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MS Environmental Biology Capstone Project

Catherine Devitt

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MS ENVIRONMENTAL BIOLOGY
CAPSTONE PROJECT

by

Catherine J. Devitt

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

REGIS UNIVERSITY
May, 2019

MS ENVIRONMENTAL BIOLOGY
CAPSTONE PROJECT

by

Catherine J. Devitt

has been approved

May, 2019

APPROVED:

____________________________________, Catherine Kleier, Ph.D. (Faculty Advisor)

____________________________________, Amy Schreier, 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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CHAPTER 1. LITERATURE REVIEW: VEGETATION CHANGES IN RESPONSE TO GONDOLA CONSTRUCTION IN BRECKENRIDGE, COLORADO

Breckenridge is a small ski town in the heart of the Colorado Rocky Mountains where the ski industry and tourism drive the economy and provide financial wellbeing for locals. With nature-based tourism at an all-time high, and total number of visits to protected areas on the rise worldwide (Balmford et al., 2009), towns like Breckenridge are growing in number and size. Recent studies observed an increase in the length and spread of recreation trail systems across the world's natural areas (Ballantyne & Pickering, 2015; Wipf et al., 2005). In Breckenridge, this increase in trail systems includes infrastructures like the gondola built in 2006-2007 connecting the town of Breckenridge to Peak 7 and Peak 8 (Hoffa & Carello, 2009; USDA, 2012). Understanding how infrastructure like this gondola impact the land is important. What are the long-term effects of gondola construction? What type of vegetation is now found in the area under the gondola and the surrounding forest? The change in mammalian presence, both human and non-human, the soil disturbances from the construction and the current maintenance regimes harm the natural landscape immediately and also further down the road. These changes cause irreparable damage to the natural vegetation and facilitate the intrusion by non-native invasive plant species.

Before the gondola construction the vegetation beneath it was mainly old growth and secondary growth subalpine forest (Hoffa & Carello, 2009; USDA, 2012), dominated by tree species including engelmann spruce (*Picea engelmanni)*, subalpine fir (*Abies bifolia)*, lodge pole pine *(Pinus contorta)*, willow (*Salix* ssp.) shrubs, and bluejoint grass (*Calamagrostis canadensis*) (USDA, 2012). The subalpine zone is the area that bridges the lower edge of the alpine zone and the upper edge of the montane forest (Kershaw, 1998). At high elevation from 10,000 to 11,500 feet, temperatures are low and growing seasons are short (Windell et al., 1986). Short growing seasons and dense snowfall make this subalpine forest home to many delicate plants (Kershaw, 1998). Because of the harsh conditions, Breckenridge forests are particularly sensitive to disturbances and invasion by non-native species (Törn et al., 2009). The non-native species typically found in Breckenridge include plants like Canada thistle (*Cirsium arvense*) (Pritekel et al., 2004). Canada thistle and other invasive species tend to be more competitive, have greater nutrient uptake efficiency and overall higher biomass than the native species (Müllerová et al., 2011). Non-native species and the management practices used to control them may have long-term effects on the land and need to be greatly considered when infrastructures like the Breckenridge gondola are constructed.

To understand the effects of the gondola construction, we first need to look at the disturbances taking place. The disturbances are described as, but not limited to, full vegetation clearing, grading excavation, and other ground disturbances for the full length of the corridor (USDA, 2012). A popular study on the effects of ski resorts on alpine vegetation in the Swiss Alps concluded that machine grading, snow grooming, and artificial snow production destroy natural habitats, decreasing vegetation cover and decreasing overall diversity (Wipf et al., 2015). To understand how this relates to the vegetation in Breckenridge, a recent study compared the vegetation along the Breckenridge gondola before and after the construction in an attempt to explain the short-term effects of the construction. Findings from this study show that the gondola construction caused changes in plant species diversity, not only in the immediate area of deforestation, but also to at least 3 meters further from the forest edge (Hoffa & Carello, 2009). This suggests that the gondola construction site could have similar responses to disturbances as the alpine vegetation in the Swiss Alps did.

Further research of Wipf et al. (2015) in the Swiss Alps study looked into revegetation efforts. Wipf and colleagues found that there was no amelioration to the damage after revegetation measures were taken, or even after the plots were given time to restore themselves (Wipf et al., 2015). This finding is supported in a paper by May et al. (1982) who looked at the success of transplanting native alpine species in Niwot Ridge, Colorado after physical disturbance damages occurred. May and colleagues concluded that the only effective way to reintroduce native species in areas of recent disturbance is via transplantation of native species with different life histories (May et al., 1982). This is an important consideration as revegetation attempts are made to restore plots to their original vegetation. In conclusion, once construction has taken place, there are immediate negative effects on the vegetation, and past these effects, revegetation efforts are typically ineffective or highly complicated.

When the gondola was constructed, the machine grading, and the excavation processes disrupted the natural soil composition. A study completed by Müllerová et al. (2011) in the Czech Republic found evidence that the changes in the chemical environment during times of construction have a negative impact on plant growth and native species diversity. They found a pH increase from 3.9 to 7.6 and base saturation increase from 9-30% up to 100% transformed the surrounding vegetation from native tundra species to competitive, nitrophilous, and species that traditionally preferred manmade habitats. Their findings are supported by Hobbs & Huenneke (1992) who reviewed the literature and concluded that the change in chemical environment leads to disruptions in soil composition, which then increases colonization of non-native species. In conjunction with the observed decrease in plant species, Müllerová et al. (2011) provide evidence that water plays a huge role in carrying construction chemicals down slopes. The study found a difference in soil and plant composition in areas along water routes compared to those not along the routes. This explains the vast spatial range that the gondola construction can affect, not only potentially increasing the presence of invasive species under the gondola itself, but also spreading along waterways into the surrounding forest especially considering its position on a snow-dredged slope.

