizontal and vertical connectivity between rooftop and ground-level green space spaces affects the species composition present (Braaker et al., 2017; Dromgold et al., 2020). For example, many ground-dwelling species may be unable to reach the heights a rooftop green space, while the environment on a rooftop green space may not be suitable for species with lower tolerances to high temperatures, wind, and sun exposure (Salman & Blaustein, 2018). Ground-level and rooftop green spaces may also suffer from interconnectivity issues because certain species may be unable to locate and travel from one area to another on account of too many obstacles or large travel distances (Braaker et al., 2017; Dromgold et al., 2020; Hunter & Hunter, 2008). Rooftop green spaces may need to be terraced for species to move from one section to another without getting lost or dying from a lack of resources, and ground-level green spaces may need green belts leading to them if they are too embedded in a dense city center (Ives,et al., 2015; Planchuelo & Kowarik, 2019; Williams & McIvor, 2014)

Exogenous effects of nearby systems can spread to these green spaces, and decrease arthropod diversity. Areas with green spaces may not experience an increase in arthropod diversity, despite technically meeting the needs of native arthropods because of this. Phenomena like the heat island effect could make soil and air temperatures inhospitable for local fauna (Heidt & Neef, 2008). Use of pesticides and herbicides on plants may also decrease populations of beneficial/non-target arthropod species; these pollutants can drift to other spaces, possibly affecting connected systems (US EPA, 2023). Furthermore, construction nearby or within green spaces can degrade resources arthropods require, and residents may physically remove arthropods because of perceived damages to ornamental plants, or wanting to remove a species deemed as a pest (Gardiner et al., 2013).

Application for Management Plans

These challenges can be overcome to promote healthier habitats for arthropods by creating systems that protect against these disturbances. When green spaces are designed with modularity, the partitioning of environments into separate modules while still allowing travel between them, certain disturbances that affect populations and communities can be mitigated (Gillaranz et al., 2017). By keeping these systems modular, rare species and species that are more susceptible to disturbances can potentially be protected from depopulation or eradication.

Modularity also encompasses resources in addition to physical space. For example, when a milkweed source for monarch butterflies is destroyed with a broad spectrum herbicide, other milkweed populations may be saved because of the physical distances between the plots. The barrier between plots of milkweed allows for visiting monarch butterflies to continue to have a suitable resource to lay eggs on. This indicates that a mix of rooftop green spaces and ground-level green spaces could be more beneficial than monotypic styles of management, especially since these two spaces have been shown to harbor different orders of arthropods species

Modular green spaces must also be functionally connected in order to achieve its promise of increasing arthropod diversity. Systems that are disconnected do not allow for emigration/immigration among green spaces and can prevent arthropods from accessing resources needed for survival (Braaker et al., 2017). Using systems with interspersed green spaces in between ground-level sections and roof-top sections could help, along with spacing these areas appropriately to allow for less mobile species to move from area to area (Braaker et al., 2017; Dromgold et al., 2020). This would allow for genetic flow between spaces, and for different arthropod species to move freely between systems to access resources they require.

Green spaces laid out in a modular design can incorporate biological services too, allowing for people to benefit from increased arthropod diversity, while the changes in resources and increased green space between plots help provide the arthropods with habitats and connectivity between areas. With arthropods providing pollination to approximately 35% of food production in the world (Lawrence, 2022), these urban green spaces may provide more than increases in diversity. Urban spaces, especially food deserts, may supplement local restaurants and grocery stores with locally grown produce as a result of combining green spaces with sustainable and responsible urban farming practices (Nicholls et al., 2023). Resulting community benefits could also help secure funding, as it affects residents of the area in a positive way, and can also give them a tangible reason to continue to support the management and creation of green spaces within their communities.

Conclusion

Systems utilizing a mix of rooftop green spaces and ground-level green spaces fulfill a wide array of arthropods' needs that would not be met with only one type of area present and can provide different resources throughout the year. Overall, there are significant differences in arthropod diversity between roof top green spaces, ground-level green spaces, and urban only environments. There were larger amounts of diversity found in ground-level green spaces, but unique species were found in each (Benedito et al, 2023; Braaker et al., 2017, Dromgold et al., 2020; Montes et al., 2022). Both green spaces showed higher diversity than urban only environments, though diversity did show variation with seasonal changes and fluctuated throughout the year. This indicates that there are specific advantages and disadvantages presented by each green space in regard to promoting arthropod diversity, and that proper management should include a mix of the two, with adequate connectivity to promote further arthropod diversity.

By using careful consideration for resource management, seasonal changes in environments, and modularity and connectivity, arthropod diversity can be greatly increased within urban ecosystems. Using a mix of green spaces, and interspersing urban farming practices within these systems can benefit both arthropods, and cities. Increasing arthropod diversity in these areas will help cities see a substantial benefit to local communities in the form of food generation and supplementation, and help protect global declining arthropod populations.

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CHAPTER 2. GRANT PROPOSAL

Assessing Arthropod Movement Dynamics: Impacts of Terracing on Vertical Connectivity in Urban Green Spaces

Abstract

Green spaces have been a popular mitigation choice to combat arthropod decline from anthropogenic effects in urban areas, though the success of green space designs varies between ground-level and rooftop green spaces. In particular, certain arthropods are unable to travel between ground-level and rooftop green spaces. Such dispersal barriers are especially intense for ground beetles (carabids) and can be exacerbated by a mismatch in basal resources that these beetles may need because of a building's structural limitations or building planner's aesthetic choices. This study is designed to assess whether relieving these dispersal barriers facilitates impacted taxa's travel between green areas, or if other filtering effects in place create differences in these community structures. If carabids are shown to be able to utilize an intermediate green space in the form of a terrace between ground-level green spaces and rooftop green spaces to move between the two areas, this would imply that the vertical dispersal barrier has been alleviated. However, once residency has been established on the rooftop, differences in rooftop populations can be assessed to indicate if resource availability and habitat suitability are also strong biological controls. By creating a terrace between ground-level and rooftop green spaces and manipulating garden plots on rooftops to mimic ground-level green spaces, I intend to use a Before-After Control-Impact (BACI) study to discover whether the addition of terracing and mimicry of ground-level green space resources releases carabids from these filtering effects. Results from this study will help green space management decisions and create more beneficial

practices for arthropod conservation and propagation in urban centers through environmental design.

Objectives

The goal of this research is to quantify the relative strength of resource availability (i.e. Specific plant species) and vertical barriers as controls on ground-dwelling carabid beetle communities in rooftop green spaces.

Questions and Hypothesis

Question 1: How will carabid diversity in rooftop green spaces change in response to terracing?

Hypothesis 1: After terracing, rooftop carabid abundance will increase, and communities will become more similar to ground-level communities because the vertical dispersal barrier is alleviated.

Question 2: How does the type of vegetation used on green roof spaces affect arthropod communities in rooftop green areas?

Hypothesis 2: After alleviating carabid communities of the vertical dispersal barrier, and when the vegetation on green roofs resembles vegetation at ground-level, carabid communities on the ground at on the roof will be more similar because the resources and habitat will be more hospitable for establishment.

Anticipated Value

Because of the rapid decline in arthropod populations, protective measures must be put in place to mitigate further losses. While green spaces have been shown to be beneficial, few studies have experimentally assessed the relative strength of resource availability and vertical interconnectivity as controls on arthropod diversity on green roofs. This work will provide evidence to support whether terracing or vegetation management should be the first action to improve arthropod communities on green roofs. Data collected through this BACI study will therefore help green space managers make more informed decisions regarding the design and implementation of strategies that help foster healthier arthropod communities in urban ecosystems.

