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MS Environmental Biology Capstone Project

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MS ENVIRONMENTAL BIOLOGY
CAPSTONE PROJECT

by

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

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CHAPTER 1. LITERATURE REVIEW

Hunting as a Management Tool for the Invasive Eurasian-Collared Dove (*Streptopelia decaocto*)

Introduction

Invasive species are widely considered to be the second biggest threat to worldwide biodiversity (Bled, Royle, & Cam, 2011; Simberloff, 2010). Introduction of these species are largely human induced and detrimental to ecosystems both economically and ecologically (Simberloff, 2010). The Eurasian-collared dove (*Streptopelia decaocto*) is an invasive species that is highly successful with population size rapidly growing in North America (Bled et al., 2011). Wildlife managers are becoming increasingly concerned about this dove species due to its potential to disrupt native communities (Romagosa & Labisky, 2000). Invasive species management is difficult and typically relies on prevention or eradication (Simberloff, 2016). Hunting is an excellent method of invasive species control, specifically for eradication, and it generates revenue for conservation (Decker, Stedman, Larson, & Siemer, 2015). Unfortunately, there are a limited amount of studies that evaluate the impacts of collared dove introductions, and far fewer studies that examine methods to control its populations. Therefore, a thorough examination is needed to understand the potential impacts associated with the Eurasian-collared dove (ECD) and show that hunting is a needed management tool to control populations in North America. Hunting will be most effective by increasing public involvement and knowledge about hunting as an invasive species management technique.

History and Impacts of the Eurasian-Collared Dove

The ECD originated in India where it has been successful for centuries, and has since made its way to ecosystems across the world (Scheidt & Hurlbert, 2014; Bagi, Kraus, & Kusza, 2017). The invasion of the collared dove began in the Middle East and eventually continued through Europe (Bagi et al., 2017). The collared dove has completely invaded Europe with an estimated population size between 24 and 43 million individuals (Bagi et al., 2017). The European invasion of the ECD happened entirely within 30 years during the mid-1900's (Bled et al., 2011). A captive population of collared doves in the Bahamas was unintentionally released in the early 1970's, and that population grew in the wild, eventually making its way to Florida (Bled et al., 2011; Scheidt & Hurlbert, 2014). Population expansion through North America has been comparable to that of Europe, with the dove colonizing the west coast 25 years after introduction (Bled et al., 2011). The ECD is predicted to move northwesterly in North America to follow favorable habitat and climatic conditions (Scheidt & Hurlbert, 2014; Slager, 2019). The current geographic distribution of the ECD is now estimated at over 93 million km^2, with that extent increasing daily (Bagi et al., 2017). Unfortunately, human expansion and development is correlated with the expansion of this bird.

The ECD's most worrying aspect is the expansion through entire continents in a short period of time (Ingenloff et al., 2017). The biggest concern is that the collared dove prefers urbanized habitats, which are consistently growing and allow this species to colonize new areas (Beckett, Komar, & Doherty, 2007; Bonter, Zuckerberg, & Dickinson, 2010; Scheidt & Hurlbert, 2014; Bendjoudi et al., 2015; Bagi et al., 2017; Ingenloff et al., 2017). Dove abundance increases with urbanization due to opportune food sources, and availability of suburban trees, telephone poles, and buildings for roosting (Scheidt & Hurlbert, 2014). These collared doves have generalist diets which allow them to acclimate to new food sources in these urban areas (Bendjoudi et al., 2015). Although they prefer anthropogenically-altered areas, the ECD is also increasing in abundance in forested areas (Bonter et al., 2010). In Algeria, Bendjoudi et al. (2015) reported that the collared dove invaded quickly and is predicted to colonize agricultural fields and groves in the future. Unfortunately, in northeastern Colorado, the dove has been found in at least 23 urbanized and rural towns containing agricultural fields where the doves feed on grain (Beckett et al., 2007).

There are two main reasons why the dove is successful in rapid population growth: breeding and dispersal (Bagi et al., 2017; Ingenloff et al., 2017). Most dove species have between 2-3 broods per year, but the ECD typically has 4-5 broods per year (Bagi et al., 2017). With large increases in population, the collared dove needs the ability to move to new habitats. Ingenloff et al. (2017) found that, in Europe, the ECD was more peripheral in its invasion and expansion, meaning that the dove tended to inhabit less advantageous areas compared to favorable-resourced habitat. With populations growing so fast in Europe, the dove needed to colonize any area possible in order to sustain such growth, even if that area did not contain favorable resources, and that same scenario is expected to be happening in North America (Ingenloff et al., 2017).

Few studies have assessed the impacts of the ECD on native species. However, there are concerns that the collared dove can outcompete other avifauna with their large populations and generalist diets, and the dove has potential to introduce disease (Romagosa & Labisky, 2000; Beckett et al., 2007). If the collared dove outcompetes native birds for resources, we could see declines in native avifauna populations and the species that rely on them for ecological processes (Romagosa & Labisky, 2000; Beckett et al., 2007; Simberloff, 2010). Native dove species are most at risk due to dietary overlap between the native species and the ECD (Romagosa & Labisky, 2000; Beckett et al., 2007). Behavioral dominance of the ECD has been observed in Florida, where the collared dove may be dominant, and show aggression, over native species such as the mourning dove and white-winged dove (Romagosa & Labisky, 2000; Simberloff, 2010; Beckett et al., 2007).

The collared dove has the potential to carry diseases such as the West Nile virus, the Newcastle disease, and the St. Louis encephalitis virus (Beckett et al., 2007). Newcastle disease from the collared dove increases mortality rates in wild birds and chickens, which could be detrimental for biodiversity and agriculture (Beckett et al., 2007). Introduction of these diseases could kill native bird species and economically hurt many people if their chicken livestock is killed (Beckett et al., 2007). Also, with increasing ECD populations in agricultural settings, large amounts of grain could be consumed by the dove and damage crops of farmers (Beckett et al., 2007; Bendjoudi et al., 2015). More research is needed to understand the potential impacts of the ECD. Since the dove is expanding rapidly, however, and has the potential to negatively impact native avifauna, there is a crucial need for further understanding of the species and management of its populations.

Hunting as a Management Tool

Hunting has long been regarded as a management tool for population control of certain species and has been successful around the world (Decker et al., 2015). In Spain, wild boars decimated farmlands due to population booms (Quirós-Fernández, Marcos, Acevedo, & Gortázar, 2017). A hunting ban in Spain from 2001-2013 led to an increase in wild boar populations, and once the ban was lifted, hunters harvested twice as many wild boar in the 2013-2014 season (7,593 boars) compared to the 3,723 boars in the 2000-2001 season (Quirós-

Fernández et al., 2017). This increase in the number of boars hunted after the ban indicates that the hunting ban led to an increase in boar populations (Quirós-Fernández et al., 2017). Hunting these boars helped save crops from further boar destruction, and increased resources available for native wild animals (Quirós-Fernández et al., 2017). In New York, white-tailed deer populations are growing out of control, and wildlife managers have been using hunters for years to help control these deer (Riley et al., 2003). The need for hunting is high, but unfortunately, hunters are unwilling to harvest antlerless deer, which is needed to effectively control populations (Riley et al., 2003). In Canada, snow geese populations are rapidly increasing in size, with a 10-fold increase between 1970 and 1998, and are becoming debilitating to ecosystems due to rampant resource consumption (Menu, Gauthier, & Reed, 2002; Calvert & Gauthier, 2005). Therefore, wildlife managers have used hunting to control these populations, which has led to population stagnation in snow geese (Menu et al., 2002; Calver & Gauthier, 2005). Overall, hunting is effective in limiting population growth of many species.

Another key aspect of hunting is the revenue generated from hunting-related activities. In Canada, hunting-related expenditures (e.g., licenses, apparel, gear, etc.) exceeded $1.8 billion in 2012, which was a good portion of the $14.5 billion spent in nature-related expenditures (Arnett & Southwick, 2015). Game bird and small game hunting generated $312 million and $114 million, respectively (Arnett & Southwick, 2015). In the United States, over $33.7 billion was generated from hunting in 2011 alone, and supported over 680,000 jobs (Arnett & Southwick, 2015). In 2009, taxes collected on hunting expenses were greater than $484 million, with that money going to wildlife conservation programs, and in 2011, hunters in the United States spent roughly $796 million on licenses and permits, going to the respective state's wildlife agency

(Arnett & Southwick, 2015). Hunting and fishing generate roughly 59%, or $3.3 billion, of conservation funds for state wildlife agencies (Rott, 2018).

Unfortunately, there are few studies on how hunting might control the ECD (Bagi et al., 2017). However, in the past, a decrease in hunting intensity has been correlated with an increase in collared dove populations (Bendjoudi et al., 2015). In the 2009 and 2010 hunting seasons in the United States, over 17 million mourning doves were harvested each year (Raftovich, Wilkins, Williams, Spriggs, & Richkus, 2011). Mourning doves and collared doves are similar in terms of size, diet, geographic range in the US, resource use, and habitat preferences, so mourning dove harvests can indicate potential harvest values for the ECD (Bonter et al., 2010; Raftovich et al., 2011). This suggests that hunting can effectively control populations of the ECD. If hunting is to be effective, however, public participation is vital. New York's wildlife managers urged the public to become aware of the white-tailed deer population problem and indicated public awareness as a crucial element in support of hunting as a management tool (Riley et al., 2003). Decker et al. (2015) show that public participation and hunter activity increase when hunting is related to environmental stewardship and conservation. People are more willing to hunt if the species being harvested causes ecological and economic problems (Decker et al., 2015; Rott, 2018). Therefore, by increasing public awareness on the potential of the ECD to disturb native species, introduce disease, and disturb crop production from foraging, support for hunting the collared dove will increase (Romagosa & Lubisky, 2000; Beckett et al., 2007; Decker et al., 2015). If hunters can harvest similar amounts of collared dove as they are mourning doves, then hunting will control populations and help ecosystems and societies throughout North America. Simberloff (2010) argues that keeping species out and eradication are the two best methods for invasive species control, but keeping the collared dove out of areas will be difficult with their ease of dispersal as an avian species, and that is why hunting is needed (Bagi et al., 2017; Ingenloff et al., 2017). Finally, the amount of money generated from hunting the collared dove will help wildlife managers develop and research other methods of controlling the ECD's population.