Past the initial effects of the gondola construction in Breckenridge, certain measures of management like trimming and cutting of plants are required to keep the area cleared for maintenance workers. In a recent study completed in Cucumber Gulch, a wetland preserve located between the town of Breckenridge and the ski resort, right along the Breckenridge gondola, Carello et al. (2016) noticed that winter recreation trail maintenance negatively impacts the growth of willows that dominate the area, as well as the vegetation surrounding these willows. The study compared plots that had willows that were clipped versus plots with unclipped willows to replicate areas that are maintained versus plots left unmaintained. Not only did they find that there were fewer catkins produced in the clipped plots, but these maintained areas were higher in diversity. While an increase in diversity may sound like a positive result, the increased diversity was due to invasive weeds, compounding the evidence that areas under the gondola are dangerously susceptible to invasive species intrusion, not only immediately after construction, but in the long run as well (Carello et al., 2016).

The greatest changes associated with gondola construction are those associated with the overall change in land use and the massive increase in human presence. The International Union for the Conservation of Nature (IUCN) (2000) warns that the increase in human travel is an important mechanism for the long-distance dispersal of plants, especially invasive species. It is well known that there are negative impacts on vegetation due to human presence through ground trampling. For example, Törn et al. (2009) found that the only species able to survive after trampling disturbance are tolerant species, and that sensitive species no longer exist in areas disturbed by trampling (Törn et al., 2009).

Since the gondola is a raised infrastructure, it is important to consider other ways that human intrusion and presence affect vegetation. As people visit Breckenridge from all corners of the world, the possibility of them acting as vectors carrying invasive species with them becomes increasingly probable. Clothing such as hiking/ski boots, socks, laces and trousers act as an unintended human-mediated seed dispersal method (Mount & Pickering, 2009). Through their research in Kosciuszko National Park, Australia, Mount & Pickerington (2009) found that seeds from over 179 species, 134 of these weeds, collected on all the clothing studied. This mode of non-native seed dispersal is especially applicable along a gondola line where a large area of susceptible subalpine vegetation is covered in a short period of time. Further, Hobbs & Atkins (1988) concluded that disturbed areas (such as the area under the Breckenridge gondola) tend to comprise rougher surfaces which provide ideal conditions for seed establishment and germination, even further increasing the probability that non-native seeds will have high growth rates in the under-gondola ecosystem (Hobbs & Atkins, 1988).

Beyond the introduction of outside species by human vectors, the simple fact that the gondola brings human presence to areas where it has not been in the past will have a dramatic effect on the surrounding mammalian presence, and therefore vegetation. In the subalpine ecosystem of the Swiss Alps, Patthey et al. (2009) found that outdoor winter sports have a significantly negative impact on key indicator species on a large scale. The study concluded that the presence ski lifts and related winter recreational activities caused a mean 36% decrease in key indicator species. Along the slopes, and specifically along the gondola path in Breckenridge, we can expect a decrease in animals (Patthey et al., 2009), while near the lodge the density of generalist predators will increase. Storch & Leidenberger (2003) found that areas of the subalpine forest of the Bavarian Alps with high tourism frequencies coincide with increased presence of generalist predators. They hypothesize that the easily available food remains and other garbage left behind by the tourists is the cause of this increase (Storch & Leidenberger, 2003). As these findings may seem contradictory, the conclusion that can be made is that human presence in the subalpine regions of Breckenridge likely has an effect on the typical occurrences of surrounding species, which in turn affects the vegetation that is utilized by these species.

Since construction, the gondola has been critical in providing reliable mountain access for bikers, hikers, skiers, and snowshoers alike. The addition of the gondola provides a new and unique way to experience the mountains, allowing recreational opportunities to reach those who would otherwise not be comfortable or capable of hiking or climbing in these same areas. This ideally allows a greater demographic to appreciate the landscape and get involved in the conservation and preservation efforts of these lands in the future (Kubota & Shimano, 2009).

While there are many perceivable benefits to the addition of the Breckenridge gondola, as stated in the previous paragraph, any new addition to the landscape will affect its surroundings. In regards to the Breckenridge gondola, the initial deforestation of the site negatively affected vegetation, wiping out native plants. The changes to soil composition made the land more susceptible to invasion by non-native species, and the increase in human presence in the area under the Breckenridge gondola is currently allowing for non-native species to make their way into the area. Finally, in a subalpine ecosystem along ski slopes, revegetation efforts are not expected to be successful. In conclusion, the changes from the gondola construction and human presence will change the natural vegetation, and cause irreparable damage to the surrounding ecosystem. To fully understand the effects the gondola construction has on the surrounding area, more research is needed on the current vegetation of these sites. Specifically aim to better understand what species of plants begin to grow in the area, native or non-native invasive, and to what degree native plant communities re-establish themselves in the same pre-disturbance areas. Answers to these questions will be imperative in future decision-making on nature-based tourism infrastructures, specifically gondolas. Further, it will give towns like Breckenridge more information on the vegetation that is now present under these infrastructures to help them better maintain the area to facilitate the growth of native plants.

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CHAPTER 2. GRANT PROPOSAL: VEGETATION CHANGES IN RESPONSE TO GONDOLA CONSTRUCTION IN BRECKENRIDGE, COLORADO

Abstract

With nature-based tourism on the rise in the U.S., ski towns like Breckenridge, Colorado are under pressure to create new and improved infrastructure to support increasing demand for updated ski resorts. To aid in tourist transportation, in 2006 the city of Breckenridge built a 28-tower gondola system connecting visitors from the town of Breckenridge to peaks 7 and 8. While infrastructures like this gondola provide an improved tourist experience, the vegetation impacts from construction and maintenance need to be thoroughly studied and considered in management decisions going forward. During gondola construction, a process of clear cutting took place; trees were cut down and removed to make room for construction. Most importantly, this clear cutting removed the tall canopy trees and caused a canopy gap allowing sunlight to reach ground level in areas that had historically been shaded. This change in light exposure can affect the number and type of vegetation that grows in an area. Due to the new levels of sunlight, I hypothesize that post-construction the area under the gondola will have an observable increase in plant species diversity, species richness, and an overall rise in shrub vegetation. To study the forest vegetation changes, I plan to collect plant species data in two areas: the land directly below the existing gondola, and then an area in the same region that was not affected by the gondola construction. I will compare the data from the two areas to answer questions about the plant species diversity, richness, and overall vegetation differences in a forest affected by gondola construction compared to an area that was not affected by gondola construction. This

study will aid in further decision-making on tourism-based infrastructure, and help us to better understand the subalpine forests of Breckenridge and their ability to recover from anthropogenic disturbances like the 2006 gondola.