Literature review

Arthropod populations have been declining at an unsustainable rate since the 1950s (Wagner et al., 2021). These losses directly result from anthropogenic effects such as climate change, widespread pesticide use, and habitat loss (Wagner et al., 2021). Although arthropods comprise 85% of all known animal species and support 35% of the entire world's food supply, these animals are often overlooked in conservation efforts despite providing critical environmental services to humans (Lawrence, 2022). In urban city centers, the need for aesthetics often outweighs the need for suitable habitat, resulting in areas that are poorly populated or devoid of native arthropods (Bille et al., 2023 ;Gardiner & Prajzner, 2013).

To help reduce declines in arthropod biodiversity, many policies and projects have been put in place to combat the anthropogenic effects imposed upon them. Ground-level green spaces and rooftop green spaces have been shown to be effective in increasing arthropod diversity in urban areas but to different extents (Dromgold et al., 2020; Salman & Blaustein 2018). Some disparities can be attributed to the fact that rooftop gardens have an inherent height barrier and environmental conditions brought on by structural design constraints from the buildings they sit on, and the selection of vegetation causing dissimilar environmental conditions and resources between the two green spaces (Dromgold et al., 2020; Giacomello 2021; Salman & Blaustein 2018).

There are noticeable disparities between ground-level green spaces and rooftop green spaces regarding arthropod taxa, precisely the absence of carabid species from rooftop green spaces (Benedito et al., 2023; Braaker et al., 2017; Dromgold et al., 2020). Verticality and vegetational differences between the two green spaces are indicated to be the strongest controls placed upon carabids (Benedito et al,. 2023; Braaker et al., 2017,). Assemblages devoid of carabids have been observed on single story roofs, indicating maximal differences in green space height of sub 14 feet (Benedito et al., 2023; Braaker et al., 2017,). Environmental factors assessed on rooftops also show large differences in soil temperatures because of these design restrictions and subsequent vegetation choices. Rooftop green spaces are designed around diminutive and shallow-rooted plants because of structural design limitations, resulting in lower overall cover and vegetation quantities (Giacomello 2021). Many carabid species are predatorial and may lack the requisite prey sources because of the differences in prey food availability. Soil temperatures may also prevent generational succession, as the temperatures are too high for eggs and larvae to survive (Benedito et al., 2023).

I propose that to help alleviate barriers created by verticality and vegetation selection, we bridge the gap between ground-level green spaces and single-story rooftop green spaces via an intermediate green terrace between these two areas and choose vegetation that more similarly replicates ground-level green space conditions. Creating an intermediate step for arthropods would help determine if the dispersion barriers are primarily from the vertical placement or if there is a behavior aspect that will need to be explored. Further, by creating similar conditions to ground-level spaces, differences in conditions can be fully identified as driving factors in taxa filtering.

Methods

Plot Design

This study will use a Before-After Control-Impact (BACI) design to assess differences in green area communities between plots in two sections in Boulder County, CO. Plot A is a single-story control building with a ground-level green area and rooftop green area with two subplots 2mx8m each, one side with plants that are short and uniformly growing and non-flowering, and one with plants that vary in terminal growth heights, mixes in flowering and non-flowering species, and densely shading varieties centralized to reduce soil temperatures underneath, spaced 5m apart. Plot B will be an impact plot, with a similar single-story building at least 15m away from building A, where an intermediate terrace is placed between the ground-level and rooftop green area, with the rooftop area containing the same style of subplots as building A. All collections will be done in the same year, starting bi-weekly in May 2024 and ending in October 2024, with collections happening simultaneously to avoid differences in resources and weather. Terracing will be added the second week of June, 2024, with the completion of terracing being marked to delineate the before (pre-July 31st, 2024) and after (post July 31st, 2024) sections of the study. Terracing is anticipated to take approximately 12 hours to complete. The time leading up to July 31st will be established as the "before" portion of the study, and post July 31st (halfway into the study) will be the "after" portion. After The following year, post-sampling will be done bi-weekly in June, July, and August for the proceeding five years to continue monitoring effects and changes post-study.

Data Collection

Arthropod collection will occur at the beginning of the study on May 1st,2024, to establish carabid presence prior to terracing in ground-level and rooftop green areas in both subplots and one year after terracing in ground-level, terrace, and rooftop green areas in both subplots, with bi-weekly sampling to determine trends from May 2024 to October 2024. Collection will be done via pitfall traps for one week during bi-weekly sampling periods. Arthropods collected will be sent to the USDA Systematic Entomology Laboratory for identification. Species richness, community composition, and species evenness will be compared to one another. By using a BACI study with identified and explicit controls that are highly correlated with the site, one control site and one impact site can be used, as the design creates co-variates in time (Before, After) and space (Control, Impact sites), and avoids the use of multiple sites and impractical replication of treatment to gather and contrast data (Smokorowski & Randall, 2017; Stewart-Oaten & Bence, 2001).

Data Analysis

Data will be analyzed using R software (R Core Team, 2021). I will perform a two-factor ANOVA with interactions and model selection. This analysis will be done to determine differences in diversity measures between plots, measures of diversity within the terrace to infer if movement through the terrace is occurring, and differences in measures between aesthetically chosen rooftop areas and areas that mimic ground-level green space conditions.

Project Requirements

I will request a Boulder County Open Space Research permit, a scientific collection permit from Colorado Parks and Wildlife, and express written consent from homeowners/business owners for collection on their property, access to their rooftops, and building of a terrace on the side of the building (see fig.1 for a map of the study area). I will do this by contacting the homeowner, showing detailed plans for collection sites and detailed plans for non-permanent structures without foundations to avoid additional permitting and to allow for future removal if deemed necessary by the homeowner.

Negative Impacts

Collection methods require the collection and euthanasia of local arthropods. However, the study area is small, and I do not anticipate large impacts within Boulder County.

Budget

Item	**Justification**	**Cost, unit Source**	**Quantity**	**Total Cost**
Terrace Building materials and tools	Materials and tools required to build a 1mx3m2.4m terrace	For a full cost breakdown, please see attached itemized table. (Home depot)	1	$3,686.52
Labor Stipend	For building the Terrace for the impact phase, split between two workers	$20/hour	40	$800
UC Riverside Entomoligcal ID	For identification of	$74.40/hour	20	$1488

	species of arthropods from collected samples			
Gas	For travel between study sites	$0.72/mile	1000	$720
Indirect Costs	For research cost coverage required by Regis	$743.83	1	$743.83
				Total: $8,364.19

Timeline

Task	**Start date**	**End date**
Begin Before phase pitfall trap monitoring, placing samples bi-weekly, and collecting after 7 days. Send Samples to USDA after each collection.	May 1st, 2024	July 16th, 2024
Build Terrace	July 16th, 2024	July 17th, 2024
Begin After Phase pitfall trap monitoring, placing samples	July 17th, 2024	October 1st, 2024

bi-weekly, and collecting after 7 days. Send Samples to USDA after each collection.		
Data processing	October 6th, 2024	October 31st, 2024
Begin Write-up	September 3rd, 2024	September 13th, 2024
First Draft	September 16th, 2024	September 23rd, 2024
Second Draft	September 30th, 2024	October 7th, 2024
Third Draft	October 14th, 2024	October 21st, 2023
Deliver Report to Shareholders	November 1st, 2024	November 1st, 2024

For a detailed gant chart (fig. 2) please see the maps and charts appendix.

