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MS Environmental Biology Capstone Project

Ryan Lee

MS ENVIRONMENTAL BIOLOGY
CAPSTONE PROJECT

by

Ryan S. Lee

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Ryan S. Lee

has been approved

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APPROVED:

____________________________________, John Sakulich, Ph.D. (Faculty Advisor)

____________________________________, Kristofor Voss, Ph.D. (Chapters 1 & 2)

____________________________________, Michael Ennis, Ph.D. (Chapter 3)

____________________________________, Anna Braswell, Ph.D. (Chapter 4)

____________________________________, Ariel Wooldridge, M.S. (Exit Survey & Repository)

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Introduction

Anthropogenic influences have introduced point source and non-point source pollution into our watersheds. Common point source and non-point source pollutants include sediments, household and industrial chemicals, and heavy metals (copper, lead zinc, etc.). Point source pollution derives from one source like a pipe, whereas nonpoint source pollution originates from various sources that are harder to identify (Polluted Runoff, 2018). Though heavy metals are found naturally in our watersheds in low concentrations and are essential for all organisms, they alter the toxicity and pH of water when found in higher concentrations (Zengchao et al., 2018). One way to regulate heavy metal concentrations is by controlling the pollutants that stormwater delivers to watersheds. Stormwater runoff collects heavy metals by moving across paved surfaces and collecting pollutants that rest on top of the pavement. To mitigate heavy metal pollution in watersheds, it is necessary to focus on those best management practices (BMPs) that are most effective for stormwater control in terms of heavy metal retention while considering the environmental context that may affect their efficiency. The primary objective of this review is to perform a comprehensive assessment of the most effective BMPs for heavy metal retention in stormwater runoff.

Understanding the characteristics of heavy metals leads to more effective strategies for their removal by matching the BMPs that are the best fit for different characteristics. In particular, heavy metals are found in both the aqueous and particle bound phases in stormwater runoff (Vezzaro et al., 2012). The distribution of heavy metals between these two phases within stormwater influences the degree to which they can be controlled by BMPs. Heavy metal sorption rates are not only determined by their phases (particulate and dissolved), but are also influenced by flow rates into the BMP. Understanding these characteristics (heavy metal phases and flow rates) of the expected stormwater runoff allows managers to accurately design BMPs to improve their sorption effectiveness.

To manage stormwater runoff, (design of BMPs) has been informed by trial and error processes, experimental results, and historical knowledge to manage stormwater runoff. The goals of BMPs are to route stormwater runoff to a desired direction and to remove pollution before it reaches receiving waters. Various BMP designs aid in pollution control and heavy metal sorption through chemical (e.g. chlorine disinfection), physical (e.g. filtration), and biological (e.g. plant uptake), processes (Büyüksönmez & Beighley, 2012). The most common BMP designs include retention ponds, retention basins, wetlands, vegetated swales, infiltration basins, etc. The need for different controls comes amidst the different types of heavy metals on the stormwater, their phase, and the influent flow rate. These factors are explicitly linked to the sources of heavy metals. Heavy metal sources include roadways, neighborhoods, agriculture, parking lots and urban settings. There is a need for effective BMPs as urban environments continue to increase the input of heavy metals in stormwater runoff.

BMPs use a combination of filtration and sorption processes to remove heavy metals from polluted stormwater runoff. Filtration uses a barrier to physically extract the particulates from the polluted stormwater. In contrast, sorption is the combination of absorption and adsorption (Büyüksönmez & Beighley, 2012). Adsorption is the chemical process that bonds molecules together, in BMPs it chemically extracts the heavy metals from the polluted stormwater (Büyüksönmez & Beighley, 2012). Both processes are performed in BMPs to retain heavy metals from stormwater runoff. The degree to which the BMPs use both filtration and sorption processes depend on the characteristics of stormwater

The characteristics of the stormwater dictate which BMPs are suited best for a particular situation. The methods involved in stormwater retention include analyzing the flow of stormwater and the phases in which heavy metals are found. Retention ponds are the most effective for removing particulate bound heavy metals in slower flowing stormwaters. In contrast, vegetated swales are more efficient for removing dissolved heavy metals from faster flowing stormwaters. To increase the sorption rates of heavy metals in these BMPs, engineered supplements like vegetation, permapave, and filters that use sand and crushed concrete can enhance heavy metal retention under certain conditions.

Managing Flow Rates and Particulate Phases

Non-porous surfaces, that make up roads and paved surfaces (i.e. asphalt and concrete) allow for stormwater runoff to build momentum and increase its flow rate. The flow of stormwater creates a problem as it entrains the non-point source pollutants along its path, and ultimately delivers it to the nearest waterway. Slowing down the flow of stormwater runoff is necessary for the efficiency of heavy metal sorption in BMPs. BMPs seek to restrict the flow of stormwater to control its eventual input into the waterbody. To do this, BMPs use barriers such as vegetation, porous materials, and other boundaries (e.g. concrete structures) to reduce flow rates. Heavy metals are found in higher concentrations at the outlet of many BMPs because the flow rate is so high that there is sufficient time for the BMP to process stormwater (Zhang & Deletic, 2018). As the flow rate increases so does the amount of heavy-metals that need to be processed, and therefore most of the heavy metal load is not completely absorbed. Particle-bound heavy metals further decrease the ability of a BMP to sorb heavy metals because they can clog filters or impede the materials used to sorb heavy metals.

Stormwater BMP designers must know how heavy metals partition between aqueous and particulate phases because certain BMPs are more suitable at removing particulate bound heavy metals, but allowing the dissolved fraction to pass through. Two ways to estimate sorption rates for particulate and dissolved heavy metals in stormwater runoff include flexible dynamic models and a Stormwater Treatment Unit Model for MicroPollutants (STUMP) (Vezzaro et al., 2012). Both models assess the outflow of a BMP and the discharged stormwater by breaking down stormwater into hydrological losses, particulates, and dissolved phases. The flow rate is gauged to measure the amount of time it takes for a system to retain the heavy metals and what heavy metal load amount is most optimally retained (Vezzaro et al., 2012). Retention ponds removal efficiency for copper and zinc during inflow rates of 1.5 l/s was 80.5% and 32.9% for inflow rates of 13 l/s. Biofilters removal efficiency for copper and zinc during inflow rates of 1.5 l/s was 39.5% and 78.7% for inflow rates of 13 l/s (Vezzaro et al., 2012). Thus, retention ponds are more effective at removing heavy metals from lower velocity stormwater runoff, while biofilters are more effective at high velocity heavy metal removal. Essentially this model can be used to estimate the metal removal efficiency of BMPs, and how the efficiency depends on flow rate and phase. Using these methods have helped understand the BMPs best suited for removing particulate versus dissolved heavy metals.