Background/Rationale/Significance

Breckenridge is a small ski town in the heart of the Colorado Rocky Mountains where the ski industry and tourism drive the economy and provide financial wellbeing for locals. With nature-based tourism at an all time high, and total number of visits to protected areas on the rise worldwide (Balmford et al., 2009), towns like Breckenridge are growing in number and size. Recent studies observed an increase in the length and spread of recreational trail systems across the world's natural areas (Ballantyne & Pickering, 2015; Wipf et al., 2005). In Breckenridge, this increase in trail systems includes infrastructures like the gondola built in 2006 connecting the town of Breckenridge to Peak 7 and Peak 8 (Hoffa & Carello, 2009; USDA, 2012). Understanding how infrastructures like this gondola impact the native vegetation is important for future planning purposes. Specifically, understanding the current vegetation will give insight into Breckenridge's subalpine forest's ability to recover from construction disturbances and provide guidance for decision-making on future construction in Breckenridge and other ski towns alike.

Before construction, the vegetation below the gondola was mainly old growth and secondary growth subalpine forest (Hoffa & Carello, 2009; USDA, 2012). It was dominated by tree species including Engelmann spruce (*Picea engelmanni)*, subalpine fir (*Abies bifolia)*, lodgepole pine *(Pinus contorta)*, willow (*Salix* ssp.) shrubs, and bluejoint grass (*Calamagrostis canadensis*) (USDA, 2012). This forest falls into the subalpine zone, described as the area that bridges the lower edge of the alpine zone and the upper edge of the montane forest (Kershaw, 1998). While existing research has investigated the recovery of subalpine forests after natural disasters like fires and blowdown events, there is a gap of research on the effect that construction, specifically gondola, has on subalpine forests.

Gondola construction causes disturbances including full vegetation clearing, grading excavation, and ground disturbances for the full length of the corridor (USDA, 2012). A study on the effects of ski resorts on alpine vegetation in the Swiss Alps concluded that machine grading, snow grooming, and artificial snow production destroy natural habitats, which decreases vegetation cover and overall diversity (Wipf et al., 2015). Carello & Hoffa (2009) challenge the expectation that grading excavation will alter native ecosystems, decrease vegetation cover, and overall diversity. When studying the vegetation along the Breckenridge gondola immediately before and after the deforestation, Carello & Hoffa (2009) found a statistically significant increase in species diversity in the area under the gondola and up to 3 meters into the non-cleared forest.

The overall increase in light exposure when trees are clear-cut explains the initial rise in species diversity. In the subalpine forests of Colorado, Reid (1989) investigated the changes in understory vegetation after major canopy disturbances of blowdown and spruce beetle attack. He measured the increase in light availability to the understory after canopy disturbances and found that shrub richness was positively correlated with the amount of light it receives. This phenomenon could give insight to the increase in species diversity that Carello & Hoffa (2009) found in Breckenridge following gondola construction. While both of these studies could help to describe the changes in the vegetation under the gondola, only the short-term changes in diversity can be explained. Reid (1989) only describes changes that occur before the canopy regenerates and closes, and Carello and Hoffa (2009) only analyze and report data for the two years after the gondola construction. To fully understand the forest's course of recovery after gondola construction disturbances, a long-term vegetation analysis is needed.

Molino (2001) describes the "intermediate disturbance hypothesis," which states that in nature, we expect that species diversity will increase with time if intermediate disturbances regimes are present (Molino, 2001). During the time of regeneration in the area under the Breckenridge gondola, the vegetation has and continues to experience intermediate disturbances. Essentially, when gondola maintenance workers provide small disturbances at intermediate frequencies by trampling and trimming vegetation, no one species is allowed to dominate and in turn species diversity increases. With these intermediate disturbances, we can expect to see a long-term increase in species diversity in the area under the gondola.

While the current disturbances are considered 'intermediate,' the initial clear-cutting and construction at the Breckenridge gondola site can be considered a major disturbance to the landscape. Two recent studies look at the long term effects on vegetation after a major disturbance in Colorado subalpine forests, one looking at a fire disturbance, and the second analyzing a blowdown occurrence. Coop et al. (2010) examined subalpine vegetation patterns three decades after a fire in four burn areas east of the Continental Divide in Colorado. The results show improved tree regeneration and an increase in forb and graminoid richness in fire-disturbed sites compared to undisturbed sites. Second, Kulakowski & Veblen (2003) studied subalpine forest development after a blowdown in the Mount Zirkel Wilderness, Colorado. Their study showed that the long-term subalpine forest regeneration is different when the disturbance is a blowdown incident rather than a fire, as they found that 65 years post blowdown, the forest regeneration shifted from a *Picea* dominated stand to an *Abies* stand. The two types of disturbance explain differences in forest revegetation. This is because blowdowns tend to remove all of the larger trees and forest fires target the forest floor vegetation. The gondola deforestation targets both the tall canopy trees and the ground level shrubs and graminoids (Carello & Hoffa 2009); therefore, while we can make assumptions that the forest itself will have long-term regeneration success, it is difficult to hypothesize what the dominant species and overall composition will be.

While types of disturbances are important, disturbance extent can also lead to changes in forest regeneration. Rumbaitis del Rio (2006) explored understory diversity in Routt National Forest, a subalpine forest in northwestern Colorado, after a primary and a secondary disturbance. This forest first withstood a blowdown disturbance and then was partially salvage logged in the late 1990's. This research suggests that in areas of Routt National Forest that are solely affected by a blowdown event, there was an overall increase in diversity with species richness and vegetation cover remaining unchanged. In contrast, the areas that were later salvage logged experienced a reduction in species richness, diversity, and vegetation cover. This research indicates that in an area like that along the Breckenridge gondola, richness, diversity, and vegetation cover responses are highly dependent on two factors: whether or not vegetation remains of the cut area are left to aid in the subalpine forest's revegetation effort and whether or not they endure a secondary disturbance like salvage logging.