References and Curriculum Vitae

Please see attached documentation for References and Curriculum Vitae

Maps and Charts

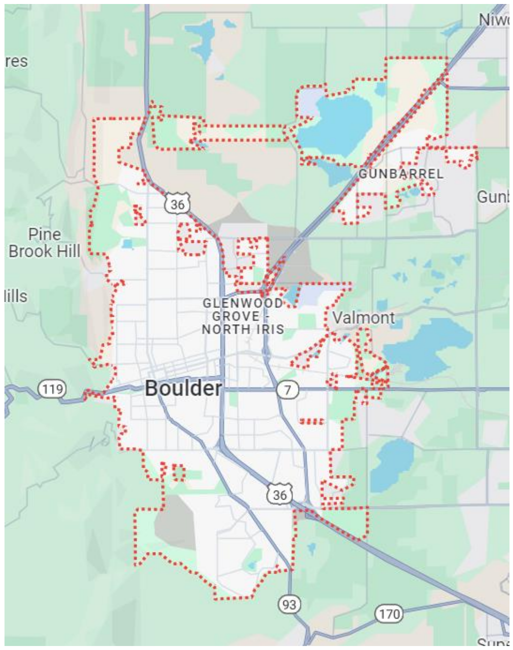

Figure 1. A map of the proposed study area, in Boulder County, CO

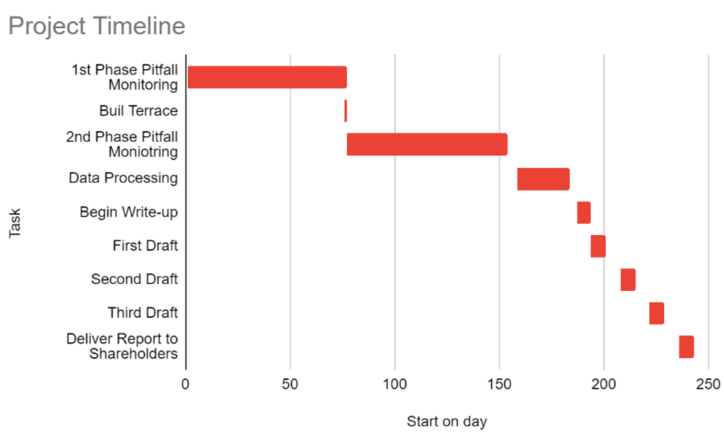

Figure 2. A gant chart of the proposed study

Curriculum Vitae

AARON **ITTNER**

Redacted , Aurora, CO 80013 · (720) 000-0000

Aittner@Regis.edu

Current master's student eager to use my education and work experience to a higher degree. Looking forward to collaborating with a team, but also a self-motivated worker intent on helping anywhere and everywhere I can, while quickly incorporating new skills and continuing my education.

EDUCATION

AUGUST 2023- CURRENT

MASTERS IN ENVIRONMENTAL BIOLOGY, REGIS UNIVERSITY

Coursework skills include; advanced statistical analysis using r studio for linear models, generalized linear models, ANOVA, and PCA tests, research/field sampling and cataloging specimens, GIS modeling and analysis, research design, and advanced ecological modeling and analysis.

AUGUST 2013- MAY 2019

BACHELORS IN EXERCISE SCIENCE, METROPOLITAN STATE UNIVERSITY OF DENVER

Coursework skills includes; EKG reading, stress testing protocols, kinesiology and anatomy, intake for exercise testing and personal training and therapy, and human physiology.

EXPERIENCE

AUGUST 2021 – PRESENT

PIPE/MECHANICAL TRADES I, CO STATE DPA

With a team, I take measurements from mechanical systems, such as water parameters like general hardness, pH, dissolved oxygen, nitrates and nitrites, water pressure output, water vacuum, and temperature. I also maintain and calibrate systems regarding prevention of backflow and contamination of clean water according to IAPMO standards, and report to the city of Denver and reigning water districts to ensure correct calibration and maintenance of backflow prevention devices. Along with this, I maintain and calibrate systems for ambient environmental temperature and contaminants through the use of forced air filters, humidity detectors, and DESIGO instruments.

APRIL 2016 – AUGUST 2021

TELEMETRY TECHNICIAN, ST. JOSEPH HOSPITAL

I analyzed and documented rhythms in patient charts, alerted and informed nurses and physicians to abnormalities and dysrhythmias after interpretation of baseline rhythms and rhythm conversions, and work with nurses to set patient parameters regarding ECG rhythm and spO2. I also helped inform and maintain equipment status, such as battery life, readability, and status of reporting to both Philips systems and EPIC charting, along with choosing proper equipment from a patient-by-patient basis, such as telemetry boxes and types of pads used for hypoallergenic individuals

SKILLS AND LICENSURE

- CFC Universal Certification, which is required for the safe handling and use of commercial refrigerants.
- GIS Map Creation and Analysis by using localized data and standardized maps to create custom outputs for projects.
- Statistical Data analysis and data visualization with R code and RStudio.
- Data management and reconfiguration of data, along with creation and use of Metadata files to ensure use by third-party individuals.
- Wetland delineation.
- Professional poster creation and presentation.
- Microsoft Word and Excel, as standard for completion of classes and accurately organizing data.
- Professional, scientific, grant, and report writing experience.
- Research Design and Sampling Practices, as required to complete research projects and generate useful, accurate, and reliable data sets for research projects.
- Backflow Testing Certification via IAPMO, which demonstrates knowledge of backflow prevention devices and regulations regarding them.
- Professional symposium presentation of data and research
- Wrote novel sampling protocol for deer observations

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CHAPTER 3. JOURNAL MANUSCRIPT

Bald Eagle Perching Habits Across Age Stratifications

Abstract

The extraction and changes to management of natural resources can have profound negative effects on local fauna, potentially causing local extirpation of many species. Fauna requiring specific habitats to thrive can be especially susceptible to disruption, such as Bald Eagles (*Haliaeetus leucocephalus*), requiring advanced consideration in management practices. In this study, I studied Bald eagle preferences in roosting sites between trees and ice, and how life stage may affect roosting height within three vertical sections of the canopy at Barr Lake State Park, in Brighton, CO. I conducted stationary counts of Bald Eagles roosting on ice and in the adjacent riparian area, specifically parsing out counts between ages and height in trees. Bald Eagles were found to significantly prefer trees over ice for roosting areas, despite more physical area on the ice being available for resting. Once in the trees, adult Bald Eagles preferred the upper two-thirds of the canopy, whereas juveniles preferred the lower two-thirds. The preference of trees over ice for roosting areas implies the critical nature of suitable habitat, with implications from age stratification within the canopy needing to be taken into account. The outcomes of this study highlight a conflict in management projects within Barr Lake, though recommendations can be generalized to any riparian management plan.

Introduction

Effective natural resource management is necessary as anthropogenic pressures on ecosystems grow (Richardson et al. 2020). Because anthropogenic habitat destruction and degradation are ever-present threats to ecosystems, many countries create parks and sanctuaries where ecological resources can be properly managed. Many of these parks serve as refuge for many species including both resident and migratory fauna, such as raptors and geese (Brodie et al. 2023). Although setting aside protected land to conserve resources protects global biodiversity, economic interests may conflict with the goals of preservation, producing anthropogenic disturbances that can negatively impact local flora and fauna.