As previously mentioned, retention ponds are found to be the most effective BMP for sorption of slow-moving soluble heavy metals (Vezzaro et al., 2012). For that reason, retention ponds are often built near larger construction projects, parking lots, or at the crossroads of vegetated swales. Their overall purpose is to permanently or semi-permanently pool all of the stormwater runoff in one area. Unlike other BMPs where stormwater quickly flows through the system, a retention pond stores the stormwater run-off for a longer period of time. This allows for sedimentation and deposit in heavy metal particulates to occur (Jane, 2004). Studies have demonstrated the significant impact retention ponds have on the sorption of heavy metals (copper, zinc and lead) by comparing the input and output of stormwater runoff (Muthukrishnan, 2010). The stormwater at both locations is measured for concentrations of heavy metals and compared to show that retention ponds had a removal efficiency of 80.6% for Cu, 100% for Pb, and 68.7% for Zn. Not only do retention ponds tend to absorb slow moving soluble heavy metals but are desired for the volume of stormwater they can process and their relatively low maintenance making them ideal to combine with other BMP types.

In contrast, dealing with both faster flowing larger volumes and higher heavy metal content stormwater presents a considerable problem. Higher stormwater velocities and heavy metal contents occur closer to urban structures (e.g. highways) (Maniquiz-Redillas & Kim, 2016). In these conditions, it is necessary for the stormwater to be channeled toward a much larger BMP. Vegetated swales are better suited to control the faster flowing stormwater flow while retaining as much of the pollutants as possible. Vegetated swales are often used as a roadside BMP as the topsoil acts as a sponge that absorbs the maximum quantity of stormwater possible. The heavy metals that absorb into the soil are then broken down through chemical processes such as complexation (Horstmeyer et al., 2016). Vegetated swales handle a certain capacity of stormwater flow, but once stormwaters rise above vegetation, the BMP is no longer capable of performing its primary function (Gülbaz et al., 2015). To test vegetated swales, 1000-gallon rain tanks were used in to simulate high velocity (200-250 mm) surface runoff scenarios determining the most effective size (Maniquiz-Redillas & Kim, 2016). Vegetated swales are most effective when set to a minimum volume of 0.55 ac-ft. per acre to control high velocity flooding from large built areas.

A major contributor to the anticipated flow rate is the anticipated rainfall. Climatological data allow managers to design for average rainfall expectations. Various types, sizes, and shapes of BMPs have been compared in order to determine the approximate capacity of rainfall a BMP can effectively process. Guidelines used in California were found to alter their sizing parameters (e.g. BMP dimensions, filter sizes) and soil type based on their expected rainfall (Ambrose & Winfrey, 2015). When the California guidelines were compared to those used in Southeast Australia that received far less rainfall, they were found to be much larger. The results show that increased rainfall amounts determine the construction size of the BMP needed for the environment.

Selecting the Effective Materials

Designing a BMP requires selecting the proper materials that have the best qualities for heavy-metal sorption. In dry ponds and environments where evaporation rates are higher, the selection of materials is not a factor because the flow rate is close to zero (Sønderup, 2015). In climates that are humid or receive higher rates of rainfall, proper choice of materials selected for BMPs are necessary to decrease flow and increase sorption rates. Flow is typically decreased by increasing friction through the texture and size of the materials in the BMP. Some of the more frequently used materials by the National Cooperative Highway Research Program (NCHRP) to support BMPs are vegetation, sand, and concrete (Sønderup, 2015). Though many sources are used, these materials provide the most effective combination of sorption and stormwater flow dampening. The BMP designers have a plethora of options because they can utilize different combinations of materials to see which ones provide the most efficient sorption for the low rates they encounter.

Vegetation as a BMP material increases sorption and filtration to the BMP, and is beneficial (e.g. moderating water temperature, improving habitat for wildlife) to the surrounding environment. Vegetation and vegetative soil are often used to increase sorption by decreasing the volume and flow of stormwater. Vegetation has several different functions including slowing down the flow of stormwater, enhancing uptake of heavy metals by the vegetation, and enhancing infiltration. Vegetation takes up the stormwater into its roots and transports it through the plant. The type of vegetation is typically chosen by selecting particular plants that enhance the sorption of the system in which they are placed but that also require less maintenance (Büyüksönmez & Beighley, 2012). Using vegetation as a barrier to water flow gives the soil and surrounding media time for sorption processes to occur. Lastly, vegetation prevents erosion of the surrounding soil reducing the chance that pollutants on the riparian zone banks will further contaminate water quality.

Sand filters also provide a coarse base material for any BMP. Sand is used in two different ways in BMPs. First, sand filters are used to line the beds of retention ponds and other BMPs to increase sorption rates by offering a larger surface area particulates can adsorb (Sønderup et al., 2015). Second, sand is often mixed with other filter media like charcoal in order to adsorb both particulates and dissolved heavy metals (Jane, 2004). Sand is a common material selected for filtration technology because it is able to remove a variety of different heavy metals.

Crushed concrete is another material that is used in wet retention pond filters because of its ability to sorb heavy metals (P, Ni, Cu, Cr, and Cd). Sønderup et al., 2015 compared the effectiveness of crushed concrete and sand to each material individually. In the wet pond phosphorus was absorbed only by the combination filter rather than the two filters separately (retention rate for combined filter 75-90%). The crushed concrete was more efficient at removing all of the heavy metals (except lead) analyzed in this study (Sønderup et al., 2015). Crushed concrete provides the additional benefit of not getting clogged as easily over time. Clogging of filters can back up a system creating a buildup of heavy metals settling near the outflow and rendering it useless. When a combination of materials is used, the qualities from each individual material are merged providing a more efficient method for the removal of heavy metals in stormwater.

Once the materials for filters are chosen it is imperative to select construction materials that provide similar heavy metals sorption qualities. Materials have been tested not only for use in BMPs but also at the pollution source (e.g. parking lots, roadways, etc.) of heavy metal build up. Different types of porous pavements remove particulate bound heavy metals, like lead (Pb), aluminum (Al), and iron (Fe). The construction materials that are commonly used for their long-term heavy metal removal are porous asphalt, hydrapave, and permapave. Zhang & Deletic (2018) tested these three pavement types for their heavy metal removal rates (Pb, Al, Fe, Cu, Zn). Out of the porous pavements studied, permapave (90% overall removal rate) removed more soluble heavy metals compared to porous asphalt (40% overall removal rate) and hydrapave (61% overall removal rate) (Zhang & Deletic, 2018). This implies that using a combination of different construction materials is not better at sorption. Instead, using permapave by itself had the highest heavy metal removal rate.

Combining Effective BMPs and Materials

Selecting the proper BMP based on the environmental conditions and combining those methods with the proper materials helps adjust for the variability in stormwater flows.

Unpredictable stormwater demands a BMP system that considers flow rates and particulate phases. Retention ponds are the best method for removing soluble heavy metals from stormwater. However, retention ponds were found to have lower sorption rates when used alone compared to when they were used in sequence with other BMPs (Kantrowitz & Woodham, 2005). Different filters, materials and other systems used alongside retention ponds improve their overall performance. Retention ponds are commonly used in conjunction with cattail wetlands or following a series of biorention cells. When retention ponds were combined with cattail wetlands they were found to effectively sorb particulate bound heavy metals compared to being stand-alone systems (Muthukrishnan & Selvakumar, 2007). Vegetation is necessary for any BMP to decrease flow rate, increase sorption, and improve biochemical processes. Vegetated swales proved to be the more efficient BMP for a faster flowing stormwater runoff. Using vegetated swales will slow down the higher velocity stormwater runoff before it reaches the retention pond. The ideal BMP uses vegetated swales closer to stormwater collection points that flow towards BMP filters lined with sand and crushed concrete before they reach the retention pond. The retention pond will be constructed with permapave and lined with native vegetation (e.g. Poaceae, Typhaceae).