While research exists on the ability of a subalpine forest to recover after a disturbance, no studies to date have examined the specific effects of gondola construction on a subalpine forests and their ability to recover from this specific type of disturbance. The gondola is important for recreation and nature-based tourism; since construction, the gondola has been critical in providing reliable mountain access for bikers, hikers, skiers, and snowshoers alike. Furthermore, the addition of the gondola provides a new and unique way to experience the mountains, allowing recreational opportunities to reach those who would otherwise not be comfortable or capable of hiking or climbing in these same areas. This ideally allows a greater demographic to appreciate the landscape and be involved in the conservation and preservation efforts of these lands in the future (Kubota & Shimano, 2009). Understanding the anthropogenic benefits of the gondola alongside my research on the ecological effects of its construction is critical for two reasons: to provide future decision makers with the information needed to weigh the benefits of an infrastructure like this gondola, and to urge legislatures and citizens alike to consider better ways to go about construction of tourism-based infrastructures.

In unison with the mission of Regis University, my research calls for decision makers to be socially and ecologically responsible for the decisions and actions already made in building this gondola. Further research on the revegetation outcome under the Breckenridge gondola could change the prevailing views society thinks about nature-based tourism and tourism-based infrastructures.

Purpose and Specific Aims

The “intermediate disturbance hypothesis” implies that there is a positive relationship between time after disturbance and species diversity, so species diversity will increase with time (Molino, 2001). I plan to test this hypothesis and investigate how construction of a new gondola in Breckenridge, Colorado in 2006 altered the natural vegetation under and around the construction site. The findings will add to the current research on subalpine forests’ ability to regenerate after a disturbance while exploring the specific disturbance of gondola construction, which previous research has not yet addressed. I hypothesize that species diversity and richness will increase in the area under the gondola post-construction due to implications of the intermediate disturbance hypothesis. Further, I hypothesize that there will be an increase in shrub vegetation due to the increase in light exposure caused by the removal of canopy cover during gondola construction. Reid (1989) observed an increase in shrub vegetation in the subalpine forest of Colorado after blowdown and spruce beetle disturbances took down the canopy. To test these hypotheses, I will compare the area under the gondola that underwent the construction disturbances to plots in the same region of subalpine forest that were not affected by the gondola construction. This comparison will give insight as to how the gondola construction affected the area.

Methods

Study Site:

I will collect data along and around the new gondola built in 2006 that connects the town of Breckenridge to Peak 7 and Peak 8 (Hoffa & Carello, 2009; USDA, 2012). I will carry out this data collection during the summer of 2018 along the gondola cut in Breckenridge, approximately 39.48 ° north and 106.06 ° west at an elevation around 3000 m (Carello et al. 2017). The gondola cut is approximately 2,314 meters long and 30 meters wide, historically consisting of old growth and secondary growth subalpine forest dominated by lodgepole pine (*Pinus contorta*).

Data Collection:

I will collect data on all species that make up the understory vegetation and the canopy. Following Hoffa & Carello (2009), I will randomly choose six transects 50 m apart perpendicular to the gondola cut with four 1 m^2 sampling quadrats on each side and collect data on percent cover of herbaceous vegetation, species diversity and species richness. This same method will be used 15 meters north of the gondola cut to have a set of control data at a location in the same forest where there have been no gondola disturbances.

In the field, I will estimate and record percent cover in each of the 1 m^2 sampling quadrats using a quadrat frame with 10cm intervals marked. Next, I will take aerial pictures to later analyze in the lab to ensure that my estimates recorded in the field are not biased. To calculate species diversity and richness, I will identify and record each species in the quadrats and then tally the number of that species according to Plants of the Rocky Mountains Field guide (Kershaw, 1998).

Data analysis:

To test if the shrub vegetation increased due to the gondola construction, I will compare the percent cover of the two areas (affected by the gondola cut and not affected by the gondola cut) by using a t-test. This same analysis will be used to determine if there are significant differences in the species diversity and richness in the two areas, and to test if there is an increase in species diversity.

Work plan:

Throughout the 2017 and 2018 school year, I am completing all of the preliminary work for the data collection. This work includes background research, grant writing, and perfecting the techniques of estimating percent cover and species identification. Data collection will be carried out during June through August 2018 in which time I will take day trips to Breckenridge to collect data. Upon completion of data collection, I will use the 2018-2019 school year to focus on analysis of the data and assemble a final report. Finally, I will present my findings at the URSC Symposium in April of 2019.

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Application to Current Coursework:

My proposed study will fulfill my externship/research component of my Environmental Biology Master's Degree. Further, my background research and grant writing aligns with coursework for my Grant Writing course. Analysis of the data and the overall project design apply the skills I have learned in my Biostats Research Design course this semester. My work will add to years of research and data collection by Dr. Kleier and her colleagues, and my findings will add to a stronger overall understanding of the vegetation along the gondola in Breckenridge.

Table 1. URSC Budget Justification

Items	Description	Funds requested from URSC	Funds requested from other sources	Source of other funds
Supplies				
Field Notebook	**RITE IN THE RAIN FIELD NOTEBOOK**	**$4.70**		
Transect/Quadrat frame	**$70.05 + $9.95 S/H**	**$80.00**		
Plants of the Rocky Mountains Field guide	**$19.99**	**$19.99**		
Camera	**CANNON POWER SHOT**	**$109.00**		
Other				
Gas (5 trips at 160 miles/trip)	**5 TRIPS AT 190 MILES/TRIP**	**$94.80**		
Parking	**$8.75/DAY*5**	**$43.75**		
Food	**$21 PER DAY * 5 DAYS**	**$105**		
Total URSC Request		**$457.24**		

Supplies:

Transect/Quadrat frame: Calculated from online costs from Carolina Biological Supply Company. This quadrat frame is necessary for percent cover calculations.

Plants of the Rocky Mountain Field Guide: Calculated from costs on Amazon.com. This field guide will be used in plant identification to record data on species richness and diversity.

Camera: Cost estimate calculated from Amazon.com. The camera will be used to take aerial pictures of the percent coverage transects. Having pictures of the quadrats will increase the objectivity of the observer.

Field Notebook: Calculated from costs on Amazon.com, the rite in the rain field notebook will be used for data collection and field notes while out in the field.

Other:

Gas: Round trip between Regis University and the town of Breckenridge is 160 miles. The cost was calculated using gas mileage for a 2004 Ford Escape (20 mpg), and gas estimates from the corner store price on 11/28/17 ($2.37/gallon).

Parking: Parking estimates are from townofbreckenridge.com, and costs are based on a full day of parking in F lot.

