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CAPSTONE PROJECT

by

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MS ENVIRONMENTAL BIOLOGY
CAPSTONE PROJECT

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CHAPTER 1. LITERATURE REVIEW: THE EFFECTS OF CLIMATE

CHANGE ON THE MIGRATORY PATTERNS OF DRAGONFLIES

(ODONATA: ANISOPTERA)

Introduction

In aquatic and terrestrial ecosystems across the globe, the dragonfly is of great ecological importance. In aquatic ecosystems dragonflies are the top predatory insects, and are a major food source for fish and water birds. They have an important influence on the community composition of wetlands, because they prey upon invertebrates, larval amphibians, and small fish, and are eaten by larger, insectivorous fish (May, 2012). They are also useful indicators in wetland monitoring of water quality (Ball-Damerow et al., 2014). As adults, they are voracious predators of other flying insects like mosquitoes and biting flies (Migratory Dragonfly Partnership, 2018) and are known to cause high mortality for prey insects (Tiitsaar et al., 2011).

Most dragonflies will travel short distances to ponds and streams away from their natal habitat, however, some migrate long distances to find other fresh water systems (Corbet, 2004). Migration, for the species that do so, ~5% (Migratory Dragonfly Partnership, 2018), is important because it allows dragonflies to avoid unfavorable conditions associated with the changing seasons and contributes to greater biodiversity throughout their range (May et al., 2017). Because dragonflies are ectothermic, ambient conditions determine their body temperature (Cook et al., 2004), and migration to more favorable climates is one adaptation some dragonflies use to regulate this (Corbet, 2004). During these migrations, some co-migrant birds may use adult dragonflies as a primary source of food as they follow large groups on their route (May, 2012). Thus, massive swarms are also likely to bring public attention and interest to the importance of insects that contribute to regional and global biodiversity (Mazzacano, 2011).

So, what might be the effects of global climate change on the migratory patterns of dragonflies? This paper comprehensively reviews well-known migratory dragonfly patterns and the climatic events that drive them. Dragonflies are important for economic resources such as water quality and pest control, therefore, understanding the long-term effects of climate change on migratory patterns will have lasting implications for conservation ecologists. Climate change will have long-term effects on regional and global wind patterns, as well as precipitation events that are important drivers of dragonfly migrations. The timing and direction of migrations rely heavily on major wind patterns (Corbet, 2004) and for some species this combines with the occurrence of seasonal monsoonal rains (Dumont & Desmet, 1990). Thus, global climate change may alter the processes that trigger migration in dragonflies.

Climate change has the potential to disrupt the migration patterns of certain dragonflies by affecting the timing of migratory flights and the suitability of destination locations. These migrating dragonflies may be the primary source of dragonflies for aquatic ecosystems that may not contain sustainable populations of residents (May, 2012). Insect migration in general does not receive much in the way of popular or scientific attention, yet we know it is an important phenomenon. Migrating insects promote transfer of biomass and nutrients, having indelible impacts on communities that rely on the periodic influx of insect populations (May et al., 2017). Knowing how climate change will affect the migratory patterns of dragonflies will help conservation biologists understand how dynamics of populations might change and affect biodiversity.

Dragonfly Migrations

Dragonflies make a number of different types of flights: maiden flight, commuting, seasonal refuge, and migration. For the purpose of this review, I focus on dragonfly species that

migrate, defined as a one-way flight beginning near an emergence site and ending at a new reproductive habitat tens to thousands of kilometers away (Corbet, 2004). These flights can be either obligate or facultative. Obligate migrations occur as a result of drought or cold avoidance. Facultative migrations are less well-known, but some suggest that these may be triggered by population density, which cause some individuals within a population to migrate while others do not (Corbet, 2004). Some of the dragonfly species found across the globe that we know to migrate are *Anax junius* (common green darner), *Pantala flavescens* (wandering glider), *Pantala hymenaea* (spot-winged glider), *Hemianax ephippiger* (vagrant emperor), and *Tramea lacerata* (black saddlebags) (May, 2012).

    Anax junius is a species commonly found across the United States, where its migrations have been well documented. On the East Coast, *A. junius* annual migrations occur, and massive swarms containing hundreds of thousands of individuals can be seen moving in unison toward a common destination. Four of these massive swarm migrations were described in detail by Russell et al. (1997), and can be summarized as follows: (1) all occurred between late July and mid-October, peaking in September; (2) most occurred along topographical leading lines such as lakeshores and coastlines; (3) large-scale cold fronts preceded the massive swarms; and (4) *A. junius* was the main species involved. Other species observed in some of these migrations include *P. flavescens, P. hymenaea,* and *T. lacerata*. In contrast, northward movements of *A. junius* in the spring are driven by the warm air masses that move north along the coast (May, 2012). In the western United States, migrations of *A. junius* are also common, but less well documented (Russell et al., 1997; Ball-Damerow et al., 2014).

    P. flavescens, the tropical wanderer, has well-documented migrations throughout Asia and Africa. Adults appear to wander freely, hence their common name, as their wings are well-

adapted for long periods of gliding on prevailing winds with minimal effort (May, 2012). The behavior and population biology of *P. flavescens* has not been well studied in North America, but most populations are probably obligate migrants, with subsequent generations breeding thousands of kilometers from their natal habitat (May, 2012). Large swarms have been observed on several nights over the Bohai Sea of Eastern China, making *P. flavescens* the only confirmed dragonfly species to migrate nocturnally (May, 2012). Migrations taking place over the Indian Ocean from India to East Africa have also been recorded and well described by Anderson (2009).

Another migrating species in the Indian Ocean region is *Hemianax ephippiger*, the vagrant emperor. This dragonfly avoids woodlands and occupies semiarid and arid areas in India, the Middle East, and Africa. In Africa, *H. ephippiger* is commonly observed frequenting ephemeral pools, small lakes, and river valleys. Being widespread throughout the Middle East, *H. ephippiger* is highly adapted for desert conditions, with larvae tolerant of brackish water with high salinity. Migrations usually take place between India, Africa, and the Middle East, however, *H. ephippiger* has occurred in Iceland and Britain (Corbet, 2004).

Climate Factors that Influence Migration

In the U.S., massive southward dragonfly migrations in the fall are observed following the southward movements of cold fronts (Corbet, 2004). In all four of the migrations summarized by Russell et al. (1998), synoptic-scale cold fronts preceded the observations of the massive swarms. Circumventing cold temperatures is one of the key factors that triggers obligate migration in temperate species like *A. junius* (Corbet, 2004). Because metabolic rate relies on external temperature, dragonflies that remain in a region with low temperatures will not survive (May, 2012).

Wind is another important factor that triggers migration, especially for tropical species like *P. flavescens* and *H. ephippiger*. The rain-bearing winds of the Inter-Tropical Convergence Zone (ITCZ) transport large numbers of migrating dragonflies (Corbet, 2004). From late July through August, *P. flavescens* uses upper level winds to migrate from India to the Maldives, some 600 to 1,000 km away (May, 2012). As the Maldives does not contain any surface freshwater, *P. flavescens* likely continues its migration across the Indian Ocean to East Africa using the north-easterly tail winds (Anderson, 2009). Like *P. flavescens*, *H. ephippiger* is a well-known ITCZ migrant. This species is an obligate migrant, moving north with the annual monsoon fronts (Corbet, 2004). *H. ephippiger* returns to India using the strong westerly winds from the system known as the Somali Jet, an air current associated with the northward movement of the ITCZ (Goswami et al., 2006; Anderson, 2009). Hurricane force winds, common to the East Coast of the U.S., also dramatically affect migratory patterns of *A. junius* by blowing them off their course, and in some instances out to sea (May, 2012).

Dragonflies also migrate to avoid drought. The ITCZ helps tropical migrants not only by providing wind, but also rain (Corbet, 2004). Rain from the ITCZ forms temporary ponds that *P. flavescens* and *H. ephippiger* use for breeding (May, 2012). Following these seasonal rains allow migrants to avoid unfavorable dry conditions in their natal habitat (Corbet, 2004; May, 2012). Just like sudden changes in temperature and wind currents, rain-bearing systems like the ITCZ trigger large-scale dragonfly migrations.