Anthropogenic disturbances like light pollution and land use change have profound impacts on animal behavior because of alterations in resources, environmental cues, and increases in anthropogenic-related stressors (Marty et al. 2019). Reactions to these interruptions manifest in behavioral changes such as changes in sleep cycles, navigational complications sometimes resulting in building strikes, and seasonal behaviors such as mating displays and attempts (Dominioni, 2015). Land use change further fragments habitats and diminishes available resources as well (Marty et al. 2019). Fragmentation of remaining habitat causes more time to be spent foraging, higher instances of stress-related responses such as aggression, lower breeding activity, and more physical competition over resources (Coddington et al. 2023; Marty et al. 2019). Large-scale fragmentation can lead to overwintering habitats becoming unavailable, forcing migratory birds to divert to other pathways, decreasing populations within the original migratory pathways, and lowering resource-to-bird ratios in new pathways as more birds enter the system (Weeks, 2023). Local-scale fragmentation can greatly affect behavior as well, confining species to patches with appropriate habitat and increasing interspecific competition (Paxton et al. 2023). Ultimately behavioral changes or lack thereof can exacerbate declines in survival, growth, and reproduction of local fauna, with avifauna being particularly sensitive (Coddington et al. 2023).

Raptors are especially responsive to anthropogenic disturbance (Nägeli et al. 2021). Though some raptor populations perform well in highly urbanized areas because of increased prey availability due to anthropogenic subsidies (McCabe et al. 2018), anthropogenic encroachment into raptor territory and subsequent habitat destruction via land-use change have disrupted breeding and nesting sites or extirpated more sensitive raptor populations (Niedringhaus et al. 2021; Nijman et al. 2009). Areas devoid of vegetation have a lower raptor presence overall as appropriate nesting sites and foraging opportunities are diminished (Chapa-Vargas et al. 2019; Naveda-Rodríguez et al. 2019). Canopy diversity, or the variability present in height, branch density, and tree species, also strongly correlates with raptor diversity because it allows for more hunting, nesting, and perching opportunities within the canopy (Chapa-Vargas, 2019; Whitacre & Burnham, 2012). Additionally, overwintering raptor species rely heavily on the microclimates afforded by the diversity in height and density that can protect them from exposure to the elements and enhance their ability to thermoregulate (Chapa-Vargas et al. 2019; Grubb, 2003; Yackel et al. 2000). Therefore, when anthropogenic pressures limit canopy diversity, raptor incidence and diversity may decline (Klaus et al. 2020).

Bald Eagles (*Haliaeetus leucocephalus*), a charismatic and protected species in the United States, exemplify how anthropogenic factors such as urbanization, deforestation and land cover change detrimentally impact suitable habitat (Percy et al. 2023). Bald Eagles require large and accessible trees, cliffs, or structures for perching and access to water, typically nesting within three kilometers of coastline or large water bodies (American Eagle Foundation, 2018; Saafiled & Conway, 2010; Stalmaster & Gessaman, 1984). Bald Eagles will use seasonal habitats like ice fields on water bodies for foraging in the winter (American Eagle Foundation, 2018; Saafiled & Conway, 2010; Stalmaster & Gessaman, 1984). Similar to other raptor species, a diverse canopy habitat is vitally important to Bald Eagles. Locations within the canopy modify microclimate around resting perches and offer advantageous hunting perches, access to which is dictated by conspecific hunting success and social hierarchy (Yackel et al. 2000). Although lateral perching location tends to be controlled by an individual's position within the social hierarchy (Yackel et al. 2000), similar studies have not examined whether vertical perch height is similarly controlled. Because of their migratory habits, the opportunity to study perching habits of Bald Eagles may be rare in select locations and is generally lacking in the literature.

Many eagles will migrate throughout the year and will often congregate in multi-age groups at select locations over winter, with many individuals revisiting past locations annually (Mojica et al. 2008). Preservation of these overwintering sites is vitally important for them to thrive as suitable habitat and prey items become more scarce because of anthropogenic effects of climate change (Harvey et al. 2012). Barr Lake State Park in Brighton, CO, is a popular site for some of these overwintering Bald Eagles (Colorado Parks and Wildlife, n.d). The park consists of 2720 acres of mixed prairie and riparian wetland, with the namesake reservoir located at the park center. It is a popular site for recreational activities, as well, with biking and bird watching being two of the most popular. The park has two resident nesting pairs of Bald Eagles that stay year-round but is also visited by hundreds of Bald Eagles as an overwintering habitat during migration each year. Despite the importance of Barr Lake to resident and migrating birds, -water management in the park threatens to degrade habitat for Bald Eagles. Although Colorado Parks and Wildlife manages the land the park rests on, it does not own the land. The Farmers Reservoir and Irrigation Company (FRICO) controls how land and water are used due to a long-standing agreement from 1902 that grants the company these rights (Water Partnerships, n.d). FRICO in turn sells and supplies water from the reservoir to nearby farmers. Recently, root growth from riparian vegetation has damaged the banks causing FRICO to incur water losses, and therefore revenue. Consequently, in 2023, FRICO elected to repair the embankments around the reservoir resulting in all vegetation, including prime perching areas for Bald Eagles around the reservoir, to be removed.

Because of these recent and forthcoming alterations in habitat, this observational study at Barr Lake State Park aims to determine how Bald Eagles use different habitats for perching areas within the park and whether perching preferences differ by age. Because of the anthropogenic disturbances within the Barr Lake area, and from knowledge gathered from previous studies, I hypothesize that Bald Eagles will prefer to perch in trees rather than on ice, because they are a tree-nesting species. Additionally, I hypothesize that adult bald eagles will perch higher in trees than juveniles, because of the adult's dominance in the social hierarchy that enhances its ability to secure resources. Consequently, I also expect higher presence of adults in trees to correlate negatively with presence of juveniles.

Methods

Site Selection

I conducted this study on the southwest side of Barr Lake State Park, located in Brighton, CO, (Figure 1). Barr Lake State Park is an area of high ecological importance, as it includes diverse riparian areas around a large reservoir, touting over 350 bird species visiting and/or living in the park (Colorado Parks and Wildlife, n.d). The observation deck (Figure 1) is set in the open waters of the reservoir, allowing for a direct line of sight to the ice fields and surrounding trees where large numbers of overwintering Bald Eagles perch.

Field Data Collection

From the wetlands observation deck, I collected data for approximately one hour at 07:00on Mondays, Wednesdays, and Sundays from January 23, 2024 to March 7, 2024, with an additional sampling at 17:00 each Sunday. Observations lasted for approximately one hour each and began after the setup and calibration of observation equipment (spotting scope and range finder). The temperature at the beginning of each observation period was recorded from a weather station located at the Barr Lake Visitor Center. All observations occurred at the tree stand located approximately 366 meters from the observation deck, or in the adjacent ice field (Figure 1). Based on prior observations, park staff and I identified the tree stand as a reliable gathering spot for Bald Eagles. Each tree (*n* = 11) in the stand was split into three equal zones (hereafter, upper, middle, and lower from the top to the bottom of the lowest branch respectively), whose heights were estimated with a range finder.

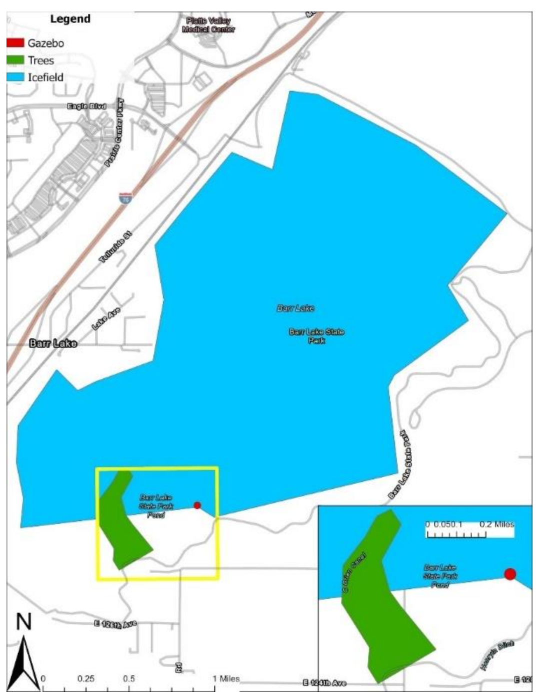

Figure 3. Map of the study sites and surrounding region within Barr Lake State Park.