Conclusion

In conclusion, this literature review examined the factors that influence the efficiency of stormwater BMPs in metal retention. The two most important characteristics of stormwater that need to be examined before selecting a BMP are the flow rates and phases of heavy metals. Using retention ponds for slower particulate bound heavy metals while using vegetative swales for faster flowing stormwaters with dissolved heavy metals provide the most effective approach for handling the various types of stormwater. To enhance the sorption qualities of the selected

BMP, several supplements can be considered including vegetation, permapave building materials, and filters that use sand and crushed concrete. By selecting the proper method and using a combination of materials that have better sorption qualities, stormwater managers can more effectively handle the multiple variables of stormwater runoff. Appropriate selection methodology provided the best solution for handling the increased heavy metal input from urban environments. The different characteristics of a combined BMP expands the sorption potential of an increased heavy-metal load.

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CHAPTER 2. GRANT PROPOSAL: MORPHOLOHICAL DIFFERENCE AMONG COLORADO PIKAS AT DIFFERENT ELEVATIONS IN RESPONSE TO CLIMATE CHANGE

Abstract

Conservation of American pika (*Ochotona princeps*) in the Colorado Rocky Mountains not only protects an indicator species, but also preserves alpine ecosystem functions. The American pika is a montane mammal species of specific concern in Colorado because its sensitive habitat is threatened by climate warming. Boulder County Parks and Open Space (BCPOS) has limited information on American pika elevation locations across the Rocky Mountains, and how habitat declines affect this species. However, the degree to which climate change may be influencing pika to move to higher elevations in the Front Range is unknown. If pika have moved to higher elevations, lower oxygen concentrations will result in a decrease in body size, whereas if they have failed to move then increases in average temperature will also decrease their body size at lower elevations. This study investigates both of these hypotheses. Therefore, I propose to use museum records of pika occurrence to model its current and historical distribution and the influence of temperature and elevation on its body size. The findings from this baseline study will aid in both conservation management plan creation for American pika and communicate the role of global influence on an alpine indicator species.

Literature Review

Climate change significantly impacts the structure and function of alpine ecosystems (Yoccoz et al., 2011). Alpine and mountain ecosystems are vulnerable to global climate change because they rely on temperatures in a narrow range. Higher annual temperatures result in decreases in snow depth and an earlier snowmelt (Yoccoz et al., 2011). Over the past three decades, snowfall decreased by 9%, while the day of snowmelt started earlier by 4 days per decade (Wipf et al., 2009). Snow depth, shifting snowlines, and snowmelt timing directly impacts the growing season and the organisms that live in alpine habitats. In this study, I will assess how climate change affects morphological traits and lifespan of an alpine mammal, the Colorado pika (*Ochotona princeps*).

To determine the ecological effects of climate change at the population level, indicator species are frequently monitored (Erb et al., 2011). Indicator species are sensitive to environmental change and give ecologists early warning of the ecological effects of climate change. Good indicator species often help determine the level of stress an ecosystem faces and are representative of the presence of other species (Cheyne et al., 2016). The American pika is considered an indicator species for the effects of climate change on biodiversity, species distribution, and biogeochemical cycles in alpine systems (Shank, 2015). Additionally, the American pika is an important species to gauge the effect of climate change on species extirpation because it may forecast how other vulnerable populations in alpine ecosystems respond to climate change.

The American pika is a generalist herbivore found in the Colorado Rocky Mountains at high elevations (Erb et al., 2011). It is also a species of concern in the Colorado Rockies and is especially threatened by climate change because of the decrease in alpine habitat size. Pika live between 8,000 and 13,000 ft in elevation, 259–1,787 mm in average annual precipitation, and 2.7–16.6°C in average annual temperature (Millar et al., 2018). Alpine mammals like pika are forced to adapt to varying temperatures, by tracking colder temperature environments or by physiologically adapting to increased temperatures. Pika do not hibernate during the winter, rather they forage for vegetation during the short alpine summer to withstand harsh winter conditions (Dearing, 1997). Pika have adapted both morphologically and behaviorally in order to efficiently thermoregulate in the face of harsh winter temperatures (Smith et al., 2016). Behaviorally, pika prefer talus habitats that have plenty of places that protect them from unpredictable weather conditions and predators (Smith& Erb, 2013). Morphologically, the American pika has a thick brown-black colored coat that provides both camouflage among the rocks and warmth during the winters. How Colorado Rocky Mountain pika populations will adapt to climate change has yet to be fully described. A lack of knowledge about morphological differences on pika limits ecologist's ability to predict species responses at the population level to expected changes in climate.

Increases in annual temperatures have resulted in heat stress in pika populations that reduces foraging times (Beever, 2003). While at the same time reducing the vegetation quality of pika habitats. Consequently, American pika populations are expected to migrate to higher elevations as temperatures continue to rise, eventually causing them to lose suitable habitat (Millar et al., 2018). Climate change will force pika to migrate to higher elevations or physiologically adapt to rising temperatures; if they fail to do either, they will fail to survive. Pikas that move to higher elevations will need to adapt their body size (length and weight) due to lower oxygen saturation (Lenfant, 1973). On the other hand, individual pikas that remain at lower elevations are forced to decrease their body size for more efficient thermoregulation (Pincheira-Donoso et al., 2008).

Regardless, climate change will likely affect morphological traits in pika populations. If body size decreases, then demographic parameters that affect population growth will be negatively affected. The consequences of lower body size in pika could include reduced fecundity and survivorship. For example, Eurasian red squirrels (*Sciurus vulgaris*) had shorter mating seasons resulting in fewer offspring when they were introduced to the stressors of high elevations (Rodrigues et al., 2010). Similar reductions in fecundity are expected in Colorado pika when faced with habitat shift changes.

Objective and Anticipated Value

The objective of this research is to investigate the effects of climate change on American pika populations. The goal of the project is to assess how pika distribution and body morphology have responded to recent climate warming in the Colorado Front Range.

This case study will increase understanding of the consequences of climate change not only for American pika populations, but also for vulnerable species in alpine habitats (e.g. marmots, snowshoe rabbits). In addition to reporting how far pika populations have increased in elevation, this study will explore whether climate change has influenced pika body size. This information will allow us to infer how other species living in similar alpine ecosystems will react to climate change. Furthermore, the study will complement broader research on local species range shifts from anthropogenic influences. The results from the data will directly aid in constructing species conservation plans and broaden the scientific community's understanding of global influences on local populations.

Question 1

To what degree are pika moving to higher elevations in the Colorado Rocky Mountains as a result of climate warming?