How Will Changing Climate Influence Migration?

Flights driven by wind can lead to maladaptive dispersal, where individuals are carried to places of low survivability (Corbet, 2004). In 1998, small numbers of *Anax junius* were seen in Britain. *A. junius* is known to occupy Central America, North America from Florida to Alaska,

the Hawaiian Islands, the West Indies, China, Tahiti, and Kamchatka (Corbet, 2000). Given this

knowledge, it was quite a surprise to find individuals showing up in the United Kingdom.

Sightings of three individuals in Cornwall, U.K., and three in the Isles of Scilly in 1998 were

officially accepted by the Odonata Records Committee (Parr, 2010). These were the first records

of *A. junius* in Britain. These individuals were likely carried across the Atlantic by the winds of

two successive hurricanes that traveled up the East Coast of the United States just a few days

before (May, 2012).

Hurricane patterns are likely to shift poleward and intensify as climate warms. Recent

reports from the Intergovernmental Panel on Climate Change (IPCC) support the idea that

tropical cyclone tracks are shifting poleward as a result of anthropogenic climate change (Weisse

& Storch, 2010). In the Northern Hemisphere, a poleward shift means that hurricanes will tend

to move from south to north, rather than the usual trajectory from east to west. Hurricane

activity peaks in fall around the same time migrations of *A. junius* are happening, thus a

poleward shift in hurricane tracks will potentially disrupt their fall migrations. This could cause

maladaptive dispersal for some individuals or even swarms as hurricane force winds blow from

south to north as migrations move from north to south.

Maladaptive dispersal cases have been recorded for the tropical migrant *H. ephippiger*, as

individuals have been observed in areas of Britain and Iceland, well outside the limits of their

breeding range. These sightings in the 1970s and 1980s coincided with unusually strong winds

that swept across the Atlantic Ocean from the Mediterranean Sea (Corbet, 2004). These

dragonflies were also found in France and Switzerland in unusually high numbers from April to

August in 1989. On this occasion, their migration started normally, beginning south of the

Sahara and heading toward the western Mediterranean Sea. However, two days in April were

marked by very strong winds that blew across the sea from Algeria and Tunisia toward France and Italy, well north of their typically known range (Dumont & Desmet, 1990).

Along with wind patterns and intensity, climate change will affect annual precipitation events, impacting the migratory destinations of *H. ephippiger* in Africa, south of the Sahara desert (Corbet, 2004). A review of the literature shows that systematic long-term precipitation decreases in the Sahel region, south of the Sahara desert, is a growing concern. Currently, environmental managers in the region are observing an accelerated deterioration in the quality and quantity of water resources as a result of drought, desertification, and changing climate (Hermance, 2014). The deterioration of these water resources will have a negative impact on *H. ephippiger* if they are unable to find adequate surface water for reproduction. Lower reproductive success in the Sahel region will result in fewer individuals making the migration back across the Indian Ocean into India, which will negatively impact the population size of the next generation.

Changes to seasonal precipitation events due to climate warming also have the potential to disrupt the annual migrations of *P. flavescens* by causing greater variability in interannual rainfall in East Africa. The National Center for Atmospheric Research Community Climate Systems Model experiments predict that future climatic warming will cause an increase in both interannual rainfall mean and variability (Wolff et al., 2011). Although a rise in mean rainfall might be beneficial for a species like *P. flavescens* because of their tropical origin, increased interannual rainfall variability might be of some concern if extreme dry periods occur before *P. flavescens* arrives in East Africa. Major droughts occurring before they arrive will reduce the quantity and quality of freshwater ponds necessary for them to deposit eggs.

Conclusion

A review of the literature shows that climate change will have long-term effects on regional and global wind patterns, as well as precipitation events that are important drivers of dragonfly migrations. Long-term changes on these drivers may alter the migrations for long distance travelers like *P. flavescens*, *A. junius* and *H. ephippiger* that rely on annual weather events. Extreme weather events like intense hurricanes and unusually strong wind currents can blow migrating dragonflies off their course. Climate change induced drought and interannual rainfall variability may be of some concern for certain species, like *P. flavescens*. *H. ephippiger* may be negatively influenced by declines in surface water availability, also brought on by persistent droughts caused by climate change.

More research is needed to examine the effects of global climate warming on dragonfly migrations. Global warming may have the potential to disrupt annual migrations in other ways by affecting phenological responses like larval development and emergence times. Future studies focusing on these responses could be useful for conservation biologists and land managers focused on preserving natural processes like dragonfly migration. In addition, future studies should focus on the impacts of influxes of migratory dragonflies in aquatic ecosystems where they will be the top predator and how they influence populations of resident and non-migratory dragonflies. Results from future studies like these, coupled with what is known about global warming effects on wind and precipitation patterns, could help us better predict the long-term changes to dragonfly migrations.

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CHAPTER 2. GRANT PROPOSAL: ASSESSMENT OF LOCAL AND
LANDSCAPE FACTORS INFLUENCING BIRD COMMUNITY
COMPOSITION IN DENVER COUNTY

Abstract

Native bird conservation in cities is becoming a major concern, as birds not only provide aesthetic value to city dwellers, but also play important roles in urban food webs by controlling pest insects and cycling nutrients. In cities, as in natural systems, bird communities are determined by bottom-up and top-down controls at a variety of spatial scales. Denver presents a unique study opportunity in that it is set in the western U.S. at high altitude, is a relatively new city, and has grown rapidly in the past decade. Consequently, I propose to conduct field surveys to statistically assess the degree to which bird communities are controlled by bottom-up factors (i.e. resources) and top-down factors (i.e. cats). Additionally, I aim to compare the relative importance of these controls at both local (i.e., 1 km) and landscape scale (i.e., 6 km^2). The results of this research will not only provide information on the influential drivers of bird species richness and community composition in Denver, but will also provide detailed data for managing and improving habitat for birds in urban areas.

Literature Review

As urbanization increases, urban biodiversity conservation, particularly that of native bird communities, is becoming a major concern for the preservation of urban ecosystem functions (Kang et al., 2015). Not only do native birds provide important ecosystem services such as controlling pest insects and cycling nutrients (Belaire et al., 2015), but they also hold high aesthetic value for city dwellers, thereby increasing awareness of the importance of biodiversity conservation (Platt & Lill, 2006).

Urban development across the world has removed a large amount of native vegetation (Platt & Lill, 2006), and in the process has extirpated native bird species from urban areas (Minor & Urban, 2010). Overall, cities have homogenized the community composition of birds by shifting from predominantly native species, to non-native urban-adapter species (Minor & Urban, 2010). These urban-tolerant birds tend to be bolder and show more aggression, making them better suited to live in areas with high disturbance (Hardman & Dalesman, 2018).

The drivers of bird community composition act in both "bottom-up" and "top-down" manner (Kinzig et al., 2005). Bottom-up controls refer to the basal resources that influence bird communities, such as resource availability, while top-down controls are imposed by predators (Shurin, 2012), such as cats and dogs (Van Heezik et al., 2010; Beckerman et al., 2007). The relative influence of these controls on bird populations may vary within an urban area. For example, in urban areas, 'habitat islands', or patches, can potentially be safe havens, harboring diverse resources native bird species need to thrive (Platt & Lill, 2006). Many common features within cities provide safe haven for birds, including parks, golf courses, cemeteries, undeveloped land, wildlife refuges (Platt & Lill, 2006), and residential yards (Belaire et al., 2014). Within these patches, predation by cats and dogs acts as a top-down influence on bird populations (Van Heezik et al., 2010; Beckerman et al., 2007). Whether cats are feral or kept as pets, urbanization has allowed them to thrive, making them the most invasive species in the world (Beckerman et al., 2007). In the U.S. alone, cats kill up to 3.7 billion birds annually (Raasch, 2013).