Conclusion

The ECD is a rapidly expanding invasive species that has the potential to harm native species (Romagosa & Lubisky, 2000; Beckett et al., 2007). With invasive species being the second biggest threat to biodiversity worldwide, urgent action is needed to control the ECD (Bled et al., 2011; Simberloff, 2010). Although direct impacts on native species is not known, the potential for disturbance is worrisome with its rapidly growing population (Beckett et al., 2007; Bled et al., 2011). Therefore, more research is needed to evaluate the impacts of the ECD on native avifauna, which can influence motivation to control the species. Hunting is a necessary conservation and management tool to control the growing populations of the ECD. Although not much is known about hunting the ECD specifically, hunting has effectively controlled populations of various species in the past. For hunting the ECD to be fully effective, public participation and awareness is crucial. Future studies should analyze the impacts that hunters have on ECD populations, which will help create hunting programs for this dove species. Hunters and the general public can benefit the environment together and help wildlife managers and agencies control the ECD, which would be a great victory for conservation.

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CHAPTER 2. GRANT PROPOSAL

Impacts of the Invasive Eurasian-Collared Dove (*Streptopelia decaocto*) on the Mourning Dove (*Zenaida macroura*) in Northeastern Colorado

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November 19, 2019

Section 1: Abstract

The Eurasian-collared dove (ECD; *Streptopelia decaocto*) is an invasive species rapidly invading North America and is of growing concern for wildlife managers due to its large populations. However, not much is known about the impacts the ECD will have on native birds, and those impacts have the potential to disrupt native communities and ecosystem functions. Therefore, I propose to assess the potential impacts of the ECD on the native mourning dove (*Zenaida macroura*) in the Flagler Reservoir State Wildlife Area (FRSWA) in Flagler, Colorado. Within this suitable habitat for both species, I will determine the population size of the two species by conducting point count surveys. Additionally, I will monitor sunflower fields within the FRSWA that are used for seed food sources to determine which species uses the food resource more often, and I will use nesting surveys to establish if both species nest in the same areas and preferred tree species. These data will be analyzed to determine the niche overlap of the two species, allowing us to determine if ECD invasions will harm the mourning dove through resource competition. Wildlife managers in Colorado and North America can use this information to better prepare for the impacts of ECD invasions and develop improved management strategies.

Section 2: Literature Review, Objectives, Hypothesis, Anticipated Value

Literature Review

Invasive species are widely considered to be the second biggest threat to worldwide biodiversity (Bled, Royle, & Cam, 2011; Simberloff, 2010). Introduction of these species are largely human induced and detrimental to ecosystems both economically and ecologically (Simberloff, 2010). The Eurasian-collared dove (*Streptopelia decaocto*) is an invasive species that is highly successful with population size rapidly growing in North America (Bled et al., 2011). Wildlife managers are becoming increasingly concerned about this dove species due to its potential to disrupt native flora and fauna (Romagosa & Labisky, 2000).

Originating in India, the Eurasian-collared dove (ECD) began its invasion in the Middle East and eventually continued through Europe (Scheidt & Hurlbert, 2014; Bagi, Kraus, & Kusza, 2017). The ECD has completely invaded Europe in only 30 years, reaching an estimated population size between 24 and 43 million individuals (Bled et al., 2011; Bagi et al., 2017). In the 1970's, a captive population of ECD was unintentionally released in the Bahamas and eventually made its way to Florida (Bled et al., 2011; Scheidt & Hurlbert, 2014). Population expansion through North America has been comparable to that of Europe, with the ECD colonizing the west coast 25 years after introduction (Bled et al., 2011). Therefore, the ECD's most worrying characteristic is its expansion through entire continents in a short period of time (Ingenloff et al., 2017). ECD abundance increases with urbanization due to opportune food sources, and availability of suburban trees, telephone poles, and buildings for roosting (Scheidt & Hurlbert, 2014). ECDs have generalist diets which allow them to acclimate to new food sources in urban areas (Bendjoudi et al., 2015). Although it prefers urbanized areas, the ECD is also increasing in abundance in forested and agricultural settings (Bonter, Zuckerberg, & Dickinson, 2010; Bendjoudi et al., 2015).

Few studies have assessed the impacts of the ECD on native bird species. However, there are concerns that the ECD can outcompete other avifauna with their large populations and generalist diets (Romagosa & Labisky, 2000; Beckett, Komar, & Doherty, 2007). If the ECD outcompetes native birds for resources, we could see declines in native avifauna populations, which would detrimentally alter community structure, function, and dynamics in many ecosystems (Romagosa & Labisky, 2000; Beckett et al., 2007; Simberloff, 2010). Decreases in native bird populations could see declines of other species that rely on those native species for things such as prey and seed distribution (Romagosa & Labisky, 2000). Native dove species are most at risk due to dietary overlap with the ECD (Romagosa & Labisky, 2000; Beckett et al., 2007). For example, the native mourning dove (*Zenaida macroura*) and ECD are similar in terms of body size, diet, geographic range in the US, resource use, and habitat preferences (Bonter et al., 2010). Both dove species primarily eat grain and seed; while favoring to nest in trees, not much is known about dove preference in specific tree species for nesting (McNair, 1997; Drobney, Schulz, Sheriff, & Fuemmeler, 1998; Beckett et al., 2007; Bendjoudi et al., 2015). Given this resource overlap, the ECD might outcompete the mourning dove for food sources and nesting sites.

In northeastern Colorado, the ECD has been found in at least 23 urbanized and rural towns containing agricultural fields where the doves feed on grain (Beckett et al., 2007). Therefore, the Flagler Reservoir State Wildlife Area (FRSWA), surrounded by an urbanized-agricultural town, in northeastern Colorado is a prime area in which to study the potential impacts of the ECD. Currently, it is unknown how the ECD may impact native birds. By comparing resource partitioning between the ECD and the native mourning dove, along with any relationships between abundances of the ECD and mourning doves, we can determine the severity of ECD invasions. This information can benefit wildlife managers in Colorado and North America by understanding how mourning doves, and other native bird species, might be impacted during ECD invasions.

Objectives

This study aims to provide crucial information on the ECD's impacts to native mourning doves due to competition from resource use overlap. Although this study is set in Colorado, the goal is to provide information on impacts of ECD invasions throughout North America.

Hypothesis and Predictions

Hypothesis 1: ECD populations will negatively impact the mourning dove due to resource use overlap of the two bird species.

Prediction 1: In areas with high numbers of ECDs, there will be fewer mourning doves.

Prediction 2: The ECD will visit seed food sources more often and for longer periods of time than the mourning dove.

Prediction 3: The ECD will have more nests in specific tree species than the mourning dove.

Anticipated Value

The findings of this study will provide information to Colorado wildlife managers on the impacts of the ECD on the mourning dove. The ECD is growing rapidly in population size and geographic range in North America, yet negative impacts to native birds are unknown. Using the FRSWA for a study site will help solidify knowledge of those potential impacts and help wildlife managers across the country understand the severity of this invasion. This will help prepare wildlife managers for potential community changes and generate better management strategies for ECD invasions.

Section 3: Methods

Study Site: The FRSWA, located 100 miles east of Denver, contains a variety of habitats for many different species of birds in its 570-acre area (Figure 1). These varied habitats, along with being located near many seed and agricultural resources, make the FRSWA a prime study area for assessing the impacts of the ECD on the mourning dove. The study will be conducted June through August of 2020 because June is peak ECD breeding season and the summer months provide favorable climatic conditions for studying ECDs and mourning doves, while avoiding winter migration months of the mourning dove (Bled et al., 2011).

Study Species: The ECD and the mourning dove are the focus of this study. In comparison to the mourning dove, the ECD is slightly larger in size and has gray plumage with a black ring around the neck (Kaufman, n.d.). The mourning dove has brown plumage with black dots on the tail; both the ECD and mourning dove feed primarily on seeds and grain (Kaufman, n.d., Beckett et al., 2007; Bendjoudi et al., 2015). Both species prefer nesting in trees (McNair, 1997; Drobney et al., 1998).

ECD and Mourning Dove Population Surveys: To assess the population sizes of the ECD and mourning dove in the FRSWA, I will use point count surveys throughout the FRSWA. Following Beckett et al. (2007), I will generate 50 randomized circles (plots) with a 30-meter radius throughout the FRSWA. Standing in the center of each circle, the field assistant or I will record any ECD or mourning dove visually or audibly observed within each plot in a 10-minute sampling period. A new set of 50 randomized circles will be generated for sampling every week, giving an estimated 33 hours of point count surveys.