Food: Cost estimates are calculated at $7 a meals with three meals a day for five days.

CHAPTER 3. JOURNAL MANUSCRIPT: USING GEODIVERSITY TO PREDICT BIODIVERSITY AT ROCKY MOUNTAIN NATIONAL PARK, COLORADO

Abstract

Geodiversity is the geological richness of an area and comprises abiotic factors, including slope, elevation, aspect, soil type, and underlying geology type. Geodiversity accurately indicates biodiversity at a large, state wide scale. My study assesses the use of geodiversity as an indicator of biodiversity on a smaller scale at Rocky Mountain National Park (RMNP) in Colorado. I hypothesized that geodiversity would accurately indicate areas of high biodiversity. To calculate geodiversity, I compiled GIS layers of slope, elevation, aspect, soil type, and geology, and calculated the variety of each of these layers and then summed these layers to produce a map of geodiversity scores. To determine the validity of this model, I mapped sites of known high biodiversity on the geodiversity map. These sites scored in the high geodiversity class, providing evidence that on the small scale, park-level areas of high geodiversity are correlated with high biodiversity. To understand how what areas of the park have high geodiversity, I overlaid a vegetation type map on the geodiversity map. This provided mean geodiversity calculations for different vegetation types. Alpine and Riparian/Wetland areas scored the highest mean geodiversity. With these models, I showed that geodiversity can be used to indicate areas of high biodiversity at a small-scale park level, a metric that can be used in park level management decisions.

Introduction

Anthropogenic climate change, deforestation, and habitat degradation all pose immediate threats to conservation of global biodiversity, necessitating new strategies and models for conserving biodiversity. A recent World Wildlife Foundation (WWF) report stated that we have lost 59% of global biodiversity between 1970 and 2010 (WWF, 2014). In response, the Convention on Biological Diversity has demanded a decrease in the rate of biodiversity loss by 2020 (Pena, 2016). With an unpredictable and rapidly changing climate, it is difficult to forecast future species distributions and extinctions, driving conservationists to seek new ways to protect biodiversity. One proposal is to identify areas capable of maintaing strong biodiversity in the coming decades and to conserve those lands.

Current methods for biodiversity retention are on a species-to-species basis (Anderson & Ferree, 2010), for example, the endangered species act works by identifying species in danger of extinction and focusing solely on the protection of those specific species. Once the species is no longer endangered, the species is taken off the list and no longer protected. This is a resource-intensive solution, and while this style of conservation has successfully saved some species from extinction, it does not address the larger problem: large scale biodiversity loss and lack of ecosystem protection. Scientists are seeking larger-scale, more efficient, and resource-savvy approaches to biodiversity protection to augment conservation efforts. One possible method would be to protect the drivers of biodiversity, such as habitat heterogeneity (Anderson & Ferree, 2010). Habitat heterogeneity plays a large role in promoting species richness by providing diverse habitats to house a large number of diverse species (Rosenzweig, 1995; Nichols, 1998). One way to identify habitat heterogeneity is with geological data, which is typically far easier and less expensive to attain than biodiversity data (Hjort et al., 2012), making this approach less resource exhaustive.

Climatic, geologic, and natural land features control the available environments and habitats in an area, suggesting that species richness can be maintained by habitat protection (Kruckeberg, 2004). For example, at Rocky Mountain National Park, the elevation gradient, provides three drastically different ecosystems: montane, subalpine and alpine tundra (Brooks, 2013). These three ecosystems are home to drastically different habitats, ranging from year-round snow cover to flowing riparian areas leading to a wide range of species (Brooks, 2013). As climate change influences important ecological variables such as temperature, precipitation, and growing days, climatic habitats will likely shift along longitudinal and elevation gradients. The climatic movement of habitats force species to migrate along with them in an effort to find new areas that have the appropriate temperatures, precipitation, and overall habitat that support them (Pearson, 2006). Unfortunately, this migration can be inhibited by natural barriers; barriers like highways and housing developments also inhibit the migration of species (Findlay & Houlahan, 1997). Due to the recent increase in urbanization and development of previously undisturbed areas, there are far fewer migration corridors, open spaces, and protected forests for these species to colonize compared to previous normals (Findlay & Houlahan, 1997).

Geodiversity protection ensures that there is an overlap between appropriate climatic conditions and appropriate geological and habitat conditions. Geodiversity describes the range of geological features in an area, including, but not limited to, rocks, minerals, bedrocks, fossils, sediments, landforms, physical processes, hydrology, and soils (NPS, 2004; Gray, 2014; Tukiainen et al., 2016). As theorized by Hunter et al. (2008), the geological environment is a "stage" that supports the "actors": species targeted for conservation. We can maintain current and future species as the climate changes if we support a variety of “stages” to support them (Hunter et al., 1998; Anderson & Ferree 2010; Gill et al., 2015; Lawler et al., 2015; Hjort et al., 2015). This method of conservation goes beyond the protection of individual species; conserving the ‘stage’ provides a long-term conservation strategy, giving us ecosystem insurance in an unpredictable and rapidly changing climate (Anderson & Ferree 2010; Hylander, 2012). In conclusion, maintaining geologically diverse landforms allows species to have suitable environments available for relocation as climates change (Brost & Beier, 2012).

Geodiversity can be used as an accurate coarse-filter surrogate measure for biodiversity. Researchers Faith and Walker (1996) found that geodiversity predicted presence of reptiles, amphibians, plants and vertebrates 84%, 69%, 67%, and 40% (respectively) more accurately than random selection, and these results have been replicated across taxa and habitat (Schintzler et al., 2011; Nichols et al., 1998; Tukiainen et al., 2016; Anderson & Ferree, 2010; Stein et al., 2014). Geodiversity is an accurate predictor of biodiversity in many different habitats and climates, providing researchers a valuable tool in conservation plans worldwide (Anderson & Ferree, 2010).

While sufficient evidence exists that geodiversity can be used as an accurate predictor of biodiversity, the scale is typically regional or national (Benito-Calvo et al., 2009; Anderson & Ferree 2010; Pellitero et al., 2016). Little research has focused on the relationship between geodiversity and biodiversity at a small scale, park level. This is important as most conservation efforts occur on a smaller scale, in national parks and national wildlife refuges. At 415 square miles, RMNP, in the northern central region of Colorado, provides an appropriate landscape to investigate small scale geodiversity and biodiversity patterns. Previous research at RMNP has used GIS data to map susceptibility to debris flow (Lambert, 2016), but research using GIS data to map geodiversity for biodiversity prediction purposes has not yet been done here.