These top-down and bottom-up controls influence bird community composition at a range of spatial scales (Belaire et al., 2014). The mosaic of habitat patches within an urban matrix represent both local and landscape factors that play a key role in shaping bird community composition (Belaire et al., 2014). Vegetation complexity and diversity on say, a neighborhood

street (i.e., 1 km) are local-scale habitat factors, while overall urban cover (i.e. roads, buildings), forest cover, and water cover at a larger scale (i.e., 6 km^2) are landscape-scale habitat characteristics (Minor & Urban, 2010). In Chicago, Illinois, native bird richness positively correlated with plants containing fruits/berries and the percentage of yards with trees, and negatively correlated with cats (Belaire, 2014). At the landscape level, patches that contribute to habitat connectivity have a significant positive affect on total bird abundance and abundances of resident species (Kang et al, 2015). When the influence of local and landscape-scale variables on native bird communities are compared, local variables such as yard characteristics and the collective effects of yard management strategies held higher influence than landscapes variables such as canopy cover and open space area (Belaire et al., 2014). In addition, nonnative birds tend to dominate zones with higher cat density, while migratory birds are associated with transects that contain more wildlife-friendly features (Belaire et al., 2014).

Both local and landscape factors influence bird community composition in urban areas. However, aside from the Belaire et al. (2014) study in Chicago, few studies have compared the degree to which local and landscape factors shape bird communities in cities (Fernandez-Juricic, 2000). In Denver, CO even less is known about the relative influence of local and landscape control of bird community composition. While the Chicago study (Belaire et al., 2014) provides insight into the environmental factors that drive bird community composition in Chicago, Denver offers a different set of unique characteristics. Specifically, Denver is at a much higher elevation, located in the western U.S., and hosts a different community of migratory and resident birds. These differences could shift the relative influence of both top-down vs. bottom-up controls on bird communities and change the scale at which they are most important. An increased understanding of the factors that control avian community composition trends and at

what scale will provide city planners, park managers, and residents with knowledge necessary to plan and manage urban areas to enhance biodiversity.

Objectives and Anticipated Value

I propose to assess the relative influence of bottom-up and top-down controls that correlate with bird community composition within Denver County. I will also compare how these controls influence bird community composition at local and landscape scales. Globally, urban development has negative impacts on avian distributions and occurrences, resulting in a homogeneous community of bird species within cities. By answering these questions in Denver County, this study will aid city planners, park managers, and residents in land management strategies that enhance biodiversity in urban areas. In addition, because no such study has been conducted in Denver, it will contribute more information to the field of urban bird ecology and be appropriate for publication in *Urban Ecosystems* or *Ecological Applications*.

Questions, Hypotheses, and Predictions

Q1. To what degree do top-down and bottom-up forces control native bird community composition in Denver, CO?

H1: Because native birds are positively associated with ratio of evergreen trees to deciduous trees and fruit/berries, and negatively associated with outdoor cats (Belaire et al., 2014), I expect to find higher native bird richness in areas with evergreen trees and fruit/berries, and lower native bird richness in areas with higher cat density.

Q2. What is the relative importance of local vs. landscape factors on native bird community composition?

H2: Because native birds respond positively to yard features (Belaire et al., 2014), I expect to find that local habitat features will hold higher relative importance on native bird richness.

Methods

Specific Aim 1 (See Q1 above): Quantify cat density, bird species presence, and habitat features

Study sites will be chosen using a method similar to that of Belaire et al. (2014). I will randomly choose 25 1-km transects along streets located within residential neighborhoods in Denver County. Transects will be selected such that their nearest points are separated by at least 500 m to minimize spatial dependencies. Bird surveys will be conducted using the standard point count method. A total of 11 point counts will take place along each transect (every 100m) for a duration of 5 minutes. All birds seen and heard within 50 m of each point will be recorded. Bird surveys will be conducted twice at each transect on randomly selected days during the peak breeding season for the Denver area, from June 1 to July 10, 2019. The point count surveys will take place from sunrise to 10:00 a.m. on days with no precipitation and minimal wind. Species will be classified as native or nonnative, and migratory or resident using Dunn & Alderfer (2017).

To estimate cat density, I will conduct surveys of outdoor cats along the same transects. I will visually survey cats continuously along each transect. Surveys will be conducted twice along each transect, once during sunrise and again just before sunset on random days (times when outdoor cat activity is greatest), between June 1 and July 10, 2019. Using a range finder, I will record each observed cat's approximate distance from the transect. I will use this data to calculate absolute density of cats using the distance package in R (Miller, 2017).

A field survey technician will conduct habitat surveys along the same transects one time on randomly selected days between June 1 and July 10, 2019. The following habitat features will be estimated visually: deciduous trees, evergreen trees, shrubs/bushes, flowers/vegetables/herbs, and native plants/trees (Belaire et al., 2014). I will rank the presence

of each wildlife resource for each 100 m section of each transect, extending 50 m on each side. A 0-2 ranking system will be used, where 0 is absent, 1 is present, and 2 is abundant.

Specific Aim 2 (See Q2 above): Assess local and landscape-scale habitat features

To collect data on landscape-scale habitat features, I will use ArcGIS 10.1 to calculate road, building, and vegetation cover within a 1-km buffer of each transect (Belaire et al., 2014; Minor & Urban, 2010). To assess other local-scale habitat features I will calculate the same cover within a 50 m buffer of each transect (Belaire et al., 2014). I will also conduct surveys of cats for landscape-level effects. For these surveys I will conduct 10 minute point count surveys at 10 randomly selected locations within a 1-km buffer of each transect and record cats using the methods discussed in *Specific Aim 1*. These surveys will be conducted once around each 1-km transect between June 1 and July 10, 2019 between 5:00 pm and 7:00 pm (when outdoor cats are likely to be out) on randomly selected days.

Data Analysis

Using the data I collect, I will use a multiple model inference approach (Burnham & Anderson, 2002) to test the degree to which top-down and bottom-up forces act to control bird richness at local and landscape scales (Belaire et al., 2014). I will compare the competing models with Akaike's information criterion (AIC_c), which simultaneously examines multiple working hypotheses to identify the best model or models (Belaire et al., 2014). To assess the relative importance of local vs. landscape factors on bird community composition I will use a permutational multivariate analysis of variance (PERMANOVA) test using the vegan package in R (Oksanen et al., 2018). I will conduct all data analysis in R statistical computing software (R Core Team, 2013).

Project Requirements, Logistics, Timeline and Negative Impacts

Timeline

Dates	Activities	Deliverables
March 1, - May 10, 2019	Randomly select transects. Compile GIS landscape data	Study sites and raw GIS data
June 1 – July 10, 2019	Conduct surveys for cats, habitat features, and birds.	Raw data from surveys
July 10 – September, 2019	Analyze data and finish draft report	Draft Report
October 1, 2019	Finish report writing	Final Report

Budget

Item	Justification	Cost, unit (Source)	Quantity	Total Cost
Range finder	To accurately determine distance of each cat from surveyor.	$99.93 (Amazon)	1	$99.93
Gas	Multiple round trips from Regis University to transects.	$0.535/mile (IRS)	800	$428
Field Survey Technician Stipend	For undergraduate student to complete field surveys of cats.	$10/hour (Regis)	100	$1000
Field Survey Technician Stipend	For undergraduate student to complete vegetation surveys.	$10/hours (Regis)	100	$1000
TOTAL PROPOSAL REQUEST				$2,527.93

Regis University will be donating use of any other equipment necessary. I will be donating any additional time over the budget requested for completion of all tasks related to field surveys, data analysis, and report writing. All field surveys will represent minimal disturbance to Denver

County lands as this is strictly an observational study which involves little interaction with natural environments.