Hypothesis and Prediction 1

Pika populations will undergo habitat range shifts because pika have limited thermal ranges on mountains. Recent pika (1965- 2018) distribution will be at higher elevations where temperatures match those of their preferred historical habitat. In earlier years (1900-1965), pika will be found lower elevations.

Question 2

What is the effect of historical temperature and elevation on body size in American pika?

Hypothesis and Prediction 2

Higher elevations will introduce decreased oxygen availability, forcing the pika to decrease in both length and weight in order to conserve energy. Increased summer and winter temperatures will cause pika populations at their present elevation to decrease their body size for more efficient thermoregulation.

Methods

Detailed Sampling and Analysis Plan

Specific Aim 1 (See Q1 above): *Construct a species distribution model to map the elevational range of Colorado Rocky Mountain pika over 100 years.*

I will use historical records of pika habitat elevations along the Colorado Rocky Mountains and compare those to current pika habitat data. I will obtain records of individual pika from museum collections using the Arctos database (Collaborative Collection Management Solution, 2018). The database contains 883 specimens of *Ochotona princeps* collected in Colorado since August 1903. I will categorize the data by time for earlier pika (1900-1965) and later pika (1965- 2018) species collected. Exact latitude and longitude coordinates of where each American pika was collected and the date they were collected are contained in these records.

The coordinates will be used to extract the elevation from a DEM (USGS, 2018) in ArcGIS to determine the elevation of each specimen at different time intervals. Then I will fit a suite of species distribution models (SDM) describing the occurrence of pika in each time period as a function of elevation and other environmental variables including temperature and vegetation cover. I will evaluate model performance and make predictions of pika distribution on the best performing models. I will create a histogram that compares the elevational range of historical pika to recent pika. I will analyze the resulting SDM map and the histogram to determine whether pika exhibit an elevational shift in the Colorado Rocky Mountains.

Specific Aim 2 (See Q2 above): *Comparative analyses of morphological data (height and weight) of Front Range pika from different elevations and temperatures.*

To understand the effects of temperature on pika thermoregulation, I will use climate data to determine site-specific historical temperatures from PRISM. The PRISM data provides the best estimates for historical average temperatures for each individual pika's location (Erb et al., 2011). I will model height and weight measurements from Colorado pika as a function of elevation and temperature to assess whether decreased oxygen availability and increased temperatures have an effect on body size. Linear regressions will be used to model body sizes as a function of elevation and temperature. I predict that the effect of increased temperatures in the model will correspond to a decrease in average pika body size. Additionally, the effect of increased elevation in the model will correspond to a decrease in average pika body size.

Project Requirements, Logistics, Timeline and Negative Impacts

Date	Activities	Deliverables
Late Jan 2019- February 2019	• Conduct supplemental literature review • Acquire Arctos data and categorize by date	• Annotated bibliography of literature review • An Excel spreadsheet with pika records and associated morphological data
Late Feb 2019- March 2019	• Acquire PRISM data • Download DEM • Extract the elevation and temperature data	• Digital elevation model on ArcGIS • Excel spreadsheet with elevation and temperature
Early Apr 2019- Mid Apr 2019	• Evaluate the effect of environmental factors on pika occurrences	• Final SDM map
Mid Apr 2019- Mid May 2019	• Model morphological data in R as a function of temperature and elevation	• Linear regression model results
June 15, 2019	• Draft Report	• Draft Report
Aug 30, 2019	• Final Report	• Final Report

Budget

Item	Justification	Cost Unit (Source)	Quantity	Total Cost
Arctos Pika Records	Data for graduate student to complete data analysis	$.03 10,000 records (Arctos)	883	$.03
Personnel	Grant employee's salary for modeling and report writing	$10 Hour (Regis University)	200	$2,000
TOTAL PROPOSAL COST				$2,000.03

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CHAPTER 3. JOURNAL MANUSCRIPT: ENVIRONMENTAL FACTORS THAT AFFECT COLORADO PIKA DISTRIBTUION

Abstract

Conserving American pika (*Ochotona princeps*) in the Colorado Rocky Mountains not only protects an indicator species, but also preserves alpine ecosystem functions. The American pika is a montane mammal of concern in Colorado because its sensitive habitat is threatened by climate warming. The Denver Zoological Foundation (DZF) has limited information on American pika elevation locations across the Rocky Mountains, and how habitat declines affect this species. However, the environmental factors that successfully predict pika presence in the Front Range are unknown. Aspect, temperature, average annual precipitation, snowpack, elevation and talus area will limit pika presence. To describe the predictors of pika presence, a best fit generalized linear regression model was used to test pika presence on a validation set of pika presence and absence data. None of the environmental variables significantly influenced pika presence. The findings from this study will aid in understanding potential environmental variables that need to be considered in order to predict pika presence to understand how climate change is affecting pika populations.

Background

Alpine organisms are vulnerable to climate change (Yoccoz et al., 2011). Alpine and mountain ecosystems are susceptible to global climate change because these ecosystems rely on temperatures in a narrow range. Higher annual temperatures result in decreases in snow depth and earlier snowmelt (Yoccoz et al., 2011). Over the past three decades, snowfall decreased by

9%, while the day of snowmelt started earlier by 4 days per decade (Wipf et al., 2009). Snow depth, shifting snowlines, and snowmelt timing directly impact the heat stressors that organisms in alpine habitat face.

In the Colorado Rockies, the American pika (*Ochotona princeps*) is particularly sensitive to climate change due to shrinking alpine habitat size. Historically, pika habitats are found between 8,000 and 13,000 ft in elevation. Pika habitat ranges consist of 259–1,787 mm in average annual precipitation and 2.7–16.6°C in average annual temperature (Millar et al., 2018). Increases in annual temperatures have resulted in heat stress in pika populations that reduces foraging times (Beever, 2003). Pika prefer north or east facing slopes to reduce the amount of direct sunlight and warmer temperatures (Millar & Westfall, 2010). Climate change has reduced the quality of pika habitats by increasing the temperatures at lower elevations and decreasing annual precipitation. The drier, warmer temperatures result in inhospitable patches for the pika. Pika habitat needs to be constantly monitored as the habitats shift or become limited over time. American pika populations are expected to migrate to higher elevations as temperatures continue to rise, eventually narrowing their habitat range (Millar et al., 2018). In this study, I will assess which environmental factors predict American pika presence in Colorado.

The Front Range Pika Project (FRPP) was started to better understand the distribution of American pika across the southern Rocky Mountains. The FRPP monitors and records information on how the environmental characteristics of pika habitats are being affected by climate change. Pika serve as an indicator species that indicates the effects of climate change on species distributions. An ideal indicator species signals the level of stress an ecosystem faces and is representative of the presence of other species (Cheyne et al., 2016). Pika are considered an indicator species because they are sensitive to changes in their surrounding environment. Ultimately, the goal of conservation is understanding how organisms respond to climate shifts and using that knowledge to manage alpine organism populations.