Food Resource Overlap: Within the FRSWA are sunflower fields that provide seed food resources for the ECD and mourning dove. Following Beckett et al. (2007), circled plots with a 15-meter radius will be randomly generated in the sunflower fields, and surveys will be conducted for 10-minute sampling periods. 15-meter radius circles will be used instead of a 30-meter radius to aid in visibility in the sunflower fields. In the sunflower fields, while standing in the center of each circle, I will record every time an ECD or mourning dove visits a sunflower within the plot, as well as the amount of time the bird species spends at the food source. 50 randomized circles will be generated per week, for a total of 33 hours of sampling data.

Nesting Surveys: Throughout the FRSWA there are various tree stands where the birds may be nesting. Following Gibbons and Gregory (2006), I will survey those areas for ECD and mourning dove nesting sites using 100-meter line transects. Following the line transect, any ECD or mourning dove observed in a nest or landing in a tree within 25-meters of the transect will be recorded. I will also record the tree species in which the bird is observed. 20 line transects will be randomized and conducted each week.

Data Analysis: To test my first two predictions, I will conduct paired t-tests to assess (1) if the number of ECDs in the area is significantly higher than the number of mourning doves, (2) if the ECD spends significantly longer periods of time, and visits food sources significantly more frequently, compared to the mourning dove. Using an analysis of variance (ANOVA) I will determine what tree species the ECD and mourning dove nest in more often. Comparing ANOVA models for each bird species will show if each species is nesting in the same areas, indicating habitat and nesting overlap. All data analyses will be conducted using R version 3.6.1 (R Core Team, 2019).

Potential Negative Impacts: Any negative impacts will be minimal in the study area. Birds may be disturbed by human presence in their habitat, but that is not expected to significantly harm or disturb any bird.

Project Timeline:

Dates	**Activities**	**Deliverables**
Late May 2020	• Gather field supplies • Train field assistants on bird ID and sampling methods • Generate 100-meter transects	• Map containing sampling sites • GPS coordinates of sampling areas
June 2020 – July 2020	• Conduct bird nesting surveys	• Excel spreadsheet of nesting data
July 2020 – August 2020	• Conduct bird population surveys	• Excel spreadsheet of population survey data
August 2020 – September 2020	• Conduct food resource overlap sampling	• Excel spreadsheet of food resource overlap data
September 2020 – November 2020	• Data analysis • Report drafting, editing, and finalization	• Final Report

Section 4: Budget

Item	**Justification**	**Cost per unit**	**Quantity**	**Total**
Nikon Prostaff 3S 10x42 Binoculars	To aid observers in point count and nesting surveys	$129.95	3	$389.85
Gas	For 12 round trips from Regis University to FRSWA	$90 per fill-up	8	$720
Garmin – eTrex 20x 2.2” GPS Unit	Marking areas for point count surveys	$149.99	3	$449.97
Stake Flags – Bundle of 100	Marking areas for surveys	$8	1	$8
Field Assistant Stipend	For undergraduate student to complete field and laboratory work	$1,000	2	$2,000
Total Research Expenditures				**$3,567.82**

Section 5: Qualifications of Researcher

BRADLEY J. HAMILTON

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Broomfield, CO 80020 | bhamilton1732@gmail.com

Education:

Regis University, Denver, CO – BS 2019 – MS 2020
BS in Environmental Science - Chemistry Minor - GPA: 3.65/4.00
MS in Environmental Biology – In Progress

Research Experience:

Regis University

Rio Mora National Wildlife Refuge – Watrous, New Mexico

- Gathered behavioral data of American bison on the Rio Mora NWR to benefit refuge manager's knowledge of their herd
- Designed research protocol, conducted statistical analysis, produced a full research article, and presented findings

Two Ponds National Wildlife Refuge – Arvada, Colorado

- Investigated the proportion of native and invasive vegetation and the impacts of disturbance on said species
- Conducted a research protocol, statistical analysis, and wrote a research article

Conservation Action Plan

- Created a conservation action plan to conserve the Bornean orangutan
- Analyzed and researched orangutan life-history characteristics, human induced impacts, stakeholder desires, and future management plans to protect the Bornean orangutan

Professional Experience:

City and County of Broomfield **(5/15/17 to 8/2/19)**

Parks Dept. Seasonal Worker

- Maintained irrigation systems of Broomfield parks
- Collaborated with other Parks Departments to preserve wellbeing of Broomfield Parks
- Aided community members when asked for assistance

Regis University **(8/13/17 to 5/6/18)**

Resident Assistant (RA)

- Enforced University policies in the dormitory to promote a safe environment and responded to emergencies
- Coordinated with other RAs and campus partners to provide extra-curricular programs to residents
- Promoted community building to provide inclusiveness and a healthy learning community
- Served as a resource for freshmen students for academic, social, and personal problems
- Educated students about environmental issues and recreation as a part of Regis' Colorado Outdoor Recreation Experience (CORE) Community

Mile High Youth Corps **(5/17/16 to 8/12/16)**

Sawyer

- Responsible for removal of invasive species and trees of potential fire hazard from state parks/wildlife areas
- Operated chain saw for tree removal and woodchipper for mulching
- Collaborated with multiple city's foresters for tree removal projects

Awards:

- Mile High Youth Corps - Corps Member of the Month July 2016
- Regis College Dean's List - Fall 2016, Fall 2017, and Spring 2019
- Regis University Resident Assistant of the Year – 2017-2018

Strengths:

- Proficient in all Microsoft Office applications
- Exceptional customer service skills and working with diverse groups of people
- Leadership, organizational, multi-tasking, and problem-solving skills
- Study design and execution with natural resources and wildlife
- Knowledgeable in GIS Software (Esri, ArcGIS, etc.)
- Skillful in navigating research databases to obtain primary scientific literature

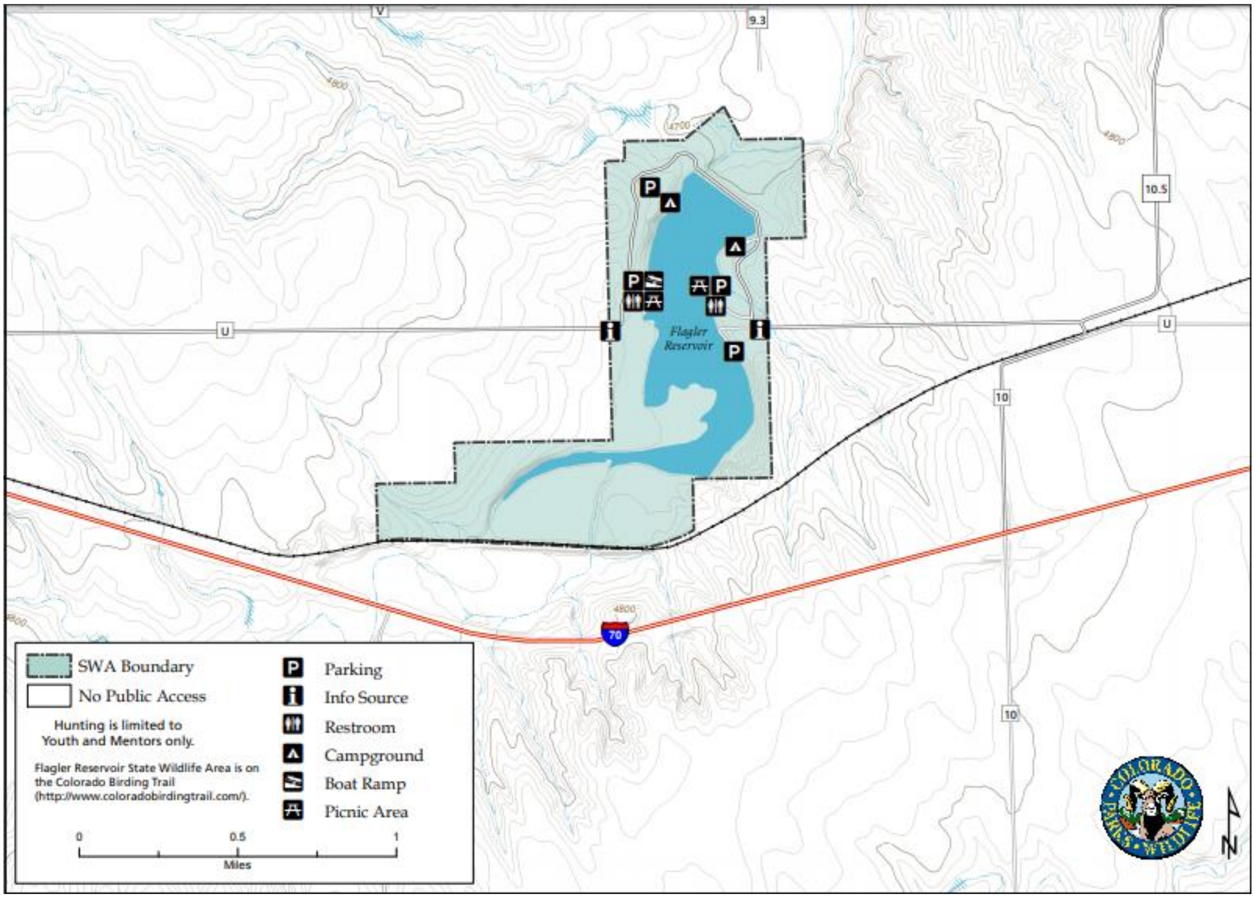

Figure 1: Map of the Flagler Reservoir State Wildlife Area; retrieved from Colorado Parks and Wildlife.