Qualification of Researcher (see Attached Resume)

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CHAPTER 3. JOURNAL MANUSCRIPT: MICROHABITAT SELECTION OF FOUR AVIAN SAGEBRUSH/SHRUB-STEPPE SPECIALISTS IN COLORADO

Abstract

In Colorado, residential development, energy development, and invasive plant encroachment reduce and fragment native sagebrush and shrub-steppe communities. Many efforts to preserve populations of migrating birds that need sagebrush and shrub-steppe habitat focus on landscape scale factors, which may not encapsulate the true needs of a species. Here, I identify the microhabitat characteristics important for four avian species that require sagebrush/shrub-steppe habitat for breeding: sage thrasher (*Oreoscoptes montanus*), sage sparrow (*Artemisiospiza nevadensis*), green-tailed towhee (*Pipilo chlorurus*), and Brewer's sparrow (*Spizella breweri*). Using the IMBCR database, I take presence/absence and vegetation data collected on BLM lands in Colorado to uncover the specific habitats being used by each species. Because these four birds have similar diets and foraging behaviors, I expect to find that all utilize similar microhabitats. PCA and PERMANOVA results showed that on BLM lands in Colorado, sage thrashers and sage sparrows occur significantly more in sagebrush habitat with lower grass and shrub height, and a high percentage of bare ground. Green-tailed towhee and Brewer's sparrow showed a more general selection for microhabitat features. The knowledge gained from this study will help inform wildlife managers in Colorado on which environmental features need to be preserved and restored to support conservation efforts of these four birds.

Introduction

Understanding factors that drive organisms to select certain habitats is necessary for effective conservation because habitat loss is the primary cause for most population declines, especially in avifauna (Knight et al., 2016; Antongiovanni & Metzger, 2005). The physical configuration of terrestrial ecosystems is largely defined by the vegetation of the dominant plant communities in an area (Rotenberry & Wiens, 1980). For example, forested woodlands contain primarily tall coniferous or deciduous trees, while prairies contain open fields of grasses and forbs. The spatial structuring of dominant plant communities has repeatedly been shown to determine the abundance and distribution of birds (Hansbauer et al., 2010; Knight et al., 2016; Uezu et al., 2005; Rotenberry & Wiens, 1980; Wiens, 1974). This spatial structuring can be horizontally and vertically complex, and for sagebrush and shrub-steppe communities, this complexity correlates positively with bird species richness (Rotenberry & Wiens, 1980).

Many efforts to assess habitat quality and suitability for birds examine the correlation between bird abundance data and habitat characteristics for the bird in question. These efforts tend to focus on landscape scale factors, such as habitat patch size and spatial positioning of habitat patches (Hansbauer et al., 2009). In fragmented landscapes, these variables are important because they relate to key vital rates (e.g., dispersal, fecundity, survivorship) that determine population trends and ultimately community composition (Antongiovanni & Metzger, 2005). However, at the landscape scale, it is unlikely that habitat selection can serve as a proxy for habitat quality and suitability (Hansbauer et al., 2009). In fragmented landscapes, situations are created where birds may choose suboptimal habitat because of spatial limitations (Hansbauer et al., 2009). The true needs of a species, like nest-site selection, may go unrecognized in a landscape scale study that fails to account for the micro-scale habitat characteristics that a bird

requires, such as grass height and canopy cover (Hansbauer et al., 2009; Rotenberry & Wiens, 1980; Wiens, 1974). Knowing the true needs of a species allows wildlife managers to prioritize those environmental features that need to be preserved or restored to support avian recovery and persistence (Swaisgood et al., 2017).

In Colorado, habitat loss and fragmentation of sagebrush and shrub-steppe ecosystems is occurring due to residential development, energy development, encroachment by invasive herbaceous plants, and pinyon-juniper encroachment (Colorado Parks and Wildlife, 2019). These systems are home to breeding bird populations of sage thrasher (*Oreoscoptes montanus*), sage sparrow (*Artemisiospiza nevadensis*), green-tailed towhee (*Pipilo chlorurus*), and Brewer's sparrow (*Spizella breweri*), all of which are considered sagebrush/shrub-steppe specialists that share this habitat during the summer season (Wickersham, 2016). The sage thrasher, sage sparrow, and Brewer's sparrow are sagebrush obligates, selecting large patches where sagebrush cover is 1-2 m high (Wickersham, 2016). Green-tailed towhee are shrub-steppe specialists, and breed in a variety of shrubby environments made up of sagebrush, willow carr, and oak (Wickersham, 2016; Wiens & Rotenberry, 1981). All are classified as ground foragers, with the exception of the Brewer's sparrow, which prefers to glean insects from foliage (Telander, 2014). Nests of each species are placed in dense areas of shrubs, with the sage thrasher and sage sparrow using the canopies, and Brewer's sparrow and green-tailed towhee situating their nests in the lower (<1 m) parts of shrubs (Wickersham, 2016).

When birds like these sagebrush/shrub-steppe specialists have similar habitats and niche requirements, competition may be more likely. The competitive exclusion principle states that organisms with similar niche requirements cannot coexist in the same space, and in systems with limited resources, one organism will outcompete another (Hardin, 1960). One way that

competitive exclusion may be mitigated to allow the coexistence of these birds within sagebrush and shrub-steppe landscapes may be that they have evolved different patterns of resource use, an evolutionary effect known as "the ghost of competition past" (Connell, 1980). For example, potentially competing birds can coexist through evolutionary responses that allow them to use the same resources. They may use these resources at different times of the day, or utilize specific sizes of the resource (i.e. seeds, arthropods) (Rotenberry, 1980). Another way they may mitigate competition is by vertical partitioning, where certain birds utilize different levels of vegetation. This type of habitat partitioning is especially apparent in woodlands and rainforests where vertical heterogeneity is high (Rotenberry & Wiens, 1980; Wiens, 1974).

Due to the type of habitat these four birds utilize, all are listed as priority species, or animals that are of management concern, as identified under the Land Bird Conservation Plan set forth by Partners in Flight (PIF) (PIF, 2000). Private, state, and federal land management organizations, like the Bureau of Land Management (BLM), hope to stem the decline of these species by mitigating or limiting the amount of activity associated with multiple land-use practices, such as mining and recreation that lead to habitat loss. Knowing which factors of vegetation configuration these birds select will help guide conservation efforts attempting to address a particular threat. Aspects of sagebrush and shrub-steppe environments, such as percent of vegetation and bare ground cover, are obvious candidates as critical variables in analyzing the niches of these four birds.

In this paper, I ask the following questions: (1) How do the sage thrasher, sage sparrow, Brewer's sparrow, and green-tailed towhee apportion sagebrush/shrub-steppe habitat on BLM lands in Colorado? (2) Do they compete or diversify their niche in some other way? Because these species have similar diets during the breeding season, and because they have similar

foraging behaviors, I expect to find that all four will select for similar microhabitats. Therefore, I also expect to find that all four species compete for available habitat. I answer these questions by comparing the vegetation characteristics of sites where these birds are found using data from the Integrated Monitoring of Bird Conservation Regions (IMBCR) database.

Methods

Data collection

Since 2008, the IMBCR program has collected bird abundance and related habitat data annually in late spring and summer. Surveys for birds are conducted by biologists and qualified technicians across public and private lands in the western United States. Surveys are conducted based on a random sampling design, protocols for which can be found at the Rocky Mountain Avian Data Center website (Hanni et al., 2018). The sampling design of the IMBCR program includes surveys at 16 evenly spaced points within randomly selected grids. The algorithm used for random selection ensures that grids are spatially independent. At each point, bird abundances and vegetation characteristics such as percent cover of shrubs, grasses, and canopy, and mean vegetation height are recorded.
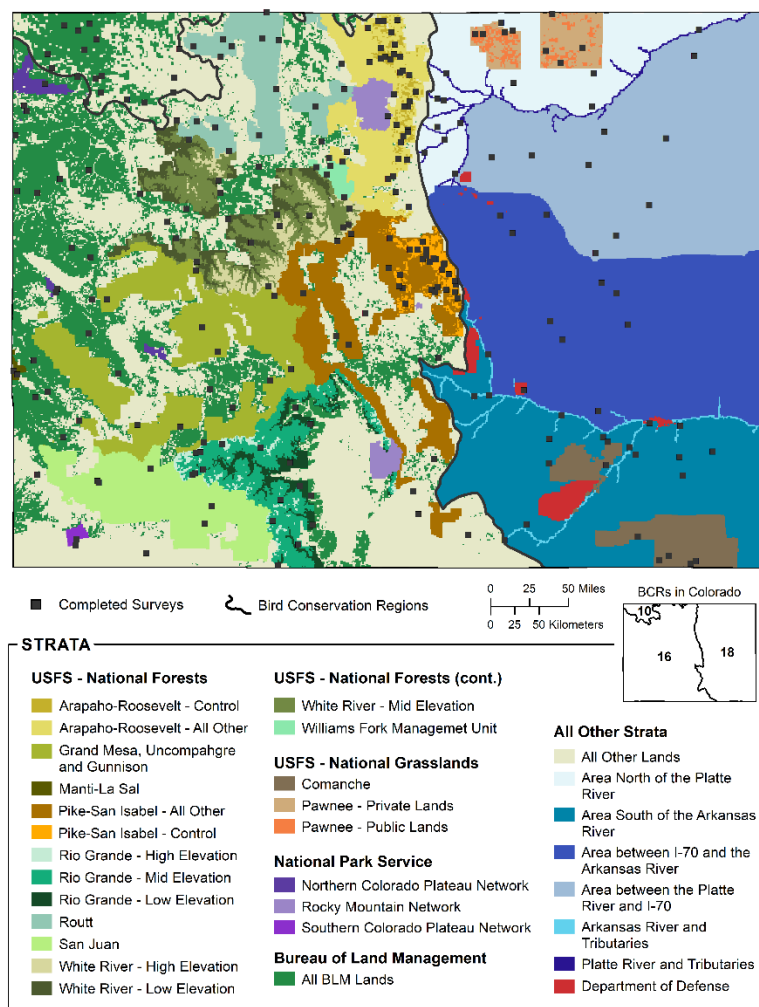
Figure 1 This map shows all IMBCR sampling strata for Colorado. BLM lands are in darker green and black points are locations of survey grids.