The eight national park sites in the Rocky Mountain National Park (RMNP) show evidence of substantial pika population declines. Researchers predict an even more dramatic decline during this century (Millar et al., 2018). Further research is needed on pika distributions to fully understand which variables are creating this decline in pika populations. Researching the environmental forces that are driving pika towards extinction will aid further research to inform management practices for pika. Considering pika habitats are getting warmer and their preferred range is shrinking, management needs to focus on protecting areas where pika are expected and the characteristics of those future habitats.

Question

Which environmental factors predict American pika (*Ochotona princeps*) presence in Colorado?

Hypothesis

Aspect, temperature, average annual precipitation, snowpack, elevation and talus area will affect pika presence. Aspect, temperature, and elevation will affect temperature pika are experiencing at a given location and pika are susceptible to heat stress. Precipitation is a proxy for resource abundance. Pika depend on talus area for protection from both predators and extreme high/low temperatures. Snowpack provides insulation for pika during harsh winter freezes.

Predictions

An increase in average monthly temperatures will decrease pika presence. Decreasing elevation, talus area, precipitation and snow pack will decrease pika presence. South facing slopes will have a decreased pika presence.

Methods

Species Selection

The American pika is a generalist herbivore that is a member of the lagomorph group in western North America. Pika are found throughout high-elevations of the Rocky Mountains in Colorado, Wyoming, Montana, Alberta, and along the Pacific Coast (Erb et al., 2011). Pika do not hibernate during the winter and use foraging behaviors to cache vegetation to survive harsh winter conditions (Millar & Westfall, 2010). The pika populations have adapted their behaviors and metabolism to their environment by controlling their body temperature based on the time spent above ground. Pika are susceptible to chronic and acute heat stress and therefore thrive in a narrow climate range (Beever et al., 2010). Temperatures above 80°F are considered deadly to the pika, while temperatures above 72°F greatly reduce their above ground activity (Erb et al., 2011). During the summer, pika are actively foraging for food and storing hay and food to prepare for winter. Decreased winter precipitation or earlier snow melts threaten pika as they are more susceptible to winter freezes (Erb et al., 2011). Pika prefer rocky slopes (talus habitats) that have plenty of places to hide from predators and adverse weather conditions (Smith & Erb, 2013). The American pika's thick brown-black coat provides camouflage among the rocks and provides warmth during the winters. Pika feet have sharp claws and rigid pads, making them agile and extremely well suited for their present environment (Krear, 1965). Pika behaviors and fitness depend on a narrow range of environmental conditions; the population will suffer severely as these conditions begin to shift.

Site Selection

The study area comprises 45 sites across the Front Range in Colorado. The Colorado Rockies were selected for this study since there is noticeable pika population declines across the area. The alpine habitats are all located between 8,000-13,000 ft in elevation. Study sites were a combination of Colorado Parks and Wildlife (CPW) sites and researcher sites from the University of Colorado Boulder. The subset of sites were selected after stratifying by geography, elevation, and access. Nearly 529 observations are made on American pika presence or absence and the environmental characteristics at these sites.

Observation Methods

Citizen science protocols were used to collect the data. Managing and restoring the pika population is possible by providing baseline data on pika presence and the environmental factors in which they are found. Prior to going into the field, citizen scientists completed a three-hour training on how to detect pika presence, sampling procedures, and specific recording procedures. The citizen scientists' hiked to specific study sites using Gaia GPS receivers and topographic maps. Once the citizen scientist were within 200m of the GPS coordinates, standard information is recorded (i.e. arrival time, site name, and observers' names). The observers determined whether or not they were within 200 m of an alpine talus habitat. Once the talus habitat is defined, the observers find the best pika habitat within the talus by looking for a meadow that fringes the talus area. The citizen scientists observe pika presence through either visual observations or auditory observations of pika calls. The observers record environmental variables around the sites including temperature, talus boulder size, talus area, scat collection, depth of talus, precipitation, percent cloud cover, wind speed, and vegetation type. Observers recorded the presence or absence of pika and scat; if present, they collected it for further examined at the Denver Zoo lab. Observers used outdoor thermometers or smartphone for temperature data directly above the talus. They record cloud cover range (0-10%, 11-25%, 25-50%, 50-75%, and 76-100%). Observers measure the longest axis of the largest boulder and the and talus depth as the deepest crevice within 12 meters of active pika signs. The observers estimate talus area using five categories (less than 1,000 sq. m, 1,001-5,000 sq. m, 5,001-10,000 sq. m, greater than 1 hectare (two to ten football fields), greater than 5 hectares). Additionally, observers measure wind speed, precipitation, and vegetation.

Searching for pika was not always successful and there were multiple reasons that the observers needed to end the search early. If the observers cannot identify a talus at the study site they end their search. Additional reasons to end a search include; lightning, altitude sickness, temperatures over 75°F, pika not detected, or presence of pika was detected outside of the thirty-minute window.

Model Development

Historical records of pika habitat elevations along the Colorado Rocky Mountains are compared to current pika habitat data. Citizen survey observations of individual pika are obtained from using the Denver Zoological Foundation database. The database contains 433 specimens of *Ochotona princeps* collected in Colorado since February 2006 (Fig 1). These records contain the exact latitude and longitude coordinates where each American pika was collected and the date collected. The coordinates are used to extract the elevation and aspect from a digital elevation model (DEM) (USGS, 2018) in ArcGIS to determine the

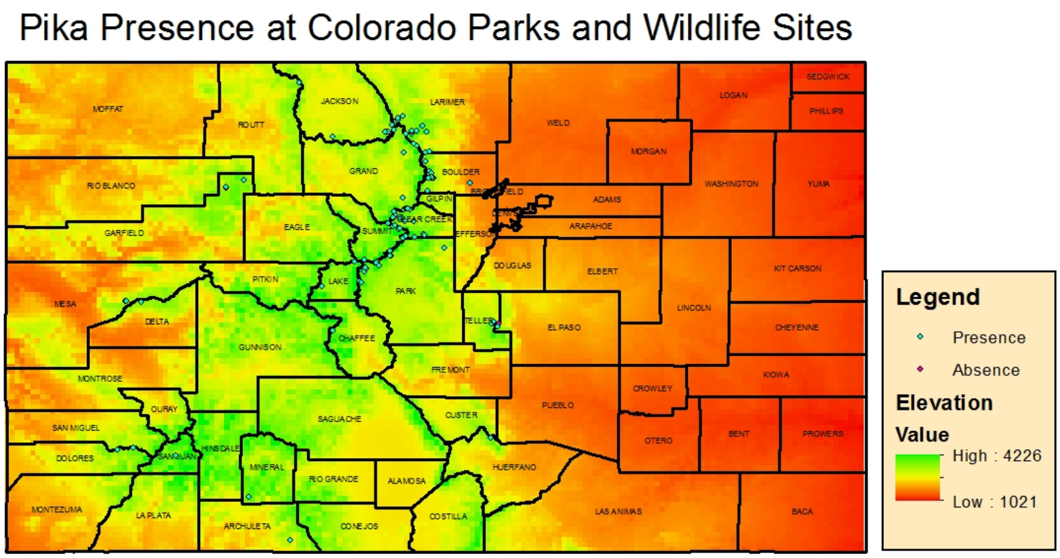

Figure 1 Colorado Parks and Wildlife sites based on Pika presence and absence. The map is color coded to show changes in elevation.

elevation and aspect of each location of observation. The database recorded temperatures at the locations in which pika were observed.