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CHAPTER 3. JOURNAL MANUSCRIPT

High Elevations and Cold Temperatures Influence American Pika (*Ochotona princeps*) Distributions in the White River National Forest

Abstract

The American pika (*Ochotona princeps*) is commonly found throughout the western United States in high elevation habitats. This species is vulnerable to impending impacts of climate change since most pika rely on high elevations and cold temperatures to thermoregulate and buffer against heat. Some pika populations deviate from the norm by occupying low elevation habitats, meaning pika research on a local scale is needed. Pika populations that inhabit the White River National Forest (WRNF) in Colorado have not been researched thoroughly in recent years and need attention to ensure their protection from future climate change impacts. Here, I hypothesized that pika presence in the WRNF would be associated with elevation, average annual minimum temperature, and average annual wet season precipitation. Therefore, I created a species distribution model for pika in the WRNF to predict suitable habitat locations and determine which environmental factors influence pika presence. I assessed three species distribution models to determine environmental variable contribution for each model and created a combined predictive map of suitable pika habitat locations in the WRNF. Overall, elevation and average annual minimum temperature were the two highest contributing variables in all three predictive models, meaning high elevations and lower minimum temperatures influence pika presence the most in the WRNF. This information will allow wildlife managers to better understand where pika are located in the WRNF, where conservation efforts should be focused, and which environmental variables should be monitored in respect to pika presence.

Introduction

Anthropogenic climate change is one of the biggest threats to biodiversity worldwide (Beever et al., 2016; Vanneste et al., 2017). Alpine habitats are especially threatened by climate change (Vanneste et al., 2017). Alpine ecosystems are defined by high elevations (generally above tree line), cold-adapted plants and animals, boulder fields and talus slopes, and environmental stressors such as low temperatures, short growing seasons, low nutrients, and limited water during summer droughts (Rundel & Millar, 2016). Since alpine ecosystems and their species are adapted to cold temperatures, rising temperatures due to climate change may alter high elevation communities at unprecedented rates (Vanneste et al., 2017). This makes alpine environments useful indicators of climate change as cold-adapted species are prone to change under slight alterations to the environment (Varner & Dearing, 2014; Rundel & Millar, 2016; Vanneste et al., 2017). Higher global temperatures threaten precipitation stability and vegetation communities, and alterations to these communities are worrisome for the variety of fauna that rely on the specific habitat restrictions of alpine environments (Varner & Dearing, 2014; Beever et al., 2016; Vanneste et al., 2017). For alpine fauna, shifts and loss of specific vegetation and forage types can be harmful to a variety of animal populations (Vanneste et al., 2017). Therefore, alpine species should be of utmost concern in conservation efforts in the face of a warming climate, especially because these species can only migrate so far upward in elevation before running out of space (Erb, Ray, & Guralnick, 2011; Vanneste et al., 2017).

One such alpine animal species that is especially vulnerable to increasing climate change threats is the American pika (*Ochotona princeps;* Erb et al., 2011; Jeffress, Rodhouse, Ray, Wolff, & Epps, 2013; Beever et al., 2016). The American pika occupies a wide range of habitats throughout western North America, typically inhabiting high elevation sites from British

Columbia to as far south as New Mexico (National Wildlife Federation, n.d.). The pika's primary habitat occurs on talus slopes, which are areas that have seen rockslides, and pika occupy any area in these rocky slopes where they can fit their body (Fig. 1; National Wildlife Federation, n.d.). Within these talus slopes, pika generally live in colonies and make their dens within the crevices of the rocks, which provide physical and social protection from predators (National Wildlife Federation, n.d.). Pika primarily feed on vegetation such as grasses, wildflowers, and weeds that grow around their talus slopes (National Wildlife Federation, n.d.). Once pika have collected their forage, they lay their food out to dry to avoid molding, and extra food is stored in 'haystacks' for later consumption, especially for the winter months (National Wildlife Federation, n.d.). Since pika live in alpine environments, they are very well adapted to cold, harsh conditions that do not see the growth of many forage species (Beever et al., 2016; National Wildlife Federation, n.d.). Therefore, the increasing effects of global climate change are of concern for this small mammal.

Figure 1: American pika (*Ochotona princeps*) gathering food in a typical talus slope habitat. Retrieved from https://earthjustice.org/irreplaceable/american-pika.

Unfortunately, climate change threatens the American pika in several ways (Jeffress et al., 2013; Smith & Nagy, 2015). For instance, pika have high metabolisms, so they need to collect food regularly, and most of this foraging occurs during the summer months when they are vulnerable to heat extremes (Yandow, Chalfoun, & Doak, 2015). The talus slopes used by pika help buffer against heat during the summer months which allows them to live in these areas

(Yandow et al., 2015). However, talus slopes can only buffer so much heat, and if temperatures continue to higher extremes, pika will be injured or killed due to overheating regardless of their habitat (Yandow et al., 2015). These rising temperatures might also decrease the amount of snowpack at high elevations, and precipitation in general, both of which the pika use for thermoregulation and buffering against hotter temperatures (Erb et al., 2011).

Climate change also threatens pika diets. With alpine ecosystems overall being sensitive to climate change, expected shifts in high elevation vegetation could impact pika (Varner & Dearing, 2014; Vanneste et al., 2017). The vegetation that pika consume are specific to these ecosystems, and the loss of their food source from climate change could result in extirpations of populations in North America (Varner & Dearing, 2014). There is potential for pika to retreat upslope to gain elevation and reach colder temperatures, but unfortunately, pika already living in high elevations can only move upward so far (Galbreath, Hafner, & Zamudio, 2009). Therefore, pika do not have many options for survival if climate change continues at its current pace, and although this species is not listed as threatened, predicted population extirpations say otherwise (Galbreath et al., 2009; Beever et al., 2016). Over the past century, studies throughout western North America have found many local pika populations going extinct due to climatic variables and habitat alterations (Galbreath et al., 2009; Beever et al., 2016). However, the effects of climate change on pika, and pika population responses, are not uniform across western North America (Varner & Dearing, 2014).

In certain areas throughout western North America, some pika populations have been found to be more adaptable than others and occupy different habitats than typical for this species (Varner & Dearing, 2014; Smith & Nagy, 2015). For example, pika populations have been found at low elevations in the Columbia River Gorge in Oregon (Varner & Dearing, 2014). In these low elevation sites, pika can be found on a variety of substrates such as lava flats, talus slopes, and grassy areas (Smith & Nagy, 2015). Varner and Dearing (2014) studied a population of pika near sea level in the Columbia River Gorge and found that these pika had altered their forage habits based on their environment. The pika at sea level primarily fed on moss, which is unusual for this species, but very sustainable given their environment (Varner & Dearing, 2014). This shows that, given differing habitat circumstances, pika can have plastic diets which will help their survival (Varner & Dearing, 2014). Further research is needed to assess the plasticity of pika diets as climate change impacts increase.

There is also evidence of temperature having differing impacts on pika (Varner & Dearing, 2014; Smith & Nagy, 2015). Smith and Nagy (2015) studied pika populations in California to determine how temperature influenced extirpations in a variety of locations and found that pika populations were not impacted by warming temperatures. Cooler temperatures did not, however, lead to any recolonizations of pika once extirpated from an area (Smith & Nagy, 2015). This suggests some uncertainty about temperature's effect on pika and how it impacts their populations (Smith & Nagy, 2015). Varner and Dearing (2014) found similar results in regard to temperature, proposing that higher elevation sites may be more detrimental to pika long term. At higher elevation, the ambient air temperatures vary more than at lower elevations, leading to the potential for more heat extremes (Varner & Dearing, 2014). Also, the talus slopes preferred by pika, especially if darker-colored substrate, do not buffer against heat well, which threatens the species (Varner & Dearing, 2014). Therefore, it is suggested that pika could colonize lower elevation sites that contain more vegetation to help buffer against heat extremes (Varner & Dearing, 2014).

Overall, pika occurrence is not uniform across western North America. Typically, pika occupy high elevation, cold temperature locations (Erb et al., 2011; Jeffress et al., 2013). However, there is evidence that pika can occupy low elevation, warm temperature locations (Varner & Dearing, 2014; Smith & Nagy, 2015). Therefore, it is essential to examine local pika populations to determine how climatic and environmental variables influence pika presence. One area needing attention is the White River National Forest (WRNF) located in the Rocky Mountains of Colorado. Pika have been researched in the Rocky Mountains previously (Erb, Ray, & Guralnick, 2014), but not much focus has been put on this species in Colorado. A better understanding of the pika located in the WRNF will help realize what environmental variables impact this species.

The goal of this study is to better understand what environmental variables influence pika occurrence in the WRNF. Additionally, this study will allow us to determine if pika presence in the WRNF follows typical high elevation, low temperature distributions (Erb et al., 2011; Jeffress et al., 2013), or if these pika have the potential to follow atypical, low elevation distributions (Smith & Nagy, 2015). I hypothesize that pika presence in the WRNF will be correlated with average annual minimum temperature, average annual wet season precipitation, and elevation because pika will prefer areas with higher amounts of snowpack and colder temperatures (elevation being a proxy for ideal climatic conditions). I will use species distribution modeling (SDM) to determine the relationship between environmental and climatic variables and the occurrence of pika. SDM has been used worldwide for a variety of species to predict their range for further habitat protection (Franklin, 2013; Hijmans & Elith, 2017), SDM including a number of pika research projects throughout western North America (Erb et al., 2011; Jeffress et al., 2013; Beever et al., 2016). The information I provide with this research will help wildlife managers better understand the distribution of pika in the WRNF. This will allow us to better determine where pika may occur and help us focus conservation efforts in those areas, and also provide information on how the impending impacts of climate change may influence pika populations in the WRNF and throughout Colorado.