The data used in this analysis was taken from BLM lands in Colorado only (Figure 1). Because grids are independently sampled, I summarized all vegetation characteristics by grid. To do this, I calculated the mean value across the 16 samples within each grid, using a log(x+1) transformation in most cases (Table 1). Bird abundance data was converted to presence/absence within each grid and only grids where at least one of the focal sagebrush/shrub-steppe specialists was observed were retained: sage sparrow (SAGS), sage thrasher (SATH), Brewer's sparrow (BRSP), and green-tailed towhee (GTTO). Focusing on these sites where at least one of the

focal species was present allowed me to assess the degree of association between these bird species.

Table 1 – Environmental variables used in analyses. All estimated within 50m radius of each point

Variable	Description	Log(x+1) transformed
Snags	# of dead trees	✓
Canopy cover	% of canopy cover	✓
Canopy height	Mean height of overstory	✓
Shrub cover	% of shrub cover	
Shrub height	Mean height of shrubs	✓
Water	% of ground covered by water	✓
Woody	% of woody ground cover	✓
DeadAndDown	% of dead and down trees	✓
Herb	% of herbaceous ground cover	✓
Litter	% of ground cover w/bare and/or litter	
dead grass	% of residual, dead grass	✓
live grass	% of ground with live grass	✓
dead grass height	Height of residual, dead grass (cm)	
live grass height	Mean height of live grass/herbaceous cover (cm)	

Statistical Analysis

To test whether habitats differed between locations where each of the four bird species was present and absent, I used permutational multivariate analysis of variance (PERMANOVA. I conducted separate analyses for each species, with the presence/absence data of each species as the explanatory variable, and a Euclidean distance matrix of the transformed environmental data as the response variable. This allowed me to statistically quantify whether the multivariate habitat structure significantly differed among sites where each bird was present and those where each bird was absent. These analyses were conducted in R version 3.4.1 (R Core Team, 2017), using functions provided in the ecodist (Goslee & Urban, 2007) and vegan packages (R Core Team, 2017).

To assess whether the four bird species may be competing for habitat, I first used principal components analysis (PCA) to condense the 14 environmental variables into a smaller number of synthetic variables. The first two principal components were retained to summarize

the variation in microhabitat characteristics. I used the scores from these two principal

components as explanatory variables in four separate binomial generalized linear models (GLM),

one for each species. In each model I assumed that the log(odds) of species presence was linearly

related to both the principal component scores and the presence of other species. This allowed

me to assess the degree to which dominant habitat gradients and presence of potential

competitors correlate with species presence. These analyses were conducted in R version 3.4.1

using standard base functions (R Core Team, 2017).

Results

The mean height of shrubs and canopy across sites was 0.92 m (range: 0.13-3 m) and

2.27 m (range: 0-16.6 m), respectively, and mean canopy cover was 2.72% (range: 0-25%). Bare

ground cover averaged 78% (range: 21-98%) across all sites. These variables were highly

represented in the first two principal components. The first component of the PCA (horizontal

axis, figure 2) was primarily driven by shrub height, canopy height, and canopy cover, and

represented 24% of the variation. The second component of the PCA was mostly driven by bare

ground cover and represented 21% of the variation.

Brewer's sparrows and green-tailed towhees had the highest presence, occurring at 80%

and 73% of sites, respectively. Sage sparrows and sage thrashers were present at 45% and 44%

of sites, respectively. The sage sparrow (p=0.003) and sage thrasher (p=0.039) showed

significant differences in environmental space (results from PERMANOVAs), preferring areas

with a higher percentage of bare ground, and lower shrub and grass height (Figure 2). Sage

sparrows were present more in areas with 81% bare ground (p=0.003), 16.8 cm grass height

(p=0.04), and 0.69 m shrub height (p<0.001, results from two-sided t-test, Figure 3). Areas

where Brewer's sparrow (p=0.374) and green-tailed towhee (0.076) were found did not differ in

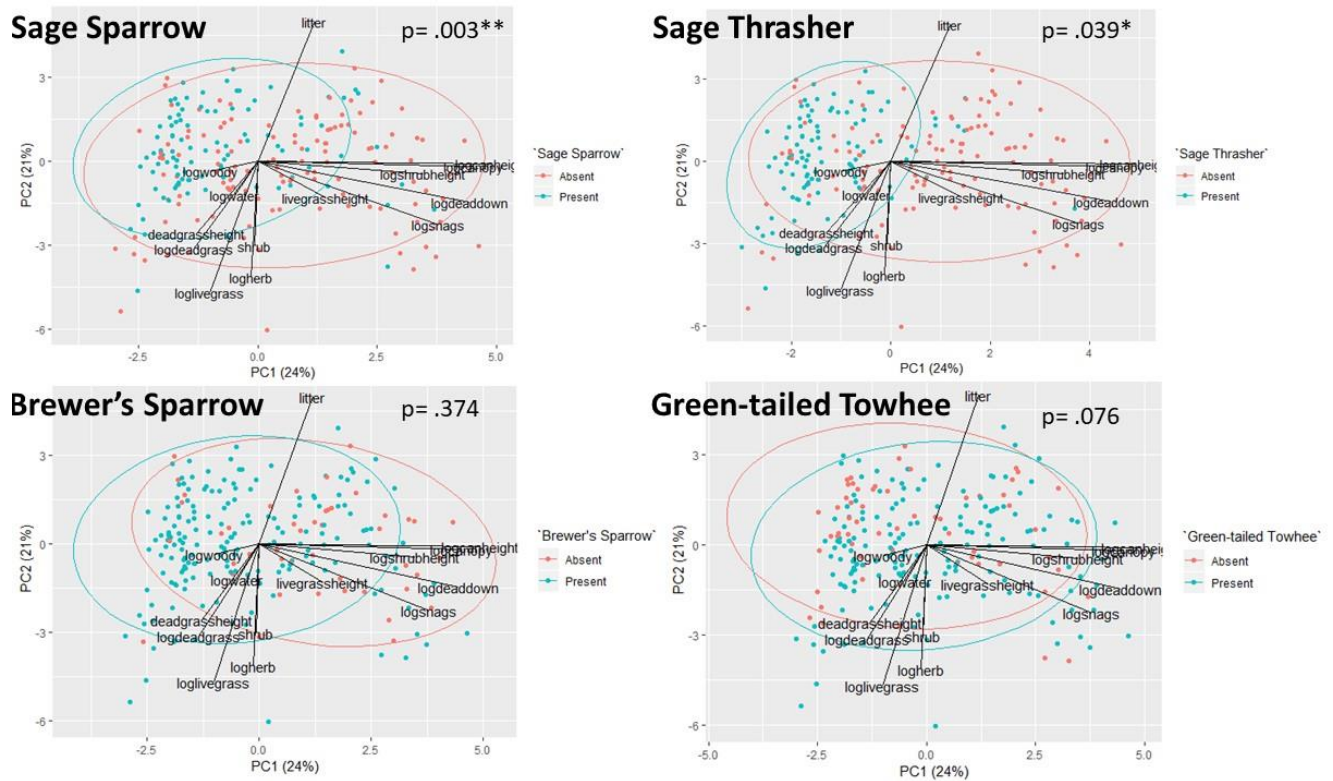environmental space (results from PERMANOVAs, Figure 2).