To understand the effects of the precipitation and total snowpack on pika presence, climate data were obtained from PRISM (a collection of climatic datasets from various monitoring networks provided by a climatic group). The spatial resolution collected is 4 km while the temporal resolution was monthly (2006-2016). The PRISM data provides the best estimates for historical annual precipitation for each individual pika's location (Erb et al., 2011).

Model Analysis

All analyses are performed in R [Version 1.1.456]. The data frame is log transformed and split create both a build and validation set. The build set contains 75% of the pika presence/absence data while the validation set contains the remainder. The purpose of a building set is to train the models that are selected and a validation set is used to verify the best fitted model. Basic generalized linear models are fit to analyze the effect of each particular environmental variable on the presence/absence of American pika.

Finding the best fit model requires fitting generalized linear mixed-effects models (GLMM) and then using the drop1 test sequentially to remove unnecessary terms (environmental variables). Once the best fit model was chosen, the validation set was used to predict the difference of occurrence in log odds between sites with and without pika. A ROC curve and AUC was used to justify predictive power of the model. The threshold score was used to determine the 90^{th} percentile of the absence data and the 10^{th} percentile of the presence data. Once the threshold score was determined, a confusion matrix was created to determine the percent of predicted presence values that were actually present and the predicted absence values that were actually absent.

Results

The environmental factors of aspect, temperature, average annual precipitation, snowpack, elevation and talus area did not predict Colorado pika (*Ochotona princeps*) presence (Table 1). After accounting for site, log aspect (pvalue = 0.21), log temperature (pvalue = 0.28), and log snowpack (pvalue = 0.47) had a non-significant positive effect on pika presence. While the interaction of log aspect and log temperature had a non-significant negative effect on pika presence (pvalue = 0.25) (Table 1). The model that best explained presence did not include precipitation, elevation, or the interaction between temperature and snowpack. Individually, each environmental factor did not have a significant effect on the pika presence, with the exception of snowpack, which had a significant increasing effect on pika presence (p-value = 0.025) (Fig 2).

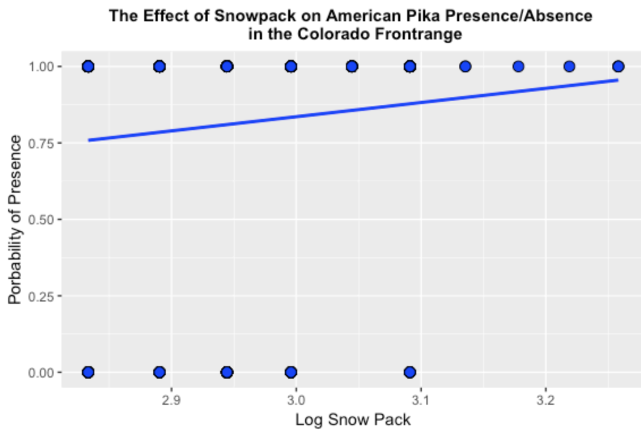

Figure 2 The effect of log snowpack on pika presence. Log snowpack has a significant increase on pika presence (p= 0.0248). (Y axis 1 indicates pika presence, 0 indicates pika absence).

	Dependent variable:
	Pika Presence
Intercept	−19.475 p = 0.253 (−52.821, 13.871)
logaspect	4.250 p = 0.213 (−2.435, 10.935)
logTemp	3.516 p = 0.285 (−2.922, 9.954)
logSnowpackin	1.990 p = 0.475 (−3.459, 7.439)
logAspect:logTemp	−0.953 p = 0.246 (−2.559, 0.653)
Observations	447
Log Likelihood	−146.804
Akaike Inf. Crit.	305.608
Bayesian Inf. Crit.	330.223
Note:	*p<0.1; **p<0.05; ***p<0.01

Table 1 The best fit model for how environmental variables and site effect pika presence.

The building set was tested on the best fit model to predict pika presence and determined the difference between presence and absence in predicted log odds (Fig 3). The difference of occurrence in log odds between site with and without pika is reported as CI:1.32-1.71. The ROC curve and AUC were used to measure the predicative power. The ROC curve justified that the model predicts pika presence or absence better than random chance (AUC 0.926). The threshold score was determined by calculating the lower 10th percentile of pika presence and 90^{th} percentile of pika absence (Score: 1.24). The threshold score will allow us to predict pika presence using the best fit model as long as we have environmental data present. The confusion matrix for the validation set indicates the percent of actual presence versus predicted pika presence (71.92%), and the percent of actual absence versus predicted pika absence (13.70%).

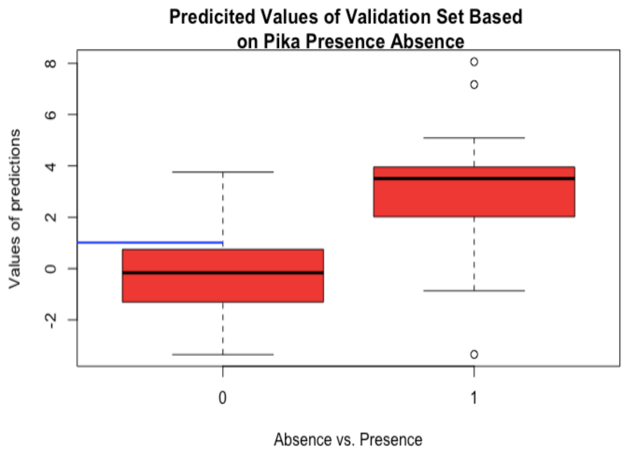

Figure 3 The predicted log (odds) pika presence in the validation set. The threshold score was set to 1.24 for validation data.

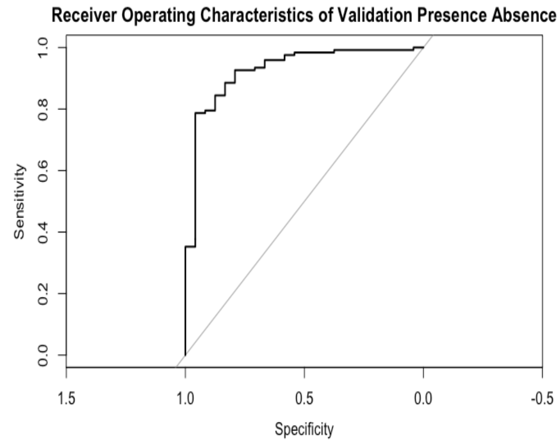

Figure 4 The ROC curve shows that the model has strong discriminatory value. The model predicts pika presence or absence better than random chance

Discussion

Aspect, temperature, average annual precipitation, snowpack, elevation, and talus area do not determine pika presence in Colorado. Thus, the environmental variables did not support the hypothesis that aspect, temperature, and elevation were important predictors. Similarly, a study by Beever et al., these factors did not provide support that pika are susceptible to heat stress (Beever et al., 2010). In contrast, studies have suggested that pika depend on talus area, snowpack for protection (Erb, 2013). Erb suggested that pika rely on precipitation for resources (Erb, 2013). Other studies stress the importance of these environmental variables to predict pika presence, while the current study did not support any one particular variable. In this study, I expected to see fewer pika present in locations that had higher temperatures, higher elevation, southern aspects, lower annual precipitation, snowpack, and talus area. One possible explanation is that environmental variables chosen were highly dependent on one another. For example, elevation is an indicator for snowpack, temperature and talus area. Alpine species depend on a combination of environmental factors for fitness and reproduction success (Yoccoz et al., 2011). Further studies are needed to demonstrate how climate change affects that size of pika's preferred habitats and dispersal patterns due to these changes.