The goal of this project is to identify areas of high geodiversity at RMNP and to determine vegetation types and ecosystems with high geodiversity. Additionally, I aim to validate that this method of calculating geodiversity is accurate at a small park level scale. To calculate geodiversity at RMNP, I incorporated topographic and landscape variables into the geodiversity calculations. I did not include climate variables due to their extremely low resolution, which gave very low variability in such a small area.

The main quesitions of interest are:

1) Is RMNP home to wide range of geodiversrity?
2) What percentage of the park falls into each geodiversity category (high, medium, low)?
3) Do areas of high geodiversity coincide with certain vegetation types?
4) Is this method of calculating geodiversity an accurate predictor of biodiversity at RMNP?

I hypothesize that:

1) Since riparian areas are typically home to high biodiversity compared to other vegetation types, I expect these areas to have the highest geodiversity.
2) I hypothesize that areas of high geodiversity will correspond with areas of high biodiversity.

Methods

Study Site

Rocky Mountain National Park is a 415 square mile park in the northern central region of Colorado. RMNP at its highest point rises 14,258 feet above sea level and hosts a variety of climates, environments, and habitats for its bountiful wildlife, including mountains, alpine lakes, wooded forests and mountain tundra. It's small relative size compared to other areas where geodiversity has been calculate, and its large elevational range of 7,800 feet to 14,258 feet that provides huge opportunity for both geo- and biodiversity make it an ideal site for my research.

Data Collection

One of the main benefits of using geodiversity as a proxy for biodiversity is that the vast majority of geodiversity data are free and available in public databases like SUUGO and PRISM (USDA, 2006; PRISM, 2015). Data collection requires no groundwork and bares no extra cost. Data were collected between 2005 and 2019, and I digitally received the data February 8th, 2019.

Elevation

Elevation is a known predictor of vegetation type; typically higher elevations are home to tougher living conditions, such as lower temperatures and decreased oxygen (Körner, 2007). Ecosystems change along elevation gradients include plant diversity, productivity, species traits and physiology (Lomolino, 2001; Whittaker & Niering, 1975; Raich et al., 1997; Fernández-Calvo & Obeso, 2004; Pellissier et al., 2010; Ziska et al., 1992). Additionally, elevation can act as a proxy for changes in both temperature and precipitation which can lead to changes in species richness along elevational gradients (McCain, 2001). I derived elevation data from a *Digital Elevation Model (DEM)* which is an approximation of the earth's surface, providing topographic and landscape information. The DEM was originally downloaded from the USGS National

Elevation dataset (USGS, 2002) and then provided to me in raster format at the highest resolution (10m) from the U.S. National Park Service.

Topography

Slope. Vegetation also has a strong relationship with slope. In general plant cover and specie richness increase with decreasing slope (El-Hassanin et al., 1993). This can be explained by the affects of slope on soil moisture and soil stability. For this project, I calculated slope using the Slope tool in ArcGIS on the DEM layer.

Aspect. Topographic variation, including aspect, is critical in predicting vegetation. The aspect of the slope influences factors like temperature, soil moisture and solar radiation. In the northern hemisphere, north facing slopes are typically more shaded, cooler, and wetter, while the southern aspects are hotter, drier, and have increased solar radiation. Likewise, aspect has been shown to affect overall vegetation cover and species richness due to the differing water stress (Nadal Romero et al., 2014). I calculated aspect using the Aspect tool in ArcGIS on the DEM layer, recorded by compas degree on a scale of 1-360.

Geology

Geology significantly impacts what types of vegetation are able to grow in an area, for example areas of biotite schist will foster different species than volcanic rock. Geological data were provided by the “Geological Map of Rocky Mountain National Park and Vicinity, Colorado.” These data were produced as part of the Geological Resources Evaluation of RMNP created by the National Resources Information Division Inventory and Monitoring Program and the Geological Resources Division of the National Park Service. Geologic data were provided in a vector format and contain 46 classes. I dissolved the data and then rasterized it using the Polygon to Raster tool based on the geology type.

Soil

Different soil types are capable of supporting different vegetation (USDA, 2006). For example sandy soils drain water faster than more loamy soils, resulting in species that are more tolerant of drier sites. Soil data were developed in conjunction with the U.S. Department of Agriculture, Natural Resources Conservation Service, which is part of the National Park Service Soil Inventory and Monitoring Program. This dataset is in a vector format and contains 62 classes of soil types. Similar to the geology layer, I dissolved it and then rasterized it using the Feature to Raster tool based on soil types.

Vegetation

Vegetation type is one way to understand the biodiversity that depends on differing geodiversity scores. For example, riparian and wetland areas will have higher biodiversity compared to all other areas in the park. The vegetation layer in this research was provided by Rocky Mountain National Park. In this layer, 45 different vegetation types were classified, 10 of these were waterbodies or unvegetated areas, and were not included in the study (Natural Lakes/Ponds, Outwash, Disturbance/Dead and Down, Streams/Rivers, Unvegetated Surface, Exposed Soil/Man made, Reservoirs/Stock tanks). I used the remaining 35 for my coarse-scale analysis. I classified the 35 vegetation types into 6 more fine vegetation types (Alpine, Aspen, Montane, Riparian/Wetland, Shrub/Herbaceous, and Subalpine) (Table 1.)

Geodiversity Calculation

To calculate geodiversity scores in 140m cells at RMNP, I first converted soil and geology rasters to a resolution of 140m. I used the Resample tool to convert all rasters to have the same cell size (140m). Since the soil raster was the most coarse, I used it to define the output cell size using the nearest resampling technique. To ensure all of the layers were at the same extent, I set the snap raster to the elevation layer. The elevation layer was chosen since it, aspect, and slope were already the same extent. Next, I set the output coordinates to be the same as the elevation raster layer. I also set the cell size in raster analysis to the elevation layer. Next, I used the Resample tool on the soil raster and the geology raster to ensure they had the same extent as the elevation, slope and aspect rasters.