Figure 2 Plots of presence and absence points of each species in principal components space for PC1 and PC2. Ellipses represent 95% probability intervals for presence and absence.

Both negative and positive associations between species are reflected in the results from

the GLMs (Table 3). Negative coefficients with significant p-values for birds as predictors

indicate that the bird is negatively associated with the bird in the dependent variable column.

For example, after controlling for habitat (i.e. the first two principal components), the green-

tailed towhee (GTTO) was negatively correlated with both sage sparrow (SAGS, p < 0.001) and

Brewer's sparrow (BRSP, p = 0.05). When green-tailed towhee are present, the odds of finding

sage sparrow and Brewer's sparrow decrease by 80% (95% CI: 58 – 91%) and 69% (95% CI: 7 –

92%), respectively. Conversely, after controlling for habitat, sage thrasher (SATH) was

positively correlated with the other three species, and therefore are likely to be found where the
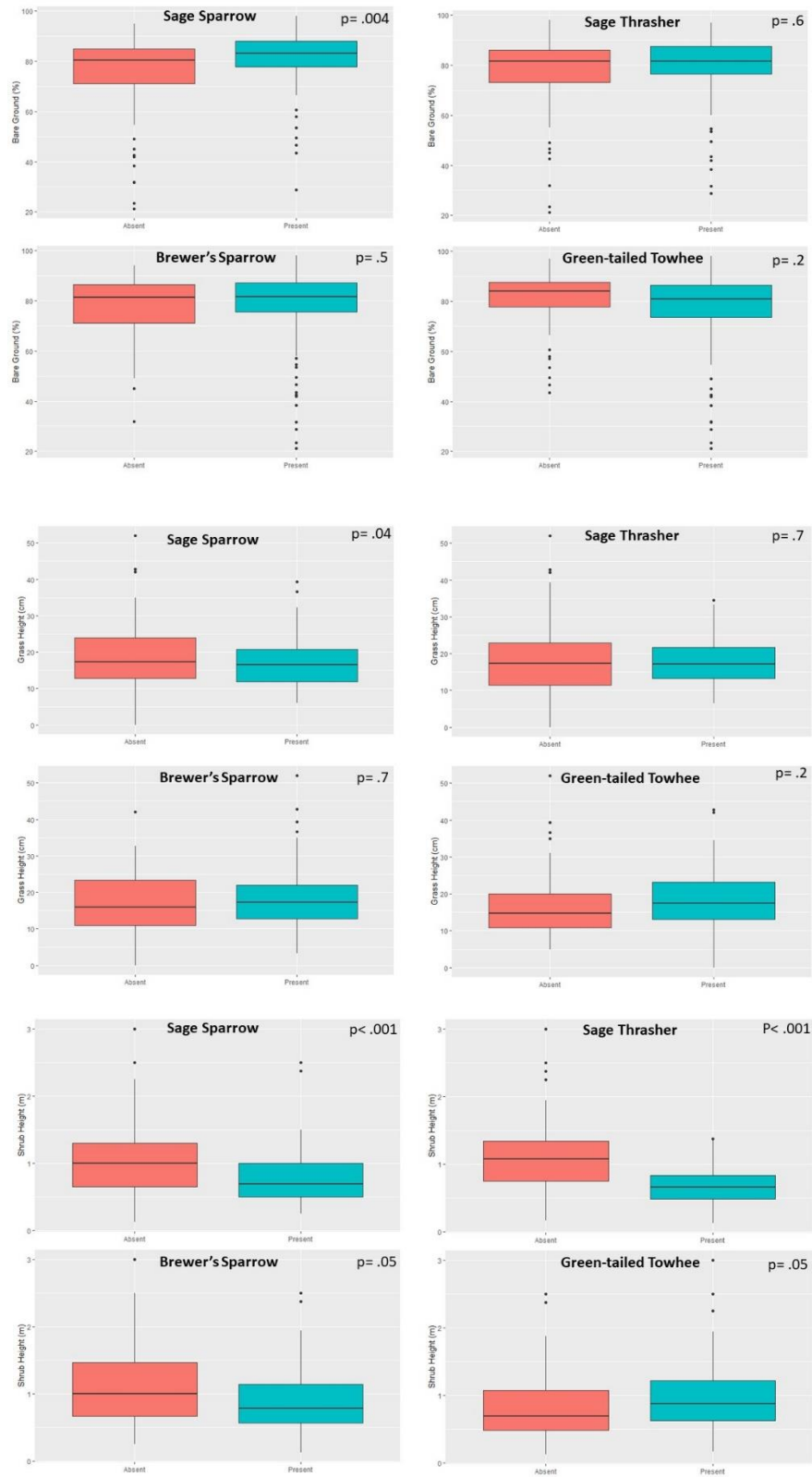
Figure 3 Comparison of vegetation characteristics at presence and absence locations for all four birds. P-values are derived from two-sided t-tests comparing the means of vegetation characteristics between presence and absence locations.

others are present. When sage thrasher are present, the odds of finding sage sparrow, Brewer's

sparrow, and green-tailed towhee significantly increase by 239% (95% CI: 52 – 677%, p < 0.01),

549% (95% CI: 92 – 2639%, p < 0.01), and 139% (95% CI: 2 – 505%, p = 0.06), respectively.

Table 2 – Summary of results obtained from GLMs, where the presence/absence of each species is a function of principal component scores and presence/absence of other species.			
Dependent Variable	Model inputs	Regression coefficients	p-values
Sage Sparrow	PC1	-0.25	0.04
	PC2	0.28	<0.01
	GTTO	-1.69	<0.001
	BRSP	1.83	<0.01
	SATH	1.23	<0.01
Sage Thrasher	PC1	-0.97	<0.001
	PC2	0.24	0.06
	GTTO	0.87	0.06
	SAGS	1.22	<0.01
	BRSP	1.87	<0.01
Brewer's Sparrow	PC1	-0.15	0.21
	PC2	-0.14	0.20
	GTTO	-1.17	0.05
	SAGS	1.61	<0.01
	SATH	1.66	<0.01
Green-tailed towhee	PC1	0.03	0.83
	PC2	-0.17	0.12
	BRSP	-1.16	0.05
	SAGS	-1.63	<0.001
	SATH	0.85	0.05

Discussion

In this investigation of four avian shrub specialists in Colorado, I found that the sage

sparrow and sage thrasher were significantly more present in habitats with a higher percentage of

bare ground cover, and lower grass and shrub height. Green-tailed towhee and Brewer's sparrow

resembled a more general selection of microhabitat characteristics. The green-tailed towhee

showed negative associations with two of the other species, while the rest were positively

associated with one another, suggesting that the presence of one species was likely to indicate the presence of another. My results suggest that any negative and positive relationship between species is driven by either habitat or competition. Thus, my predictions for microhabitat selection were supported for two of the four species, and my predictions for competition warrant further investigation.

Results for sage thrasher microhabitat characteristics corroborate the findings of similar work, which found that their abundance positively correlated with woody cover and bare ground, and negatively correlated with grass cover (Rotenberry & Wiens, 1980). These results also corroborate with findings for sage sparrows, preferring clumped sagebrush habitat with understory containing low herbaceous cover (Petersen & Best, 1985). The selection for these habitat features by sage thrashers and sage sparrows is likely due to their ground-foraging behavior, feeding on insects found in higher densities within woody cover (Wickersham, 2016).