Methods

Study Site

Located in the Rocky Mountains of Colorado about 60 miles west of Denver, the WRNF encompasses nearly 2.3 million acres (Fig. 2) of land containing high elevation mountaintops where tourism and ski slopes are prevalent. The WRNF is an expansive area that contains a variety of ecosystems and species, many of which occur at high elevations, where environmental conditions are harsh. One such species is the American pika, which can be found in talus slopes at high elevations. The WRNF has an elevational range typically spanning from 6,000 to 12,500 feet, with 10 peaks exceeding 14,000 feet. The 8 wilderness areas in the WRNF also allow for protection of many different species including the American pika (U.S. National Forest Service, n.d.).

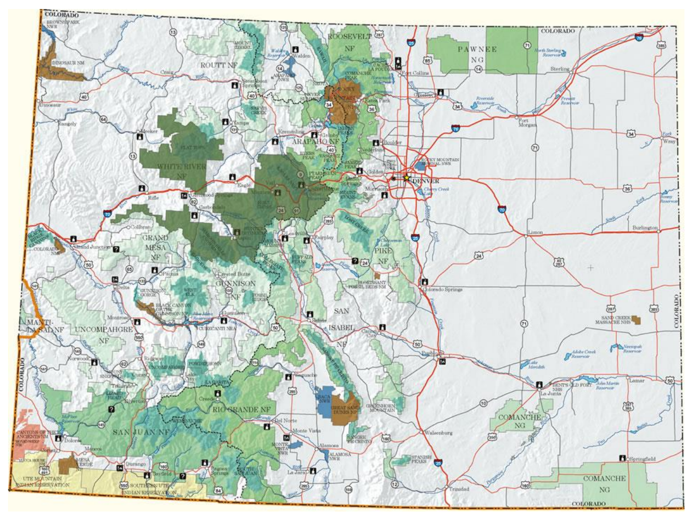

Figure 2: Map of Colorado with the White River National Forest shown in dark green. Retrieved from https://www.fs.usda.gov/detail/r2/recreation?cid=stelprdb5387861.

Data Collection

I obtained pika occurrence data through the Front Range Pika Project (FRPP; Front Range Pika Project, 2020). The pika occurrence data were compiled from a variety of sources which included recent observations of pika from FRPP volunteers and staff, Colorado Parks and Wildlife, and historical pika observations from various sources from the Global Biodiversity Information Facility (Front Range Pika Project, 2020). This pika occurrence dataset included if pika were present or absent, the location of the pika observation (latitude and longitude), and how pika were observed. The dataset contained 380 records of pika occurrence and absence dating back to the 1930's. However, I omitted data collected between 1930-1980 (67 data points) from this study due to the lack of environmental variable data for this time period, and because the goal of this study was to determine current pika distribution in the WRNF. The remaining 313 points were collected between 1980-2019.

I collected environmental variables data from the United States Department of Agriculture's Geospatial Data Gateway (GDG; USDA, 2016). To acquire these variables, I selected the Colorado counties that contain the WRNF spatial extent in the GDG website and selected specific environmental variable raster maps for those specific locations. I gathered 10-meter resolution rasters of the National Elevation Dataset for elevation, and climatic variables were from the Climate PrismRaster data on the GDG (USDA, 2016; PRISM Climate Group, 2004). The climatic variables I downloaded were annual and monthly precipitation averages for Colorado between 1981 and 2010. This was the current 30-year data available for Colorado (PRISM Climate Group, 2004).

Data Manipulation Using GIS

I used ArcMap version 10.5.1 (ESRI, 2011) to clip the elevation and climatic raster data to a more appropriate spatial extent for analysis in the WRNF. I added the climate rasters for the months of November, December, January, February, March, and April together using the Raster Calculator tool in ArcMap to create a 'wet season' raster (ESRI, 2011). Subsequently, I added the remaining months, May, June, July, August, September, and October, together to create a dry season raster. I created dry and wet season rasters to assess the effects of precipitation, mainly in the form of snow, during the wet season months in Colorado compared to the drier months. Splitting precipitation this way highlights snowpack for this model, which makes more ecological sense when assessing pika and their distributions.

I utilized the elevation raster to create new rasters that contained the slope and aspect of the WRNF spatial extent. This was done by using the Slope and Aspect tools in ArcMap (ESRI, 2011). I resampled the elevation, slope, and aspect rasters using the Resample tool in ArcMap to give all environmental variable rasters the same resolution for further analysis (ESRI, 2011). I projected all rasters in the geographic coordinate system of North American Datum 1983.

Species Distribution Model

Following Hijmans and Elith (2018), I conducted a species distribution model to assess which environmental variables most influenced pika presence and to predict suitable habitat locations for pika in the WRNF extent specified through ArcMap. All species distribution model analyses were done using R version 3.6.1 (R Core Team, 2019). I loaded all rasters into R, each raster being an environmental variable used for this modeling process. These environmental variables were elevation, slope, aspect, average annual precipitation from 1981-2010 (annual precipitation), average wet season precipitation from 1981-2010 (wet season precipitation), average dry season precipitation from 1981-2010 (dry season precipitation), average annual maximum temperature from 1981-2010 (maximum temperature), and average annual minimum temperature from 1981-2010 (minimum temperature). I also loaded pika presence locations into R for the basis of this model. Pika absence data were not available, and, therefore, were randomly sampled within the WRNF extent, totaling 300 random absence points (Hijmans &

Elith, 2018). Random absence points are necessary for implementing species distribution models that require species absence data, and the 300 random absence points closely match the 313 presence points. I then extracted raster values for each pika presence and absence point to get all environmental data per pika location (Hijmans & Elith, 2018).

There are many different models that can be used to conduct a species distribution model (Hijmans & Elith, 2018). I conducted six different species distribution models, including a generalized linear model (GLM), BIOCLIM, Maxent (Phillips, Dudik, & Schapire, 2017), domain, random forest, and support vector machine. All six model types are regarded to be effective and efficient for species distribution modeling (Hijmans & Elith, 2018). I assessed models based on their Area Under the Receiver Operator Curve (AUC) score (Hijmans & Elith, 2018). Models that contain high AUC scores represent species presence predictions, low AUC scores represent species absence predictions, and scores close to 0.5 represent a random guess between species absence and presence (Hijmans & Elith, 2018). Therefore, models with high AUC scores were desired to show pika presence predictions within the WRNF extent. I used the three models with the highest AUC scores to average those models together to assess which environmental variables contribute to pika presence the most, and to create a predictive map of pika presence in the WRNF extent.

Results

Model Selection and Overall Findings

I selected and combined the Maxent (AUC = 0.92), GLM (AUC = 0.89), and random forest (AUC = 0.97) models because they had the three highest AUC scores, meaning they best predicted pika presence. I averaged and weighted the three models by AUC scores, creating a predictive map showing suitable locations pika presence (Fig. 3). All three models had minimum temperature and elevation as the highest contributing variables to the model, showing that these variables influence pika presence more than any other variable used in the species distribution models.