During each observation period, each site and zone's total quantity of eagles (i.e., tree stand or ice field) was recorded, including zones whose eagle totals were zero. Eagles observed in trees were counted in each zone (lower, middle, upper) and divided by age class (adult or juvenile). During each visit, each of the eleven trees was scanned for 5.5 minutes, and the icefield was scanned for 7.5 minutes, as it was a substantially larger area to cover. Only eagles with complete white plumage of the head and tail were classified as adults; all other individuals were classified as juveniles (Sibley, 2016).

Statistical Analysis

To assess whether eagles preferred to nest on trees or ice, I combined juvenile and adult counts into total counts for trees and ice, and used the resulting totals as the dependent variable. Then, I fit a series of generalized linear models (GLMs) that assumed that log(total eagle count) varied as a function of all combinations of the following fixed effects: site, date, time, and temperature. A null model with intercept only was fit as well to compare to these fuller models. Models were then ranked by Akaike's Information Criterion (AIC), and models whose ΔAIC <4 were averaged in a multimodel inference approach, using the resulting conditional average.

To assess differences in canopy zones for adult and juvenile counts, I fit two series of generalized linear models that assumed that log(adult or juvenile count) varied as a function of all combinations of the following fixed effects: zone, date, time, and temperature. To assess if the presence of the other age class affected the response variable, juveniles received an additional predictor of "adults", while adults received an additional predictor of "juveniles". Models were then ranked by AIC, and the model with the lowest score was selected. This model was used to perform post-hoc analysis between zones using generalized linear hypothesis tests (GLHTs).

All statistical models were fit using the statistical software R (version 4.3.2 , R Core Team, 2023) and RStudio version 4.20 (Posit Team, 2024). GLHTs were executed using the multcomp package (Hothorn et al. 2008). Data visualization was performed through ggplot2 package (Wickham, 2016).

Results

Total eagle counts ranged from 0 to 46 for trees (mean = 18.6) and 0 to 8 for ice (mean= 1.4). Canopy counts ranged from 0 to 5 adults (mean = 0.54) and 0 to 3 juveniles (mean = 0.14) in the upper canopy, 0 to 3 adults (mean = 0.43) and 0 to 4 juveniles (mean = 0.32) in the middle canopy, and 0 to 1 adults (mean = 0.09) and 0 to 2 juveniles (mean = 0.18) in the lower canopy. Temperature ranged from -12.2°C to 17.2°C (mean = -0.9°C).

Combined, both juvenile and adult Bald Eagles preferred to roost in trees rather than on the open ice field. At the median day of observation (February 18th, 2024) and average temperature (-0.9 °C), mean number of Bald Eagles utilizing trees for roosting areas (13.3, 95% CI: 11.6-15.33) was 12.9 times higher (95% CI: 8.5-19.4; $p<0.001$; Fig.2) than eagle counts over the ice (1.0, 95% CI: 0.7- 1.54) . The conditional model average also indicated that mean number of eagles significantly declined by 8.1% (95% CI: 6.7%-9.4%; $p<0.001$) each day over the course of the study.

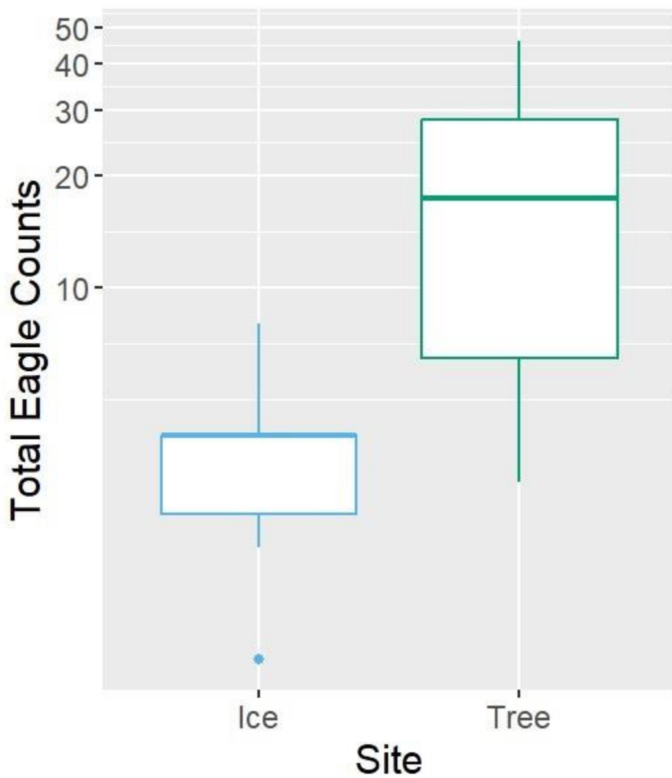

Figure 2. More eagles were found in trees than on ice. Horizontal bars in boxes represent median counts.

Average number of juveniles in each tree zone increased with number of adults present (p = p<0.001, AIC=689.3), but the effect was greatly weakened and no longer significant when zones were applied in the model. The best model for predicting the number of juveniles in trees included zone, temperature, and date (AIC = 627.9).

Significantly more juvenile eagles were observed in the middle tree zone (average eagle counts on median day and mean temperature = 0.24, 95% CI: 0.17-0.34, p<0.001; Fig. 3) than in the lower tree zone (average eagle counts on median day and mean temperature = 0.13, 95% CI: 0.08-0.20, p<0.001; Fig. 3) and the upper tree zone (average eagle counts on median day and mean temperature = 0.10, 95% CI: 0.06-0.17, p<0.001; Fig. 3). There was not a significant difference between lower and upper zones (p = 0.651).

Although more juveniles were found in the middle zone than in the lower and upper zones, adults were found more frequently in the upper zone compared to the middle and lower zones. Significantly more adult eagles average eagle counts on median day and mean temperature = 0.41, 95% CI: 0.31-0.53, p<0.001; Fig. 3) were observed in the upper tree zone than in the lower tree zone (average eagle counts on median day and mean temperature = 0.07, 95% CI: 0.04-0.20, p<0.001; Fig. 3) and the middle tree zone (average eagle counts on median day and mean temperature = 0.41, 95% CI: 0.31-0.53, p<0.001; Fig. 3). There was not a significant difference between middle and upper zones (p = 0.311).