Presence of the other two species, Brewer's sparrow and green-tailed towhee, did not seem to be driven by the microhabitat features I investigated in this study. For the Brewer's sparrow, these results are not surprising because during the breeding season they are the most abundant bird found in sagebrush ecosystems (Wickersham, 2016), suggesting they can tolerate varying measures of microhabitat characteristics. My results show that their status as the most abundant birds in this ecosystem may be due to their high versatility in microhabitat feature selection. Their feeding behaviors may also account for this versatility, as they are known to forage not only on the ground for insects, but also prefer to feed on insects from bark and shrub foliage (Telander, 2014). Given that green-tailed towhees are ground foragers like the sage sparrow and sage thrasher, these results were somewhat surprising. However, resources are often not a limiting factor in shrub-steppe communities (Rotenberry & Wiens, 1980). This

characteristic of shrub-steppe communities is what allows so many of these species to overlap in their distribution (Wiens, 1974; Rotenberry & Wiens, 1980; Wiens & Rotenberry, 1981).

The scales at which the sage thrasher, sage sparrow, Brewer's sparrow, and green-tailed towhee select habitat are also represented in the multivariate analyses I conducted. Habitat features at a range of scales are important for habitat selection by birds (Hostetler, 2016). For example, birds that are attracted to shrubs may respond to shrubs both in a park (local scale) and in the neighborhood surrounding a park (landscape scale) (Hostetler, 2016). Habitat selection for birds occurs at a range of scales, with each being important for where they are found (Hostetler, 2016; Wiens & Rotenberry, 1981). For example, a hawk seen in a particular area may be there because of the presence of trees that provide a spot to roost or nest. At a larger scale, the hawk may have chosen that spot because of the amount of open space and forested area, which provides a balance between places to roost and places to catch rodents (Hostetler, 2016). My results suggest that the green-tailed towhee and Brewer's sparrow show a generalized selection for small scale features within a landscape of shrub-steppe. This is in contrast to previous work, which found that Brewer's sparrows occur in areas with shrubs of smaller physical dimensions, and green-tailed towhees occur more in areas with taller shrubs (Knopf et al., 1990).

Only the green-tailed towhee was negatively associated with two other species: the Brewer's sparrow and sage sparrow. This may be due to the fact that green-tailed towhee are not considered sagebrush obligates like the other three, and therefore are not as likely to be found with Brewer's and sage sparrows. Green-tailed towhees are more likely to be found in ecotones, where other shrub species encroach on sagebrush habitat (Knopf et al., 1990). In addition, Wickersham (2016) notes that sage thrashers, although considered sagebrush obligates, also breed in other types of arid shrublands, such as greasewood, which may explain why sage

thrashers were not significantly associated with green-tailed towhee. Like most animals, birds generally compete for space and resources (Hansbauer, 2009; Rotenberry & Wiens, 1980; Hardin, 1960), however, the sage thrasher, sage sparrow, and Brewer's sparrow all had significant positive relationships with one another, suggesting that they are all likely to be found in areas where at least one of the others are present. This is likely explained by some other resource, such as insects, that all of these species require and was not accounted for in the vegetation model.

As mentioned before, resources such as food are not typically a limiting resource in sagebrush environments (Rotenberry & Wiens, 1980), therefore allowing these species to avoid competitive exclusion due to limiting resources. However, these birds may also be partitioning food resources in some other way, either by using them at different times, or by utilizing different characteristics of prey organisms, such as size (Rotenberry, 1980). An examination of prey organisms foraged by horned larks, sage sparrows, Western meadowlarks, vesper sparrows, and white-crowned sparrows sharing the same habitat space showed no significant dissimilarities between prey and prey morphologies, further supporting the idea that competition is not an important factor in structuring shrub-steppe bird communities (Rotenberry, 1980). The results for competition from my study show little support for this idea, which is due to its limitations.

Only accounting for certain vegetation characteristics to attempt to describe competition and coexistence in this study is certainly one of its limitations. Another limitation of this study was using only presence/absence data rather than abundance. Doing similar analyses with abundance data by looking at population densities, may reveal competition between species. Using abundance data would allow for inferences to be made as to whether intraspecific competition may be taking place. It would also reveal whether competition between species is

density dependent, something that is not possible using presence/absence data alone. Further research to examine the microhabitat selection of these species should use abundance and population densities to get a better idea of how they apportion their habitat.

My results suggest that for the sage thrasher and sage sparrow, maintaining large areas of sagebrush habitat interspersed with bare ground, shorter shrubs, and native grasses may be beneficial to conservation efforts. My results also suggest that the presence of certain species, like sage thrasher, are likely to indicate the presence of sage sparrow and Brewer's sparrow. Studies like this shed light on the specific habitat requirements of organisms, and how they compete for those habitats. For these four species, habitat loss and fragmentation due to energy development and invasive species encroachment are major concerns for land managers and federal agencies like the BLM (Colorado Parks and Wildlife, 2019; Wickersham, 2016). Landscape scale management practices may be necessary to conserve the habitats these four sagebrush/shrub-steppe specialist require, however, understanding the microhabitat scale requirements can identify the local needs of each species, and in turn help verify the success of specific management approaches (Hansbauer et al., 2010).

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CHAPTER 4. ENVIRONMENTAL STAKEHOLDER ANALYSIS:

SOUTHWESTERN WILLOW FLYCATCHER CONSERVATION PLAN FOR

RIO MORA: DESCRIPTION OF STAKEHOLDERS AND ACTION TO

RESTORE RIPARIAN HABITAT

Introduction

The southwestern willow flycatcher (*Empidonax traillii extimus*), or SWFL, was listed as

an endangered species in 1995. Since then, it has been the center of a substantial amount of

research, monitoring, and management activity. Prior to 1993, when the flycatcher was proposed

for listing, little about the natural history of this species was known. To date, thousands of

population surveys throughout its historical range have been conducted, and numerous studies

about its ecology and natural history have provided substantial information (Sogge et al., 2010).

The SWFL is one of four subspecies of willow flycatchers, distinguishable by subtle differences

in morphology, color, and habitat use (U.S. Fish and Wildlife Service, 2002). Their current

breeding range includes northwestern Mexico, western Texas, New Mexico, Arizona, southern

California, southern Nevada, southern Utah, and southwestern Colorado. This range is similar to

their historical range, however, the quantity of suitable habitat has been significantly reduced

because of landscape and hydrological alterations (U.S. Fish and Wildlife Service, 2002).

The SWFL breeds in mostly dense riparian tree and shrub communities of rivers,

swamps, and other wetlands such as lakes and reservoirs. These habitat patches must be at least

30 feet wide and 0.25 acres in size and include native willows, seep willow, boxelder,

buttonbush, and cottonwood for ideal nesting sites. This subspecies still nests in native

vegetation, however, modern changes to riparian habitat have forced them to adapt to thickets

dominated by non-native trees like tamarisk and Russian olive, or mixed native and non-native stands (U.S. Fish and Wildlife Service, 2014).

In northern New Mexico, the Rio Mora National Wildlife Refuge (RMNWR) is a 4,224 acre conservation area. Within the Refuge, the Mora River was historically used as breeding territory by flycatchers. The Mora River has gone through many changes over the last several decades, thanks to landscape conversions for agriculture, grazing, and recreation (Rio Mora Conservation Science Center, 2019). These activities have channelized the river resulting in the loss of riparian vegetation and introduction of invasive species ultimately causing declines in SWFL populations. Because SWFLs are native to New Mexico, and because they are indicators of healthy riparian habitat, managers at the refuge would like to see SWFL populations increase throughout the area (U.S. Fish and Wildlife Service, 2002). Some proposed ways to do this include: 1) placing fences around sections of suitable habitat to keep people and other animals out, 2) planting willows and cottonwoods to create suitable habitat, and 3) controlling cowbird populations that parasitize SWFL nests. Of these options, the best way to increase the population of SWFL in RMNWR is to increase suitable SWFL habitat by planting willows and cottonwoods along the Mora River. This option best addresses the current needs of the SWFL, is not highly controversial, and comes with incentives to stakeholders, such as tax breaks and grant funding (NMLC, 2019).