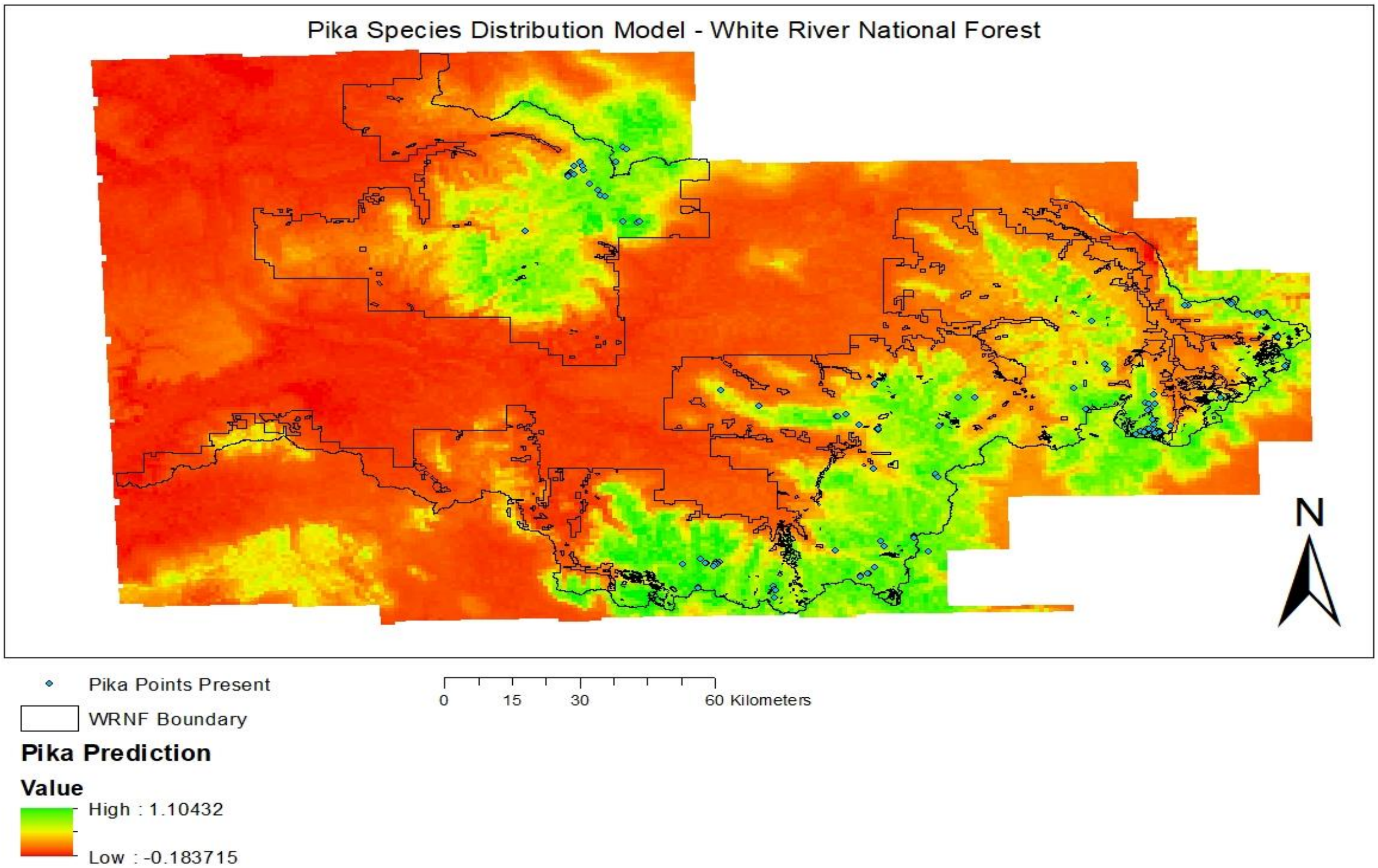

Figure 3: Predictive map of pika presence locations in the WRNF extent. Based on the combined, averaged, and weighted models: GLM, Maxent, and Random Forest. High values (green areas) indicate suitable pika locations, while low values (red areas) indicate unsuitable pika locations. The WRNF boundary is outlined in black, and pika presence locations are visualized using blue dots.

GLM Results

Table 1: Generalized linear model of pika presence as a function of environmental variables.

	Dependent variable: Pika Presence
Intercept	−2.478 (−11.720, 6.344)
Elevation	0.003*** (0.001, 0.005)
Ann. Precip	−52,544.790 (−230,005.700, 119,560.500)
Wet Season Precip	20,687.080 (−47,070.900, 90,553.600)
Dry Season Precip	20,686.520 (−47,071.490, 90,553.030)
Max Temp	−0.212 (−0.557, 0.141)
Min Temp	−0.388** (−0.722, −0.076)
Observations	490
Log Likelihood	−171.374
Akaike Inf. Crit.	356.748
Note:	*p<0.1; **p<0.05; ***p<0.01

The GLM used the binomial method where presence and absence were a function of elevation, dry and wet season precipitation, annual precipitation, minimum temperature, and maximum temperature (Table 1). The only two variables that were statistically significant were elevation (p = 0.007) and minimum temperature (p = 0.02). With increasing elevation, the probability of finding pika also increases, and with increasing minimum temperature, the probability of finding pika decreases.

Maxent Results

For the Maxent pika species distribution model, a variable contribution graph was generated to determine which variables contributed the most to model creation (Fig. 4). Elevation (~ 48%) had the highest contribution to the Maxent model, followed by minimum temperature (~ 22%) and wet season precipitation (~ 19%). This means that these three variables were most heavily used to build this model to predict where pika are located in the WRNF extent.

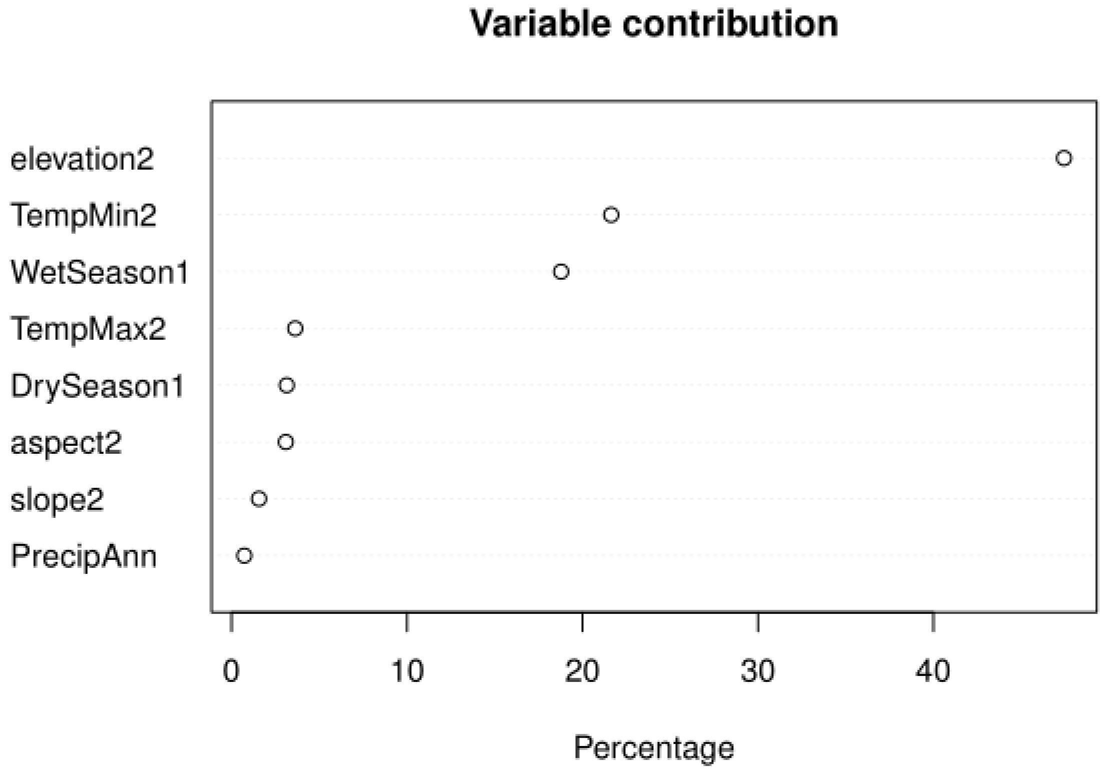

Figure 4: Maxent variable contribution graph. Higher percentages show which environmental variables contributed the most in predicting pika presence locations in the WRNF extent.

Random Forest Results

Similar to the GLM and Maxent model, the Random Forest model can be used to determine which variables contributed more to the predictive model than other variables (Table 2). Variable contribution in Random Forest models is determined by Importance Values that can be calculated from the model. Minimum temperature had the highest scoring Importance Value for this model, followed by elevation and maximum temperature (Table 2), meaning those environmental variables contributed the most to making this model.

Table 2: Random Forest Importance Values per environmental variable. High importance values indicate high contribution to the Random Forest model.

Variable	Importance Value
Min. Temp	26.87
Elevation	19.62
Max. Temp	19.51
Ann. Precip	13.57
Dry Season Precip	12.85
Wet Season Precip	12.26
Slope	8.32
Aspect	5.92

Discussion

All three models had minimum temperature and elevation as significant variables contributing to model production, indicating that pika presence in the WRNF is influenced by cold temperatures and high elevations. This partially supports my hypothesis that pika presence in the WRNF would be influenced by minimum temperature, elevation, and wet season precipitation.

In the GLM, elevation and minimum temperature were the only two significant variables in the model. With increasing elevation, the probability of finding pika also increased. For minimum temperature, the relationship was inverse of that with elevation, meaning that with increasing minimum temperature, the probability of finding pika decreases. With the Maxent model, elevation, minimum temperature, and wet season precipitation had the highest variable contribution to this model, in that order. The third model used to create the predictive map, Random Forest, had minimum temperature, elevation, and maximum temperature as the highest contributing variables for the model.

The Maxent model had wet season precipitation as a highly contributing variable to model production. Precipitation as an influencing variable of pika presence makes ecological sense but was not supported by all three models (Erb et al., 2011). Additionally, the Random Forest model had maximum temperature as a highly contributing variable, but this showed where pika would not be located. Maximum temperature, therefore, is correlated with pika absence. All three models, however, relied on elevation and minimum temperature more than the other environmental variables to predict pika distribution in the WRNF. In the WRNF, pika are thus most heavily influenced by elevation and minimum temperature, such that these pika will be found in high elevation sites that have low minimum temperatures. Therefore, these pika follow distributions and suitable habitat locations that are typical for pika across western North America (Erb et al., 2011; Jeffress et al., 2013; Beever et al., 2016). Since pika presence in the WRNF relies on cold temperatures and high elevations, there is potential for these pika to be threatened by impending impacts of global climate change (Erb et al., 2011; Yandow et al., 2015).

Previous research on pika throughout western North America has shown that some pika populations may be adaptable to climate change (Varner & Dearing, 2014; Smith & Nagy, 2015). Pika populations in California have been found to inhabit low elevation areas and alter their diet to their new environment (Varner & Dearing, 2014; Smith & Nagy, 2015). However, since pika in the WRNF rely on cold temperatures and high elevations, it is not likely that they will adaptable to climate change. Therefore, pika in the WRNF will be good indicators of climate change impacts (Jeffress et al., 2013; Beever et al., 2016). This also means that WRNF pika should be monitored carefully to ensure population extirpations do not occur. The predictive map created will help wildlife managers effectively locate pika habitat to conserve and protect to benefit pika populations.