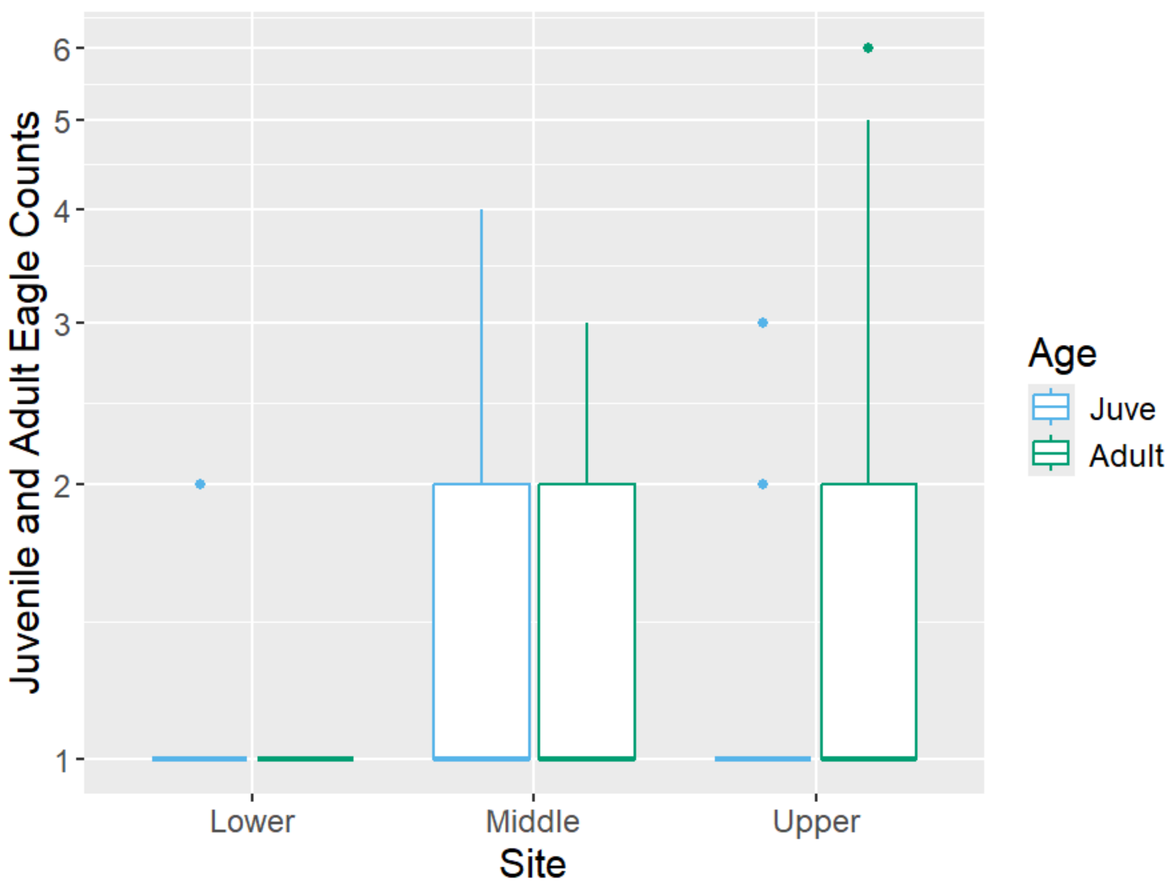

Figure 3. Adult Bald Eagles perch higher in the canopy than juveniles. “Lower”, “Middle”, and “Upper” refer to location within the tree canopies. Points represent outliers, and lines represent 95% confidence intervals.

Discussion

The major goals of this study were to see how Bald Eagles used ice and tree habitats for roosting, and how age class may play a factor in vertical perching habits. To answer these questions, I conducted field observations of Bald Eagle roosting counts and habits at Barr Lake State Park. This observational study in Barr Lake sheds light on the roosting preferences of migratory Bald Eagles that overwinter in the area. As predicted, Bald Eagles perched in much greater numbers in trees rather than on ice, highlighting the need for suitable perching habitat within the riparian area. Within trees, juveniles and adults preferred perching in the upper two-thirds of the tree with adults most frequently observed in the upper third and juveniles found in the middle third. Contrary to the third hypothesis, juvenile presence increased as adult presence increased, and was not significant after accounting for tree zone . This finding implies that there are differences in perch height between adult and juvenile eagles and that management practices will require advanced care in the preservation or planting of trees that will minimize conflict between adults and juveniles.

Bald eagles perched more readily on trees than on the ice. In this study I used scan counts on tree zones and ice but did not specifically account for the area of each zone. Because the amount of physical space on the ice was far greater than that available in the selected tree stand, bird density was actually far greater in trees and lower on ice than reported here. Several factors could contribute to this preference for trees over ice. First, Bald Eagles are a tree-nesting species and would prefer arboreal roosting sites because of this trait (Woods et al. 1989). Secondly, ice fields are also devoid of cover, and may leave eagles in exposed positions during vulnerable periods of rest. Barr Lake has 789 hectares of open water, leading to a substantially large ice field without much variation in topography, leading to potential attacks from predators and a lack of microclimate variability, preventing adequate thermoregulation (Stalmaster & Gessaman, 1984). Another life trait contributing to this may be the ecological advantages that trees may provide when foraging for food. The Bald Eagle is primarily a predator, and as such, will need advantageous perches to survey for foraging opportunities (Tomé et al. 2011).

I observed that juvenile and adult eagles tended to vertically stratify in the canopy with juveniles preferring mid-canopy and adults preferring the top canopy. Adult preference for the upper and middle canopy may result from a social hierarchy whereby adults take the superior perching positions in the tree tops and juveniles are relegated to the less desirable areas (Stalmaster & Gessaman, 1984; Yackel et al. 2000). The adult eagle will use dominant behaviors to secure higher quality perching positions within a tree; they will vocalize to convey intent, and if not heeded, will physically attack and remove the juvenile from the area to gain access to the higher quality perch (Stalmaster & Gessaman, 1984). The dominant behavior shown by the adults may also explain the vertical stratification, as the higher positions within the tree in winter will have better access to sunning positions, allowing for better thermoregulation within the tree, making these spots a high-quality perching site (Stalmaster & Gessaman, 1984). Adults have also been shown to be better at both scavenging and kleptoparasitism than juveniles (Stalmaster & Gessaman, 1984). Perching height could play a factor in this, as raptors will use higher perching sites to attack others for food, and capture prey or spot carrion (Stalmaster & Gessaman, 1984; Tomé et al. 2011).

Although adults and juveniles tended to occupy different vertical zones in trees, I did not observe significant effects of number of adult bald eagles on number of juveniles after accounting for vertical position. Although number of juveniles observed in a tree increased as number of adults increased, this effect was lost when vertical position was accounted for. There may be several reasons for this counterintuitive finding. The first is that differential vertical zonation of adults and juveniles may serve as a proxy for the amount of space available within the tree, so that when height was included the marginal effect of tree height disappeared. Secondly, it is possible that including the effect of vertical zone may have mitigated any intraspecific competition for perching spots, with the remaining mitigated by horizontal perching location whose availability may be positively correlated to zone (Stalmaster & Gessaman, 1984; Yackel et al., 2000). It is also possible that my ability to quantify the effect of intraspecific competition between juveniles and adults for perching spots may have been impeded by the ultimate departure of migrants later in the season when zero counts were far more common. Finally, the number of trees observed in this study was quite small and the trees observed did not differ greatly in height. Therefore, studies involving more trees with greater height variation and that take place during the peak of migratory visitation may reveal stronger effects of intraspecific competition within vertical zones of trees.

Because of the stark differences in substrate preference and vertical roosting height between adult and juvenile Bald Eagles, management of these resources should be a top priority to help this species succeed. The results in this study indicate that there is a large disparity in suitable perching habitat density on the ice compared to the trees, further highlighting the need for park management to protect appropriate perching habitats if they desire to provide suitable habitat and resting opportunities for bald eagles within the park. The stratification between adults and juveniles within the trees may also indicate a role for taller or wider trees that provide ~~a~~ more suitable perching habitat, which may allow for inter-age mixing or adequate space between adults and juveniles to roost in the same tree. Suitable habitats for Bald Eagles near waterbodies should include large trees that provide viable perching resources (Saafiled & Conway, 2010), while giving enough space to allow for age-stratified roosting within them. Doing so will help the species thrive, and allow for future generations to find satisfactory overwintering habitats for years to come.