I reclassified some of the raster layers (slope, elevation, and aspect) using the Reclassify tool and manual breaks. I classified slope into 12 classes at 5 degree intervals (Lambert, 2016) I classified aspect into 8 classes (north, northeast, east, southeast, south, southwest, west, and northwest). I reclassified elevation into 9 classes according to Jenks natural breaks, which clusters the data based on their distribution (2507m, 2692m, 2875m, 3052m, 3213m, 3367m, 3532m, 3726m, 4343m) (Jenks, 1967; Melelli, 2017).

To calculate the diversity, or the number of unique values that are in the neighborhood of each cell within each layer, I used the Focal Statistics tool with statistics type variety (Melelli, 2017) (Figure 2.). I defined the analysis mask as a circle with a radius of three cells. The circle was used to optimize an omnidirectional resolution as opposed to the blocky output of a rectangle mask (Melelli, 2017). The output of the the focal statistics produced 5 layers of differing numbers of classes. To ensure all layers were on the same scale, I reclassified them into 6 classes according to Jenks' natural breaks algorithm. I coded the highest diversity of each parameter with a 6 and the lowest geodiversity with a 1 (Melelli, 2017).

Finally, to produce a map of the overall geodiversity, I calculated the sum of the layers using the Weighted Sum tool where each layer was given the same weight in the final geodiversity calculation (Melelli, 2017) (Figure 4.). For practical purposes, I reclassified the geodiversity map into three classes, low (5-14), medium (14-16), and high (16-26), using the Reclassify tool, and Jenks natural breaks (Melelli, 2017).

To determine which vegetation type has the highest geodiversity, I used the Zonal Statistics tool to calculate the mean goediversity within each vegetation type polygon this analysis was done both at a coarse scale, and at a fine scale (Figure 6. & Figure 5. respectively). To determine if this model was valid, I plotted sites of known high biodiversity onto the geodiversity map and recorded the geodiversity score of the cell with which it coincided.

Table 1. Vegetation types and their classification in the coarse and fine-scale analyses

Coarse-Scale	Fine-Scale
RIPARIAN/WETLAND	Cottonwood
ASPEN	Mixed Conifer with Aspen (Spruce - Fir)
SHRUB/HERBACEOUS	Shrub Upland Lower Montane - Undifferentiated
SUBALPINE	Lodgepole Pine - Low Elevation < 9500 ft
ASPEN	Mixed Conifer with Aspen (Lodgepole Pine)
MONTANE	Ponderosa Pine Shrubland
ASPEN	Mixed Conifer with Aspen (Douglas-fir)
SHRUB/HERBACEOUS	Herbaceous Upland Montane < 9600 ft
RIPARIAN/WETLAND	Shrub Riparian Cross Zone < 9600 ft
RIPARIAN/WETLAND	Shrub Riparian Cross Zone > 9600 ft
SUBALPINE	Lodgepole Pine - High Elevation > 9500 ft
SHRUB/HERBACEOUS	Shrub Upland Lower Montane - Big Sagebrush
ASPEN	Upper Montane Aspen
ASPEN	Mixed Conifer with Aspen (Ponderosa Pine)
MONTANE	Ponderosa Pine Graminoid
SUBALPINE	SubAlpine Limber Pine
SHRUB/HERBACEOUS	Shrub Upland Lower Montane - Bitterbrush
MONTANE	Montane Douglas Fir
SUBALPINE	Ribbon forests Islands
MONTANE	Ponderosa Pine Rockland
SUBALPINE	SubAlpine Mixed Conifer
ALPINE	Shrub Upland Alpine
SUBALPINE	Lodgepole Pine - Rock
RIPARIAN/WETLAND	Herbaceous Wetland Cross Zone - Wetland
ALPINE	Herbaceous Upland Alpine Fellfield
RIPARIAN/WETLAND	Riparian Upper Montane Mixed Conifer > 8500 ft

RIPARIAN/WETLAND	Riparian Aspen
RIPARIAN/WETLAND	Herbaceous Wetland SubAlpine / Alpine - Alpine Meadow
MONTANE	Juniper
SUBALPINE	Krummholz
ALPINE	Herbaceous Upland Alpine > 9600 ft
RIPARIAN/WETLAND	Herbaceous Wetland Cross Zone - Marsh
RIPARIAN/WETLAND	Riparian Lower Montane Mixed Conifer < 8500 ft
ROCK	Cliff Face - Bare Soil / Rock
GLACIER	Glacier