With forthcoming impacts of climate change, we can predict that pika populations throughout western North America may become extirpated (Beever et al., 2016). Atypical pika populations that seem more adaptable may proliferate through climate change impacts, but that is unknown depending on the severity of climate impacts (Varner & Dearing, 2014; Beever et al., 2016). Therefore, future pika research should create comprehensive SDMs to better understand the environmental variables influencing pika presence and where pika may be located at a local scale. The findings and methods of this study can be used for future studies on local pika populations in the WRNF, Colorado, and the western part of North America. Additionally, future research on pika should include vegetation, forage quality, and talus slope area as environmental variables in an SDM. Vegetation and talus slope area have been proven as important factors for pika presence in past research and could help build a more complete SDM for the WRNF and elsewhere (Varner & Dearing, 2014; Beever et al., 2016).

Since pika are considered a good indicator species of climate change, we will be able to use future monitoring and research to determine the extent of global climate change (Erb et al., 2011). For example, if we are to see pika populations in the WRNF move upward in elevation to seek colder temperatures and preferred forage, that indicates climate change may be altering the landscape and ideal pika habitat. It is important to remember that pika populations already at high elevations will only be able to migrate upslope so far before they run out of room and habitat (Galbreath et al., 2009). Also, pika being vulnerable to climate change allows us to assess the global climate crisis and see if the situation is improving or not (Galbreath et al., 2009; Vanneste et al., 2017). If high elevation pika populations are disappearing, then we know that efforts to combat climate change are not sufficient (Galbreath et al., 2009).

Conclusion

Overall, these findings will help benefit wildlife managers in the WRNF by helping them understand where suitable pika habitat is located in the WRNF and what environmental variables influence pika presence. Pika presence in the WRNF is influenced by elevation and minimum temperature as seen through the three SDMs, showing that these pika prefer cold temperature, high elevation habitats. Therefore, WRNF pika prefer typical pika habitats compared to unusual pika populations previously studied that inhabit low elevation areas (Varner & Dearing, 2014; Smith & Nagy, 2015). Since WRNF pika are limited to areas with cold temperatures, they will be a good indicator species in regard to climate change impacts (Galbreath et al., 2009; Beever et al., 2016). Monitoring pika populations in the WRNF, along with temperature and elevational shifts, will be necessary to ensure pika are not being detrimentally impacted by climate change and are not threatened by extirpation. The predictive map created in this research will allow managers to pinpoint suitable habitat locations for pika in the WRNF and focus conservation efforts in those areas. Increasing attention given to pika in the WRNF and throughout western North America via research and conservation actions will hopefully save this species from going extinct due to climate change.

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CHAPTER 4.

Resolving Refugee-Elephant Conflict in Bangladesh via Education and Rebuilding

Introduction

For decades, Rohingya Muslims have lived in Myanmar and have been subject to what the United Nations calls “ethnic cleansing” (Ullah, 2011; Daly, 2018). The Rohingya Muslims have been persecuted by the Myanmar government by being attacked, murdered, raped, and forced to flee the country (Ullah, 2011; Daly, 2018). Fortunately, the neighboring country of Bangladesh has been a place of refuge for the Rohingya Muslims (Ullah, 2011). One refugee camp, the Kutupalong refugee camp, was built in the middle of an Asian elephant (*Elephas maximus*) migration corridor (Daly, 2018). This is a concern because human-elephant conflict has led to the deaths of 13 refugees and blocking the migration corridor can detrimentally impact the elephants (Daly, 2018). This issue is even more concerning considering that the Asian elephant is listed as endangered by the International Union for Conservation of Nature’s (IUCN) Red List (Choudhury et al., 2008). Therefore, a comprehensive solution is needed to satisfy all stakeholders involved in this problem and to protect the Asian elephant from further population decline. Overall, the refugees need a new camp to better their living conditions, and while the refugees remain at the current Kutupalong camp, fencing around the camp, along with educating the refugees about how to deal with elephant conflicts, will help minimize human-elephant conflict. This comprehensive action plan will protect all involved in this situation.

Background Information

Rohingya Muslim Refugee Camps

Going back to the 1970's, the Myanmar government has discriminated against the Rohingya Muslims, and these people have found refuge in the neighboring country of Bangladesh for years (Ullah, 2011). Many Rohingya people still currently live in the Rakhine, or Arakan, state of Myanmar, and are in danger of being raped or murdered and having their homes destroyed (Ullah, 2011; Milton et al., 2017; Daly, 2018). Therefore, many people are still fleeing to Bangladesh for refuge from this ethnic cleansing; in 2017, over 600,000 Rohingya Muslim refugees arrived in Bangladesh (Daly, 2018). To account for this large influx of refugees, multiple camps have been built in Bangladesh to house them (Daly, 2018). Unfortunately, many of these refugee camps have destroyed natural habitat for a variety of wildlife, and some have blocked off crucial Asian elephant migration corridors (Daly, 2018). Consequently, since 2016 the resulting human-elephant conflict has endangered both humans and elephants (Daly, 2018). 13 humans have been killed and human retaliation against elephants in the form of hunting and injury has escalated (Daly, 2018).

Asian Elephant Life History Characteristics and Background

Asian elephant home ranges can be expansive, with female home ranges exceeding 300 km^2 and males exceeding 400 km^2 (Choudhury et al., 2008). Unfortunately, the overall geographic range and home ranges of these elephants, along with their populations, are decreasing due to habitat loss, degradation, and fragmentation (Sukumar, 2006; Choudhury et al., 2008; Islam et al., 2011). The main cause of habitat loss is deforestation for logging, agriculture, and livestock farming (Choudhury et al., 2008; Islam et al., 2011). Other causes of elephant population declines include hunting and human-elephant conflict (Choudhury et al., 2008; Islam et al., 2011). Asian elephant migration corridors are important to travelling elephants in order to find new food sources and mating opportunities (Joshi & Singh, 2008). Without these corridors, elephants will not be able to travel to new locations to mate with new elephants to diversify the gene pool (Joshi & Singh, 2008). Loss of corridors also disconnects the elephant habitat, threatening to degrade the large geographic and home ranges that thriving elephant populations require (Joshi & Singh, 2008; Daly, 2018).

Between 300 to 350 Asian elephants occur in Bangladesh, 200 of which are resident elephants, with the remainder migrating through the country at any given time (Islam et al., 2011). Over the past decade, elephants in Bangladesh, especially migrating, or trans-boundary, elephants, have become increasingly threatened as their migration routes have been disrupted by habitat loss and physical borders around countries (Islam et al., 2011). Near the Kutupalong

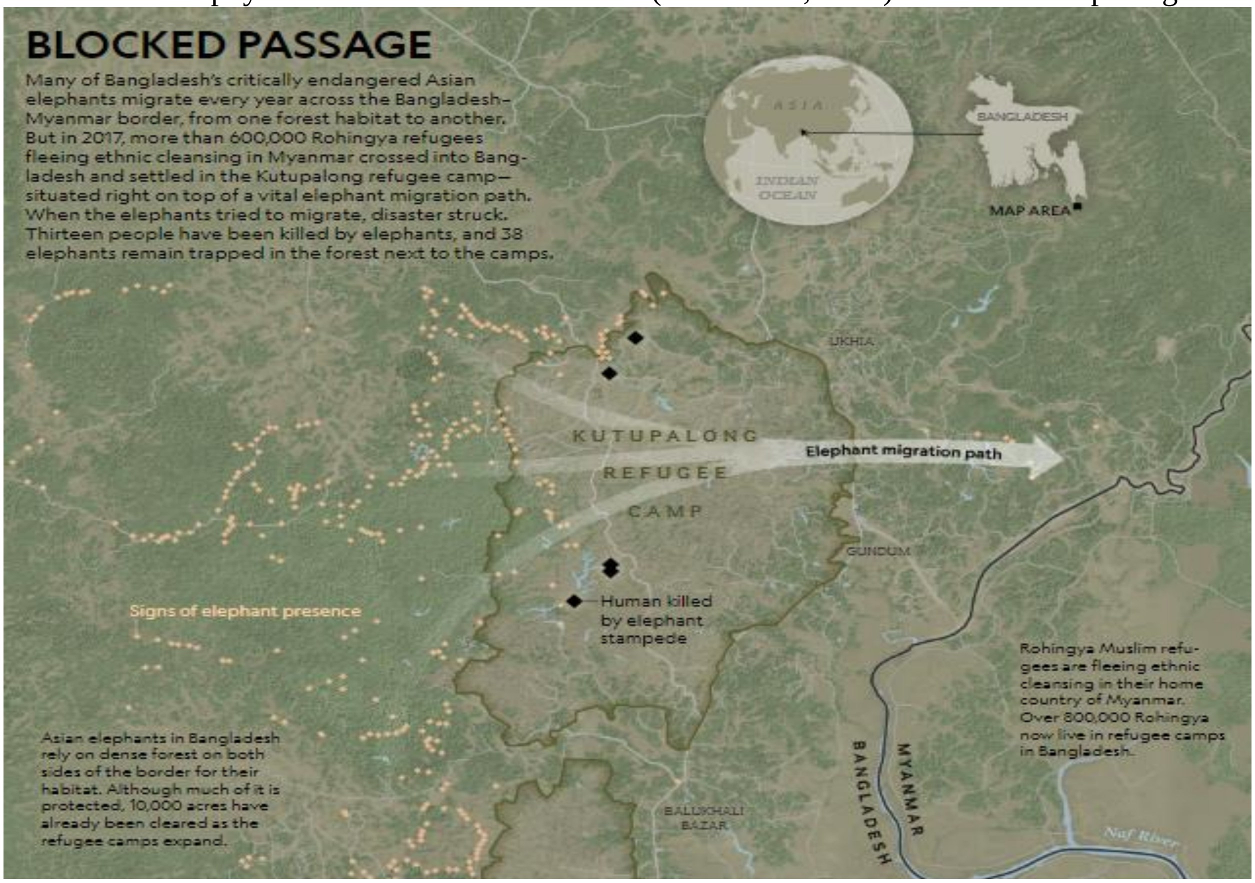

Figure 5: The Kutupalong refugee camp outlined with the elephant migration corridor shown. Retrieved from https://www.nationalgeographic.com/animals/2018/11/rohingya-refugee-crisis-elephants-bangladesh/.

refugee camp, migrating elephants move from the eastern, interior of the country toward the western part of the country and into Myanmar (Daly, 2018; Fig. 1). The ideal solution for these elephants would be to restore the migration corridor to its former condition, but any form of corridor restoration would help the conservation of this species.