Within Barr Lake State Park, management of the riparian area and resources requires a nuanced approach to preserve the habitat for Bald Eagles and to meet FRICOs fiduciary and water provision duties to the stakeholders they represent. Construction along the east and southeast banks will need to include revegetation efforts that focus on a mix of shrubs, trees, and grasses that will be strategically placed to give proper variation in height and perching locations for eagles, but to avoid further damage to the banks (Capobianco et al. 2021; Saafiled & Conway, 2010). Using a mix of grass and shrubs within areas especially close to the banks will prevent seepage from the reservoir through these areas, preventing the need for future repairs needed from this type of damage (Capobianco et al. 2021). By including trees in areas that would be sufficiently far enough away from banks to avoid damage, and with species that allow for proper perching structure and age stratification, Bald Eagles will still be able to find viable over-wintering habitat within the area (Saafiled & Conway, 2010), allowing them to survive and thrive within the park.

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CHAPTER 4. STAKEHOLDER ANALYSIS

Barr lake Water and Land Management Conflicts

Introduction

Recent decisions to alter the riparian zone along Barr Lake within Barr Lake State Park have brought to light fundamental disagreements about how lands within the park should be managed. Removal of riparian vegetation by the Farmers Reservoir and Irrigation Company (FRICO) to reduce losses in stored water in 2023 has highlighted the need for more ecologically minded management of the riparian areas, and a need for remediation of past disturbances (W. Restreppo & J. Hansen, personal communication, January 14th, 2024). Though FRICO has acted to preserve its economic interests by removing large areas of riparian vegetation and reshaping the lake's bank to prevent seepage of stored water within the reservoir, the company still plans to alter the riparian zone in other areas despite concerns of other stakeholders like Colorado Parks and Wildlife (CPW) and the Bird Conservancy of The Rockies. These organizations argue that the denuding and restructuring of the banks has caused a loss in valuable ecological resources for local biota, a potential economic loss because of a decrease in park visitation, and that changes to the landscape have reduced aesthetic value. Resolving the disagreement between FRICO and other stakeholders about how riparian zones should be managed requires a nuanced approach. While cessation of riparian zone clearance and revegetation of the disturbed areas would be ideal for the environmental health of Barr Lake, it may not be feasible. Long-standing legal agreements and ownership of the reservoir afford FRICO more rights regarding how it may use the land it owns (FRICO, n.d), but public image and potential for lawsuits resulting from lack of due diligence to maintain water quality require the company to also be responsible for remediation efforts required after the landscape is altered. In lieu of total cessation of the project, I would recommend revegetation, facilitated jointly by FRICO and CPW, of previously denuded areas because the lack of vegetation not only reduces wildlife habitat and the ability to preserve rare species (Brodie et al. 2023) but also impairs water quality since denuded areas are more prone to erosion (Brianwood & Burgin, 2009; Feng et al. 2023). Revegetation around the reservoir will help mitigate pollutant runoff by facilitating excess nutrient and pollutant uptake (Guo et al. 2018). Revegetation efforts will need to use a mix of native shallow-rooted plants that will grow and immobilize pollutants more quickly (Maucieri et al. 2020), and strategically placed deep-rooted riparian shrubs and trees for bank stability where possible (Capobianco et al. 2021). Faster growth will result in a restoration of native species habitat and resource availability, and a hybridized use of both shallow and deep-rooted vegetation will help prevent future bank degradation (Berger et al. 2014; Capobianco et al. 2021; Liu et al. 2016)

Description of Site and Issue

Barr Lake is a reservoir located in Brighton, Colorado that rests at the center of a 1,093-hectare park (Barr Lake State Park). The Farmers Reservoir and Irrigation Company (FRICO), the local farmer's union, owns the reservoir and the surrounding land. In 2023, FRICO determined that native vegetation growing along the reservoir would damage berms that help retain water it needs for agriculture (9News, 2023). To prevent berm damage, FRICO has, and will continue to, remove vegetation and re-engineer the berms around the reservoir on the east and southeast side of the reservoir (M. Phipps, personal communication March 9, 2024; Patterson, 2023).

However, while protecting berms from encroachment by native vegetation may help with water retention, it may cause other problems. When vegetation is cleared around Barr Lake reservoir, agricultural contaminants like pesticides, and nitrogen and phosphorous from fertilizer will be able to enter the lake, causing degradation of water quality below acceptable limits (Oppeltová et al. 2021). Agricultural runoff from the surrounding farmland, soil runoff from the banks around the reservoir, and subsequent eutrophication from excess nutrients within the reservoir will negatively affect the water quality within Barr Lake (Oppeltová et al. 2021). Removal of riparian vegetation also reduces the aesthetic and economic value to park managers and visitors (W. Restreppo & J. Hansen, personal communication, January 14, 2024). Reduced water quality, lack of vegetation, and the resulting lower biodiversity are the main concerns regarding the Barr Lake project. Decreased water quality may cause problems regarding the safety of the water for wildlife, agriculture, and the people of Brighton, CO who use water from the Burlington Ditch, which feeds Barr Lake and continues through the park.

Science

Riparian areas within the park provide a suite of biological services that benefit many stakeholders in the area. Riparian plants provide habitat for biota, soil stabilization, nutrient retention, and water filtration. Removal of riparian plants lowers the system's ability to provide these services and can have unintended consequences including bank erosion, enhanced runoff of pollutants and excess nutrients, eutrophication, and losses in wildlife and plants that rely on these services (Berger et al. 2014; Capobianco et al. 2021; Liu et al. 2016; Maucieri et al. 2020).

Many plant and wildlife species rely on the habitat riparian ecosystems provide (Brodie et al. 2023). Riparian areas provide foraging opportunities and sheltering habitat to resident and migratory wildlife and can harbor rare plants and animals (Brodie et al. 2023). Removal of the vegetation would greatly reduce the resources and habitats available for those species that rely on the riparian areas. Several species of animals call riparian areas home, ranging from several endemic and endangered amphibians to more charismatic species such as the Colorado state amphibian, the Western Tiger Salamander (*Ambystoma mavortium)* (CPW, n.d).

In addition to its effects on biota, removing riparian vegetation will also affect geophysical processes on the landscape. Removing riparian vegetation greatly decreases bank stability (U.S Army Corps of Engineers, 2010; Cheng et al. 2023). Plant root systems in riparian zones bind loose sediment and increase the structural stability of the bank. When vegetation is lost from the riparian zone, soil can more easily erode from the bank. Without riparian plants to limit soil erosion, brownification, a consequence of suspended humic and dissolved substances that turn the water increasingly darker and more brown, can occur leading to poor water quality (Cheng et al. 2023; Wan et al. 2023).

The parameters used to assess the water quality of Colorado reservoirs are total ammonia, nitrate, phosphate, potassium, dissolved metals, recoverable metals, dissolved oxygen, *E. coli*, pH, and chlorophyll a (EPA, 2023). Increases in nutrients like nitrate, phosphate, and potassium can lead to eutrophication (Feng et al. 2023, Liu et al. 2016), while decreases in dissolved oxygen can lead to anoxic environments. Changes in pH can create inhospitable acidic or basic environments, while *E. coli* contamination may indicate that the water harbors pathogens that cause illness. Changes in dissolved and recoverable metals will depend on the metal, but may have cascading effects in the food web if left to run rampant (Mohammadi et al. 2021).

Because riparian vegetation can take up dissolved materials in shallow subsurface pathways, it also acts to buffer loading of pollutants and excess nutrients to the water body (Eriksson & Weisner, 1997; Flemming-Singer & Horne, 2006; Maucierei et al. 2020). Once riparian buffers are removed, uptake of dissolved chemicals declines, increasing the load of nutrients and pollutants, like phosphorous and organochlorine pesticides from surrounding agricultural lands (Cheng et al. 2023; Eriksson & Weisner, 1997; Şimşek Uygun & Albek, 2022). If nutrient and pollutant levels are left unregulated, this can lead to catastrophic eutrophication of the water body from the nutrients, and contamination from chemicals such as organochlorine pesticides (Berger et al. 2014; Capobianco et al. 2021; Liu et al. 2016; Maucieri et al. 2020; Şimşek Uygun & Albek, 2022).