Future studies should include a wider temporal and geographic range of American pika in order to isolate environmental variables that predict pika presence. Being able to predict pika presence is essential to management practices and determining the effects of climate change on an indicator species. Additional studies should also consider including environmental variables such as slope, vegetation density, proximity to alpine meadows, talus depth, and talus boulder size. Analyzing additional variables may help identify pika presences and preferred niches. Millar et al. (2018) have defined preferred niches in his studies by analyzing a greater temporal and geographic range of pika. Once we are able to determine the American pika's preferred habitat, we will be able to take a step forward and analyze how climate change is altering these habitats. Analyses like the one performed here provide valuable information for protecting the American pika.

One of the limitations of my study was that the data provided by the citizen scientists may have introduced heterogeneity. Though the citizen scientists were well trained, they lack the experience and education necessary to carry out consistent observations. The temperature was only recorded during the late summer months (Jul-Oct) when hiking trails are most accessible to the citizen scientists. The temperatures lacked variance and could have proven more significant if they were recorded throughout the entire year. Monthly high temperatures at each location may provide useful data for future analysis. Because pika depend on snowpack for insulation during the winter months, temperatures are essential to understanding warm spells that leave the pika vulnerable to freezing temperatures. A second limitation of this study was the lack of absence data for pika. Compared to presence-only data, absence data provides a better representation of pika distribution and the environmental factors that they avoid and prefer. The third limitation of this study was the 4km spatial resolution of precipitation data from PRISM. A higher spatial resolution could show differences in precipitation levels where pika were present.

Understanding the environmental factors that predict American pika presence are necessary to understand the effects of climate change on alpine and mountain ecosystems. Conservation of American pika in the Colorado Rocky Mountains not only protects an indicator species but also preserves alpine ecosystem functions. Indicator species are sensitive to environmental change and they give ecologists an early warning of the ecological effects of climate change (Cheyne et al., 2016). American pika populations are in decline across the Rockies and scientists predict that this trend will continue as a result of rising temperatures (Erb, 2013). Therefore, studies like this one help build our understanding of the ecological effects on pika populations and builds baseline data to protect this species. This information provides support for listing the pika as an endangered species. The lengthy process requires a justification and a substantial amount of supporting data for the listing. Listing the American pika on the endangered species list will help increase public support, conservation efforts, and population growth. Similar studies will only further add to this needed research and help prevent further isolating populations of American pika.

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CHAPTER 4. ENVIRONMENTAL STAKEHOLDER ANALYSIS: LISTING PIKA ON THE ENDANGERED SPECIES LIST

Introduction

Many species within the alpine communities require the Endangered Species Act's (ESA) protection but are still not listed as threatened or endangered by the United States Fish and Wildlife Service (USFWS). The ESA is not without limitations and cannot possibly protect all species. It is the USFWS responsibility under the ESA to protect species that that are identified as the most in danger and in need of immediate assistance. Alpine organisms and mountain ecosystems are particularly sensitive to climate change (Yoccoz et al., 2011) because the structure and function at these ecosystems rely on temperatures within a narrow range. Increased annual temperatures from global climate change result in decreases in snow depth and earlier snowmelt (Yoccoz et al., 2011). Over the past three decades, global snowfall decreased by 9%, while the day of snowmelt started earlier by 4 days per decade (Wipf et al., 2009). Snow depth, shifting snowlines, and snowmelt timing directly impact the heat stressors faced by organisms in alpine habitats. The American pika (*Ochotona princeps*) is a species of concern in the Southern Rocky Mountains and is especially threatened by climate change because of the decrease in alpine habitat size. American pika populations are in decline across the Rockies and scientists predict that this trend will continue as a result of rising temperatures (Erb, 2013). Pika are an indicator species, and signify the effects of climate change on species distributions. I recommend that pika receive endangered with critical habitat/ or threatened classification under the ESA.

Summary of Environmental Issue

The American pika are well adapted to the cold alpine environment and have a narrow range of climatic requirements. American pika are small herbivore mammals that live in talus habitats among alpine ecosystems (Millar et al., 2018). Historically, pika habitats are found between 2,438 and 3,962 m in elevation. Pika habitat ranges consist of 259–1,787 mm in average annual precipitation and 2.7–16.6°C in average annual temperature (Millar et al., 2018). Increases in summer temperatures result in heat stress in pika populations that reduces foraging times (Beever, 2003). Pika prefer north or east facing slopes to reduce the amount of direct sunlight and warmer temperatures (Millar & Westfall, 2010). Climate change has the potential to reduce the quality of pika habitats by increasing the temperatures at lower elevations and decreasing precipitation, creating patches of unsuitable areas. Pika habitat are constantly monitored as the habitats shift or become limited over time. American pika populations are expected to migrate to higher elevations as temperatures continue to rise, eventually causing them to lose suitable habitat (Millar et al., 2018).

Pika characteristics that allow them to survive the harsh winter temperature makes them particularly susceptible to climate change (Erb et al., 2011). Pika have adaptations to the cold weather such as maintaining high body temperature, utilizing their warm coat and the insulation of snowpack. Temperatures above 80°F are considered deadly to the pika, while temperatures above 72°F greatly reduce their above ground activity. During the summer, pika are actively foraging for food and storing hay and food to prepare for winter. Decreased winter precipitation or earlier snowmelts threaten pika as they are more susceptible to winter freezes, due to loss of snow insulation (Erb et al., 2011).

A solution to properly protecting pika populations from global warming and decreases to their preferred habitat, is receiving endangered species status. Listing the American pika on the endangered species list is a difficult and lengthy process. Petitions are filed by anyone who wishes to make a case to request that the species be put on the list. Next, a substantial amount of information needs to be presented, listing why the listing is warranted. After the information is submitted, it may take up to a year or longer to approve, disprove, or warranted but precluded (used when other species have higher priority). If the data provided is approved then the proposed listing and supporting information is published and it is used to seek input from the public, scientific community, Federal and State agencies. Last, the final decision to approve or a decision to not list is made and published in the Federal Register (Wildlife Service, 2016). Petitions to list the American pika as an endangered species are an on-going battle. In fact, the Center for Biological diversity has petitioned and filed lawsuits for more than a decade (Siegel, 2009). The struggle reveals that there is more than a simple environmental issue, but the setbacks with bureaucracy and the conflicting opinions of stakeholder. Despite the complexity of the listing process, it is essential to protect pika and convince stakeholders to aid in this endeavor. Other options of pika conservation include limiting human interactions through closing certain mountain trails, and restoring alpine meadows for pika resources.