Stakeholders

The first group of stakeholders I will describe includes four major stakeholders who are directly involved with the RMNWR. They are the U.S. Fish and Wildlife Service (USFWS), Denver Zoo, Pueblo of Pojoaque tribe, and New Mexico Highlands University (NMHU). The four-way partnership between these organizations began when the refuge, once a privately

owned ranch, was donated to the USFWS. Lacking the funds to give RMNWR a budget, the USFWS turned to the Denver Zoo to manage and staff the refuge, as well as expand the research, conservation, and education programs that take place on the refuge. This is all done in partnership with the Pueblo of Pojoaque, who own the bison herd that have grazed the land since 2010, and NMHU, who have actively been conducting classes and research on the land since 2007. In addition, Regis University has recently become a partner with RMNWR, and together with NMHU can use SWFL habitat restoration as an education opportunity for their students. These five groups all share the same interests, which are to restore nature on the RMWNR, conduct conservation research and ecological restoration, protect ecosystem function and native species, and further conservation education (Rio Mora Conservation Science Center, 2019).

Another group of stakeholders share an interest in seeing rare or endangered avian populations increase. This group consists of the Audubon Society, American Bird Conservancy, New Mexico Department of Game and Fish, Bureau of Land Management, birders, and USFWS. The Audubon Society and American Bird Conservancy were formed with the same goals and ideals: to protect birds and stop extinctions (American Bird Conservancy, 2019; Audubon, 2019). In 2016, the New Mexico Department of Game and Fish produced the New Mexico State Wildlife Action Plan, which serves as a guide for identifying needs and opportunities to conserve New Mexico's wildlife (New Mexico Game and Fish, 2016). The Bureau of Land Management and USFWS share similar values, as their guiding principles are to cultivate community-based conservation and work with others to conserve, protect, and enhance wildlife and their habitats (Bureau of Land Management, 2019; U.S. Fish and Wildlife Service, 2018). Their multiple land use mission involves mitigating or limiting the activities that lead to the decline of endangered species, such as mining and recreational development (Bureau of Land Management, 2019). The

USFWS also plays a critical role in the listing of SWFL, as well as their recovery. In 1991 they began preemptive measures to identify and list the SWFL as an endangered species, before actually doing so in 1995 (U.S. Fish and Wildlife Service, 2002). The SWFL was listed after numerous petitions from the stakeholders that the USFWS ultimately represent, U.S. citizens (U.S. Fish and Wildlife Service, 2002). The last group is birders, who may organize to affect change. Birding, or birdwatching, as a hobby is a multi-billion dollar per year industry (Gaston et al., 2018). Birders generally want to see an increase in endangered species populations, and they will go out of their way to get a glimpse of a rare bird. Ultimately, all of these organizations are driven by birders, citizen scientists, and their respective members. The American Bird Conservancy and Audubon are non-profit organizations that rely on member donations and citizen scientists to collect data (American Bird Conservancy, 2019; Audubon, 2019). The federal agencies mentioned here also rely on this data to make informed decisions about conservation needs and identify population trends (Audubon, 2019). The overall goal for these organizations and the individuals they represent is to restore endangered bird populations for the betterment of nature and future human populations (U.S. Fish and Wildlife Service, 2018; Audubon, 2019; Bureau of Land Management, 2019; American Bird Conservancy, 2019).

In contrast to the stakeholders interested in ornithological conservation, there are some that are particularly interested in habitat restoration. These stakeholders include the Environmental Defense, Environmental Education Association of New Mexico (EEANM), New Mexico Land Conservancy (NMLC), and the New Mexico Department of Transportation (NMDOT). The stakeholders discussed previously are also interested in this aspect, however, these stakeholders do not necessarily share in the ornithological aspect of the plan. The Environmental Defense organization's goals are to conserve local habitats. One way they do this

is to provide incentives to landowners for protecting and promoting habitat conservation on private lands. They also present strategies to landowners for habitat conservation that are science based (EDF, 2019). The EEANM is a non-profit organization that offers New Mexicans quality environmental education (EEANM, 2019). This project is an opportunity for the organization to provide such education while helping meet the goals of the SWFL conservation plan. The NMLC's objective is to conserve watersheds to improve water quality. One way they accomplish this is by restoring native vegetation along rivers and streams. They also provide incentives to private land owners for conservation easements and other forms of land management strategies that promote conservation (NMLC, 2019). Both the NMLC and EDF can provide incentives like federal tax deductions, estate tax incentives, New Mexico state tax credits, and on rare occasions, grant funding (EDF, 2019; NMLC, 2019). In places where roads are close to riparian habitat, the restoration of willows and cottonwoods will aid the NMDOT in their effort to comply with the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), which contains a provision for establishment of native species (White et al., 2007). The ultimate goal of these organizations and the individuals they represent, such as students, educators, and environmentalists, is to restore native vegetation in areas that have been heavily impacted by humans (NMLC, 2019; White et al., 2007; EDF, 2019; EEANM, 2019).

Some stakeholders will be opposed to the action of habitat restoration. This group includes farmers and ranchers, homeowners and tenants, and anglers. While some individuals in these groups may agree that SWFL habitat restoration is a good thing, I will focus here on those who are opposed. Farmers would be worried about sharing water used for irrigation with the newly planted willows and cottonwoods, especially during times of lower than average water

levels or drought (Friederici, 2016). Ranchers would be concerned for the same reason, but for cattle, and also because dense thickets of willows may restrict cattle access to the river. Some homeowners and tenants may be opposed to the plan because they may not like the look of willows on their property, or because they fear that habitat on their property will become critical for SWFL spreading into the area (ERO Resources Corporation, 2012). This could hinder the progress of the plan by creating fragmented and unconnected segments of riparian habitat. Anglers may be opposed to the plan out of their concern that their lines get caught and tangled in the willow trees, or that they won't have access to their favorite fishing spots because willows are blocking them (Douglas & Abery, 2009).

Recommended Action

Upon careful consideration of the stakeholders and the overarching goal and needs of the conservation plan, the action of planting willows and cottonwoods is the best option. The major cause of SWFL population declines is loss of suitable habitat: dense riparian vegetation consisting mainly of native willows (U.S. Fish and Wildlife Service, 2002). In two other regions, conservation plans for SWFL recovery are already in place, and the primary action of both is to increase suitable habitat (U.S. Fish and Wildlife, 2002; ERO Resources Corporation, 2012). Because of this, cooperation of all stakeholders, maintained through hands on symposia and workshops, is imperative (U.S. Fish and Wildlife Service, 2002). The other mentioned actions for SWFL conservation would likely face more opposition from stakeholders. Fences are often unattractive, hinder movement of anglers, landowners, livestock and wildlife, and are costly to install and maintain (U.S. Fish and Wildlife Service, 2002). Controlling cowbird parasitism is often highly controversial and very costly, as it usually involves having people go

out and trap and kill brown-headed cowbirds (Ortega et al., 2005). These options also do not address the immediate ecological needs of SWFLs (U.S. Fish and Wildlife Service, 2002).

As the best option to recover SWFL populations, replanting willows and cottonwoods would involve changing the riparian vegetation composition along the Mora River. Removal of invasive riparian vegetation species and constant monitoring of the progress of willows and cottonwoods would need to be implemented over a 30-year time period. Organizations like Regis University, NMHU, and EEANM would benefit from this action, as it would provide education opportunities for their students through a hands-on approach to conservation. The re-establishment of willows will also stabilize river banks, decreasing sediment runoff and erosion, and increasing water quality (U.S. Fish and Wildlife Service, 2002).

If the benefit of higher water quality is not enough to convince the opposing groups identified above, they may be encouraged to participate in willow habitat creation through incentive programs provided by other stakeholders (i.e. Environmental Defense, NMLC). Tax incentives for ranchers, farmers, and homeowners have been effective, proven ways to gain support for conservation projects (NMLC, 2019). Restoration of natural riparian habitat has its benefits beyond SWFL conservation. It improves water quality, removes invasive plants and replaces them with native vegetation, and promotes native biodiversity (U.S. Fish and Wildlife Service, 2002). These improvements are something that groups like the USFWS, BLM, Denver Zoological Foundation, Audubon Society, and American Bird Conservancy strive to see, and their support will ensure that the project has funding for its duration.

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