Stakeholders

There are numerous stakeholders at Barr Lake State Park. The main stakeholder at the root of this conflict is the Farmers Reservoir and Irrigation Company (FRICO). FRICO represents the farmers within its union and stands in opposition to the interests of Colorado Parks and Wildlife staff (CPW). Stakeholders beyond the managers of the park and FRICO include visitors who are attracted and interested in both the aesthetic value of landscape and ecological health as well as scientists, conservationists, and hobbyists associated with The Bird Conservancy of The Rockies. The Colorado Department of Health and Environment and/or the Colorado Department of Water Resources (CDPHE/CDWR) may also have a vested interest on behalf of those using the water, because the water quality within the reservoir and adjoining ditch will need to remain in compliance to support its use as a source of drinking water, aquatic life, and recreation.

FRICO

As the owners of the reservoir, FRICO has an instrumental and economic interest in the reservoir, as the water from the lake is used for agriculture within the area by the farmers within their union (FRICO, n.d). The loss of water from the lake due to the destruction of berms by native vegetation growth caused financial loss, and repairs were needed to prevent further water loss from the reservoir (9News, 2023). Though not available for comment on how much water was lost, FRICO did apply for a state grant totaling $278,607 to help mitigate the loss (Booth, 2023). While not directly interested in revegetation efforts, the company needs to maintain adequate quality water to avoid fines or sanctions from governing bodies in addition to economic losses in the form of unusable water. This potential loss in revenue from lack of usable water and financial losses (e.g., fines) unites FRICO with CPW and guests, which also strives to maintain high water quality (CPW, n.d). As such, FRICO is purportedly working with CPW to help replant denuded areas.

CPW and Ecologically minded Guests

Colorado Parks and Wildlife has an intrinsic and instrumental (economic and aesthetic) interest in this conflict as well, as they focus on the conservation of resident and migratory species in the area and rely on the wildlife and aesthetics of the park to bring in more guests for revenue through entrance fees and concession sales (CPW, n.d). Visitors interested in utilizing the park for ecological tourism or recreation also depend on the attraction of birds, aesthetic views, and clean water for fishing and boating (CPW, n.d). The waterfront views and birding attract thousands of guests each year, so much so that groups like The Bird Conservancy of The Rockies have partnered with CPW to support bird populations within the area (Bird Conservancy of The Rockies, n.d).

The Bird Conservancy of The Rockies

Because of its partnership with CPW and interest in bird conservation, The Bird Conservancy of The Rockies is an important stakeholder in this conflict as well. The park is a rich center of avian biodiversity including both year-round resident and migratory bird species, allowing The Bird Conservancy of The Rockies to conduct scientific studies regarding birds, support conservation efforts, and provide hobbyists with events and outreach opportunities such as guided bird-watching trips (Bird Conservancy of The Rockies, n.d).

CDPHE/CDWR

Threats to water quality will also attract the attention of Colorado Department of Health and Environment and/or the Colorado Department of Water Resources, organizations that value the water as a source for irrigation and drinking because the resulting lower quality water will lead to water-quality standards being violated. This will economically impact the department as they provide labor and resources (such as field surveys and chemical analysis of the water) to manage the reservoir and prevent damage caused by poor water quality (CDWR, n.d). These interests are shared with FRICO who receives water from the reservoir, as well as multitude of farmers, businesses, and residents of Brighton, CO who rely on the lake for clean water for drinking, plumbing, irrigation, and manufacturing (Booth, 2023).

Conflicts

Although CPW and FRICO are working together with The Bird Conservatory of The Rockies to help mitigate impacts, FRICO's needs oppose the goals of CPW and The Bird Conservatory of The Rockies. FRICO needs to remove vegetation and restructure the banks, but this act causes loss of flora and fauna within the park, resulting in lower biodiversity, and therefore loss of aesthetic value to park guests. Furthermore, managers from CPW and FRICO must jointly assess how to move forward with revegetation efforts. The loss of flora along the banks can also lead to pollution and eutrophication within the reservoir, resulting in lower water quality. If water quality exceeds water quality standards, CDPHE/CDWR will require that controls be implemented to decrease pollutant loading to Barr Lake. The purely instrumental value of the reservoir to FRICO and the economic impact of the loss of irrigation water and potential costs of revegetation oppose CPW's interest in instrumental and intrinsic uses of the park to conserve wildlife and plants and attract guests with aesthetically pleasing park features.

The economic losses FRICO stands to incur if water quality drops below acceptable levels is a uniting factor with CPW, which strives for high water quality for the health of the park and the enjoyment of the guests. Having this vested interest allows for cooperation between the two entities, as evidenced by the financial aid provided by FRICO to CPW for revegetation efforts in a small section of the disturbed area (CPW, n.d).

Recommendation

State parks are an important refuge for flora and fauna and harbor rare taxa (Brodie et al. 2023). Although Barr Lake State Park possesses an engineered reservoir, the lake has nevertheless become an important area for conservation and a valuable resource for migratory species (CPW, n.d). Removal of vegetation and disturbance of habitat will reduce resources not only for fauna within the park but will also disrupt important physicochemical properties and processes within the reservoir that help maintain water quality within acceptable levels promulgated by the state of Colorado and federal governing bodies (Capobianco et al. 2021, U.S ACE, 2010).

Since FRICO values access to reliable water for irrigation over other benefits the lake provides, it is unlikely that riparian zone destruction will stop. Therefore, as the vegetation management project continues around the lake, I would recommend that FRICO be required to revegetate riparian zones after their repair to allow for preservation of flora and fauna within the park, maintenance of clean waters and stable reservoir banks. CPW should be a managerial partner in this effort to ensure selection of plants and implementation of plans are appropriate for the area. Native shallow-rooted plants, such as shrubs like willow and dogwood and grasses, can fill the need for vegetation along the banks, while also keeping water quality within acceptable parameters (Brianwood & Burgin, 2009; Capobianco et al. 2021; Chapa-Vargas; Feng et al. 2023; Guo et al. 2018; Whitacre & Burnham, 2012). Mixing in taller trees where possible would optimize this approach and can also provide habitat variability for local fauna, such as raptors that rely on taller vegetation for perching (Capobianco et al. 2021; Chapa-Vargas). Shallow-rooted plants that can be locally sourced will also stabilize the bank more so than bareground without compromising the reservoir's ability to retain water. This compromise allows for economical, aesthetic, and conservation-focused values to be met for CPW and its visitors as well as the Bird Conservancy of the Rockies, while also protecting the economic investments of FRICO.

This solution will need to be supported in the long term so that environmental resources within the park are sustained. Long-term monitoring of planted vegetation for establishment and success, water quality parameters, and water availability will ensure that the compromise is working for all involved stakeholders. Additionally, the creation of a liaison team comprising representatives from each of the stakeholder groups would be beneficial as a long-term goal. A lack of communication between stakeholders helped to create high tensions among stakeholders, with many viewing FRICO in a negative light (Finley, 2023). Concerned over the speed at which FRICO began and completed the first stage of its project, many criticized them for an apparent lack of ecological due diligence and research (Finley, 2023). The creation of a joint taskforce would allow for better cooperation and guidance between CPW, FRICO, and Bird Conservancy of The Rockies for future projects, and would facilitate better stewardship for the reservoir and park.

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