Stakeholders interests and values

Denver Zoological Foundation

The Denver Zoological Foundation (DZF) is currently in charge of the Front Range Pika Project (FRPP). The FRPP was started to better understand the distribution of American pika (*Ochotona princeps*) across the southern Rocky Mountains. The FRPP aims to gather further research and institute a monitoring program to understand how pika are being affected by climate change. FRPP monitors and records information on the environmental characteristics of habitats in which pika are found because they are an indicator species, and signify the effects of climate change on species distributions. The FRPP is one of the leading advocates in getting the public involved in the issue by using the information they have already gathered and would support a petition for Pika. By creating community engagement and education activities and engaging citizen scientists in their project they are developing a deeper public appreciation and awareness for the species. Public input not only directly affects the petitioning process but also indirectly affects state legislature decisions as they will typically vote in favor of public opinions or constituents.

Colorado Parks and Wildlife

Colorado Parks and Wildlife (CPW) currently provides extensive research on pika populations and their ability to survive. As a stakeholder, non-profit and supporter of petitioning, they can provide both information to the public and data to support the petition process. The CPW's educational services are needed to inform the public, especially those who are unware of the American Pikas' predicament. The more pressure that is put on the Federal agencies, State agencies, and the USFW the more likely that pikas will be considered as an endangered species. Additionally, biological information is used to compare status reviews among the species that are selected as candidates. The data from the CPW and their influence could help move the pika from the possible candidate category towards a more permanent selection.

Adventures of the American Pika

The Adventures of the American Pika is an organization that creates films to promote conservation efforts of the American pika. As a stakeholder and supporter of petitioning, they are able to promote the species and deliver information to a wider audience. Even though the ESA does not prioritize species based on popularity, the polar bear is an excellent example that the more well known the species is the greater the chances of it making the Endangered species list. The Adventures of the American Pika needs to make it priority to present their films as widely as possible. By placing these films and documentaries on platform's like Netflix, YouTube, and Facebook will help Pika's to gain nationwide notoriety. The films will support pika by fostering support for creating petitions and data collection.

Colorado Fourteeners Initiative

The Colorado Fourteeners Initiative (CFI) have made it their responsibility to build and restore alpine habitats. Though their mission considers the recreational use of mountains, they do so to protect alpine species from human encounters and would support a petition. The CFI will need to provide site specific data to determine how alpine habitats and pika habitats in particular are shrinking. A part of receiving an endangered species status is determining the rate of danger. The CFI uses citizens citizen data to determine hiking trails effects on alpine habitats. The data they have collected to aid in determining the immediacy of the threat of habitat shrinkage. Additionally, the CFI have the opportunity to inform both local and tourist hikers of the danger pika face.

Colorado State Legislature

Colorado's State legislature does not have the power to federally list pika under the ESA. However, a proposed amendment in 2017 to the 1973 Endangered Species Act gives state legislatures the power to regulate intrastate endangered species (Luetkemeyer, & Blaine 2017). State legislature can create strict laws to protect pika habitats from destruction, thus changing how the public regards the pika. Currently the pika is listed under the category of "Least Concern". State legislation can assist in prioritizing the pika as a species of concern and any conservation actions within Colorado. While the 2017 amendment has not come to pass, the state legislature can still act to help the pika by pushing the petition process along and encroaching its success with the support of scientific research and public persuasion. The steps that the state legislation will take, are most vital in moving the pika towards Endangered Species status by creating public awareness of the environmental concerns among pika. However, under the current makeup of the legislature support is not likely, will need to be convinced through public pressure.

U.S. Fish and Wildlife

The U.S. Fish and Wildlife (USFW) is concerned with managing species and land within the United States, and providing reports on all available information to determine pika status. An endangered designation helps protect pikas from direct harm but does not offer protection to pika habitat. While in the past the USFW determined that the pika are able to survive despite increasing temperature, they are the ones who have the greatest influence on changings the pikas status. The USFW will need to complete an exhaustive review of all the data and scientific information provided from other stakeholders to make their decision. If the USFW is provided with information that proves that pika are adversely affected by climate change and that they are unable to survive the predicted increase in alpine temperature that they will be able to warrant the pikas listing. The approval from the USFWS director is politically influenced, and the administration will most likely not shift their view without top-down pressure. Additionally, the tax payer is the driver of the USFWS and will have a strong influence on their actions.

Center for Biological Diversity

Center for Biological Diversity's (CBD) mission is to preserve as much biological diversity as possible in order to benefit both humans and nature. In August 2007, the CBD petitioned the USFW findings by not listing the pika on the endangered species list. As a stakeholder, the CBD can file scientific petitions to have the pika listed. The CBD has the ability to file a lawsuit against the USFW and argue any unfavorable findings or decisions, like they have done in the past. The CBD are influenced by their donors who finance lawsuits and marketing for CBD. The CBD is able to provide species specialists and expert opinions to support their scientific findings. The CBD is the best advocate for pushing the petition process forward.

Tourism Marketing

For years in Colorado the Big Horn Sheep has been a symbol for wildlife and conservation. As a result, there has been increased public and tourist concern regarding the species. The American Pika needs to become the new species of concern for Colorado through similar tactics with marketing. The DZF is already working on this is some aspect, but other stakeholders will need to market pika as well in order to create more concern and possible petitioners. By including pika as a marketing tool in Colorado more people will become aware of the threats they face and with to do something about it. Therefore, the tourism industry would be in support of listing pika on the Endangered Species List. Creating public support for listing the species as endangered is the step that cannot be overlooked.

Private Land Owners

Private landowners are concerned about how the value of their land benefits cultural, economic, aesthetic, and personal needs. For example, in 2016 a private landowner in Texas filed a lawsuit with the goal of delisting the Bone Cave Harvestman from the Endangered Species Act. The landowner was not able to use a descent portion of his land for community benefit and recreational uses because of the Bone Cave's critical habitat. Fear of losing profitable land to critical habitats in cases like these prove that private landowners may provide dissenting opinions pertaining to the listing of American pika on the endangered species list. One way to convince landowners is through incentivized programs or opportunities for ecotourism. By informing concerned stakeholders of the important role pika play in both the ecosystem and as an indicator species may provide enough incentive to deter lawsuits or petitions.

Conclusion

In conclusion, the best course of action is taking the necessary steps of listing the American pika on the endangered species list. The first step is to contact and recruit the necessary stakeholders to provide a substantial amount of vital information to file a petition. Next, we must apply the necessary pressure backed up by public support to have the petition approved. Lastly, the dissenting stakeholders will need to be convinced to either support this decision or dissuade them from filing a lawsuit. The process of listing the American pika on the endangered species list is not a small task by any means, but it is possible if stakeholders are properly managed.

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