Stakeholders

Kutupalong Refugee Camp

As of 2018, over 600,000 Rohingya Muslim refugees have come to Bangladesh to seek refuge in the Kutupalong refugee camp (Daly, 2018). Refugees will likely remain in this camp indefinitely because the social unrest in Myanmar is unlikely to subside anytime soon, and Myanmar's government has fenced off its border to ensure no one leaves or enters the country (Daly, 2018). Additionally, refugee camps provide poor living conditions, for they do not have adequate food supplies, health care, and housing (Ullah, 2011; Milton et al., 2017). In late 2017 and early 2018, 5 refugees have been trampled to death by elephants since the construction of the Kutupalong camp (Daly, 2018). Luckily, due to a joint effort between the IUCN, the United Nations High Commissioner for Refugees (UNHCR), and the Rohingya refugees themselves, human deaths from elephants have ceased because the refugees were educated on the issue and created a team to help mitigate conflict in March 2018 (Daly, 2018). This 'task force' is made up of 500+ refugees who manage 90+ watchtowers that overlook the borders of the camp and deter elephants from entering the camp by using spotlights and making noise (Daly, 2018). However, because these watchtowers do not adequately cover the Kutupalong camp boundary, this method does not guarantee that conflict will not occur (Daly, 2018). Ideally, refugees in the camp desire better living conditions, less frequent conflict with elephants, and staying where they are now (Milton et al., 2017; Daly, 2018).

Myanmar and Bangladesh Governments

Unfortunately, conflicts in Myanmar are unlikely to be resolved within the foreseeable future unless strong diplomatic actions are taken soon (Ullah, 2011). Since there is a history of discrimination and social unrest in Myanmar, many refugees may not return for fear of continued discrimination and violence (Ullah, 2011; Milton et al., 2017). Although resolving issues in Myanmar would solve the refugee crisis in Bangladesh, that resolution would be complicated and beyond the scope of this paper. For this reason, actions that can more directly limit human-elephant conflict should be explored.

On the other hand, the Bangladesh government has supported both refugees and elephants throughout this crisis. Although the Bangladesh government has dealt with this ethnic cleansing issue since the late 1900's, a formal governmental policy for protecting refugees was not proposed until 2014 (Milton et al., 2017). This policy provides basic humanitarian relief for refugees, registers and tracks all refugees, strengthens the borders of the country, and devises diplomatic initiatives with Myanmar (Milton et al., 2017). Therefore, the Bangladesh government is more than willing to help the Rohingya Muslim refugees. At the same time, the Bangladesh government also wants the best protection for the elephants that reside within its borders (Islam et al., 2011). The Bangladesh Conservation Act of 1974 protects all wild elephants in the country by imposing are harsh penalties for any wild elephant hunted, killed, or captured (Islam et al., 2011). Bangladesh also has a variety of game reserves and wildlife sanctuaries throughout the country to help a variety of wildlife including elephants (Islam et al., 2011). The government of Bangladesh is thus dedicated to ensuring that both the refugees and wildlife are protected.

Conservation Organizations and Other Governmental Agencies

Two important international organizations involved in this issue are the IUCN and the UNHCR, both of which have helped limit human-elephant conflict in the Kutupalong camp and elsewhere in Bangladesh (Milton et al., 2017; Daly, 2018). The IUCN has a specialized team in Bangladesh (IUCN-Bangladesh) to protect the country's wildlife and natural landscapes (Islam et al., 2011). The IUCN-Bangladesh has its own team of Asian elephant experts who monitor and research the wild elephant population in Bangladesh and help mitigate human-elephant conflict (Islam et al., 2011). This IUCN-Bangladesh team continues to help educate the people in the refugee camps on elephants and how to deter elephants away from camp (Daly, 2018). The main goal of the IUCN-Bangladesh is to maintain the elephant migration corridor that protects local elephant populations (Islam et al., 2011; Daly, 2018).

The UNHCR is an international governmental agency that advocates for refugees around the world and has been consulting with the Bangladesh government on the Rohingya Muslim refugee situation (Ullah, 2011; Milton et al., 2017; Daly, 2018). The UNHCR has been informing, guiding, and assisting the government of Bangladesh to provide adequate housing and other resources for the refugees (Milton et al., 2017). However, the Bangladesh government still does not provide satisfactory conditions for the refugees, and the UNHCR has been monitoring and assessing the situation closely to better help the Bangladesh government provide resources for the refugees (Milton et al., 2017). Currently, the UNHCR has cooperated with the IUCN-Bangladesh to find solutions to the refugee-elephant conflict in the Kutupalong camp (Daly, 2018). Additionally, the UNHCR collaborates with Bangladesh's government to set up refugee camps and produce stronger governmental policies that protect refugees (Milton et al., 2017).

Proposed Solution

An effective solution to this issue involves multiple steps to satisfy all stakeholders and ensure the protection of the Asian elephants. The overall goal of this solution is to create a new refugee camp for the Rohingya Muslims that will provide better opportunities for housing, resources, and medical care. Building a new camp creates an opportunity to situate the camp outside of elephant migration corridors where environmental damage is less likely. Creating a new refugee camp will also eliminate the need for the Kutupalong camp, which will open the migration corridor for the elephants to travel safely. However, creating a new camp and moving Kutupalong camp residents will take time, roughly 1-2 years, so other measures to ensure elephant and human safety will be needed in the meantime.

While the refugees continue to inhabit the Kutupalong camp, improving education on elephants will help the refugees better understand why the elephants need the migration corridor and how to protect themselves against any conflict with the animals (Islam et al., 2011; Daly, 2018). The Kutupalong elephant task force should continue to watch over the community, deter elephants, and teach others why elephants need migration corridors (Daly, 2018). Educating others will help all refugees understand why it is important to leave for a new camp and what to do if they encounter an elephant. Additionally, to minimize adverse effects of elephants on the refugees, fencing in combination with other elephant deterrents like beehives should be employed (Nair & Jayson, 2016; King et al., 2018). Since the Kutupalong camp has a large perimeter, building a fence around the camp will relieve elephant task force workers from monitoring the boundary at all times. Furthermore, beehives have been used to discourage Asian and African elephants from entering villages and destroying human-made structures and crops (Nair & Jayson, 2016; King et al., 2018). These beehives would be placed intermittently around the border of the camp; only a limited number of beehives would be feasible because of the maintenance they require and the large size of the refugee camp perimeter. However, the limited number of beehives in conjunction with the fencing will deter elephants and help keep the refugees and elephants safe. Moreover, the elephant task force can be educated on maintenance of beehives and fencing, which will give them additional purpose in ensuring the protection of all.

Once the refugees have left the Kutupalong camp for a new refugee camp, deconstruction of the camp can begin. Hopefully, this process will not take long, and the elephant migration corridor can return to pre-refugee camp conditions. Eliminating this camp will be the best way to restore the migration corridor. Additionally, this will lead to opportunities for the Bangladesh government, IUCN-Bangladesh, and other conservation organizations to restore the deforested area which will help create and protect habitat for a variety of species in addition to the Asian elephant. The IUCN-Bangladesh could then monitor the area and the elephants to make sure populations are stable in the country.

The government of Bangladesh will need to continue working with the UNHCR to better provide resources for the Rohingya Muslim refugees (Milton et al., 2017). Over the years, many of the refugee camps in Bangladesh have not had adequate housing, food, and healthcare resources (Ullah, 2011; Milton et al., 2017). Therefore, increased support from the UNHCR to the Bangladesh government should improve living conditions at new refugee camps. This will also allow the Bangladesh government to bolster governmental policies on refugees and create a more manageable refuge system for all parties involved (Milton et al., 2017). Additionally, the government of Bangladesh and the IUCN-Bangladesh can work together to find a suitable location for this new camp where minimal environmental and elephant disturbance will occur (Islam et al., 2011).

Conclusion

Unfortunately, the conflict between Rohingya Muslims and the government of Myanmar will not subside anytime soon (Milton et al., 2017; Daly, 2018). Luckily, Bangladesh has been taking in refugees for years to protect them from further harm in their home country (Ullah, 2011; Milton et al., 2017). Refugee camps have destroyed habitat for many species and have blocked crucial Asian elephant migration corridors (Islam et al., 2011; Daly, 2018). Given the human-elephant conflict at the Kutupalong refugee, a plan is needed to eliminate this conflict to prevent the loss of both human and elephant life. Creating a new and improved refugee camp for these Rohingya Muslims, where elephants and ecosystems will be minimally harmed, will not only better living conditions, but also restore the former migration corridor to what it once was. While refugees still live at the Kutupalong camp, educating refugees on Asian elephants and elephant deterrents like fencing and beehives will guarantee safety for all involved. This comprehensive action plan will also help other camps in the country find safe, efficient solutions to any wildlife-human conflict.

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