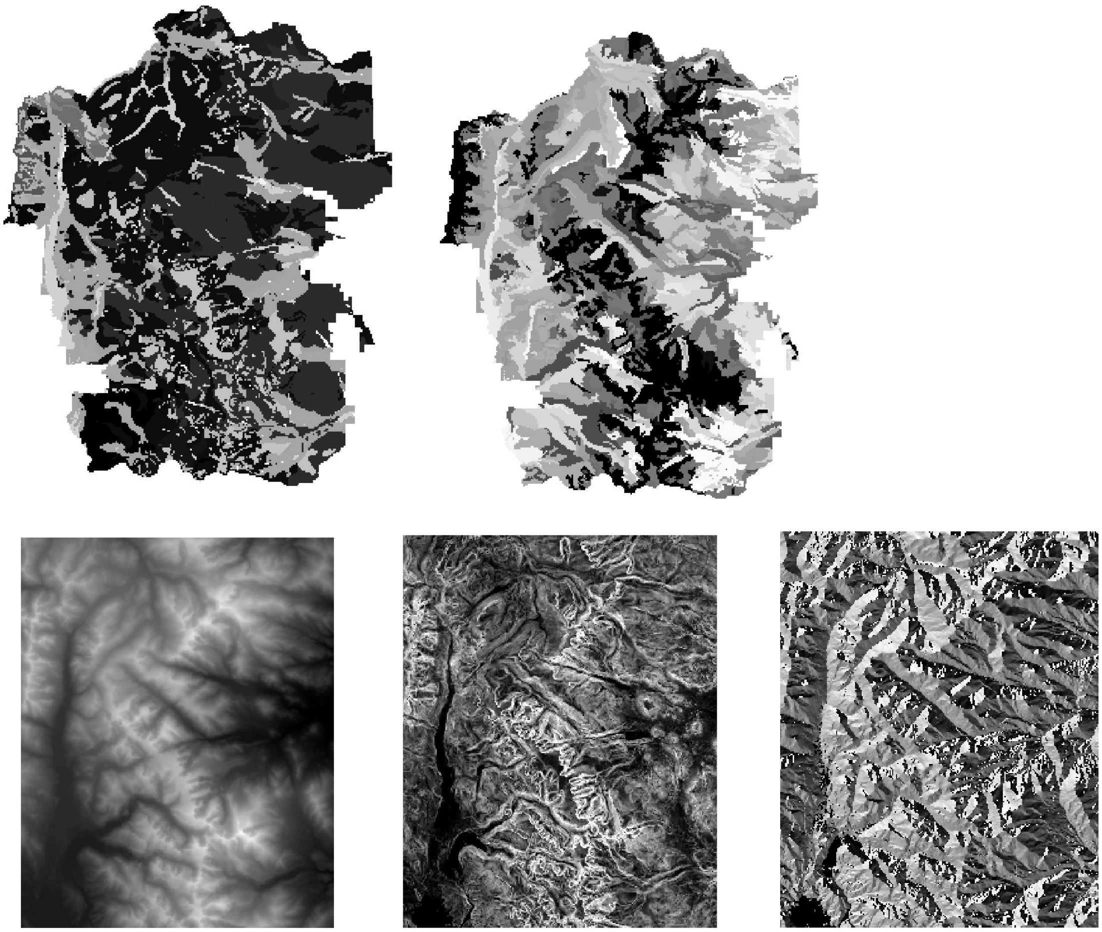

Figure 1. The original geology, soil, elevation, slope, and aspect layers.

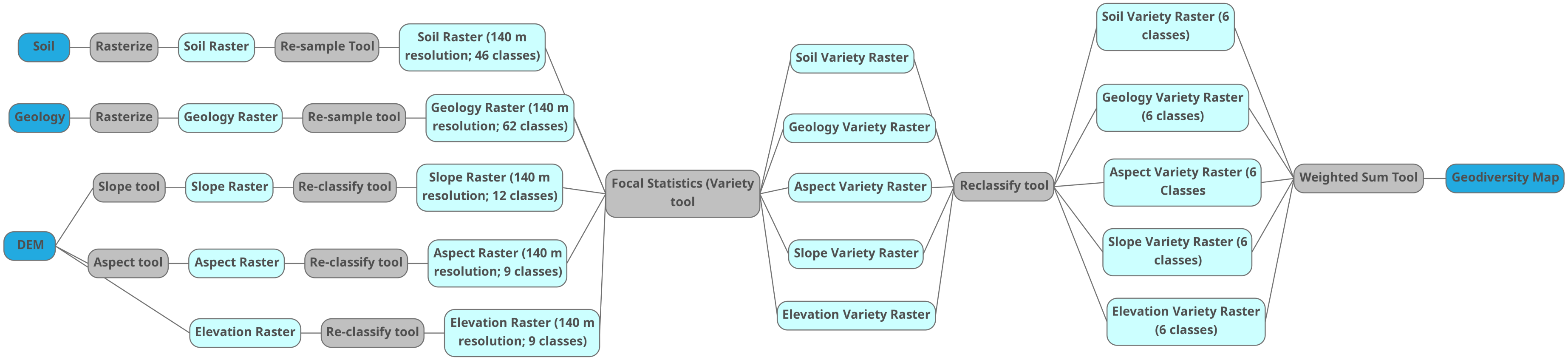

Figure 2. Flow chart showing the steps of the analysis

Results

Cell by cell analysis

Geodiversity accurately predicted biodiversity at the park level (Table 2.). There was a wide range of geodiversity in the park, with geodiversity scores ranging from 5-26 (Figure 4.). The geodiversity map (Figure 4.) is the sum of the diversity of each parameter: elevation, slope, aspect, soil, and geology (Figure 3.). It is in raster, grid format with cell size of 140m. The geodiversity index yielded scores along a scale of 5-26 with 5 being the lowest geodiversity in the park and 26 being the highest, with a maximum possible score of 30. The geodiversity map has three geodiversity classes, low (5-14), medium (14-16), and high (16-26). 30.1% of the park is classified as low geodiversity, 46.6% of the park is medium geodiversity, and 23.3% of the park is high geodiversity.

Coarse-scale vegetation analysis (Figure 5.)

When vegetation types were more coarsely grouped, alpine vegetation types had the highest mean geodiversity (15.51), followed by Riparian/Wetland (14.94), and Subalpine (14.74) (Figure 5.). Riparian/wetland vegetation mean geodiversity had large variance of 2.75. At this scale, none of the vegetation types were in the high geodiversity class (Figure 5.), and only the alpine vegetation class was in the low geodiversity class. There was less differentiation between geodiversity scores at this coarse of a scale compared to the fine-scale (geodiversity score range: 13.9-15.5).

Fine-scale vegetation analysis (Figure 6.)

At the fine scale vegetation analysis, the range of mean geodiversity scores were 9.09 to 18.88, this was a much larger range compared to the coarse-scale vegetation analysis. The highest mean geodiversity score was areas identified as glaciers on the vegetation type map at

18.88 mean geodiversity. Areas defined as Riparian Lower Montane Mixed Conifer Forest below 8500 feet (16.94) and Herbaceous Wetland Cross Zone (Marsh) (16.36), had the next highest mean geodiversity. These three vegetation types were the only ones to have mean scores in the high geodiversity class (Figure 6.).

Of the fine-scale vegetation types, the most variation was among those that were further classified as riparian/wetlands in the coarse-scale analysis. Most of them had high geodiversity scores (Riparian Lower Montane Mixed Conifer 16.94, Herbaceous Wetland Cross Zone Marsh 16.36, Herbaceous Wetland SubAlpine 15.57, Herbaceous Wetland Cross Zone Wetland 15.23, and Riparian Aspen 15.53) except for Cottonwood, scoring low (11.30).

Three cells of known high biodiversity a montane subalpine ecotone (445640, 4472071m), an alpine tundra area of ute pass (441202, 4471373m) and an aspen riparian area (450127, 4468467m) had geodiversity scores of 17, 16, and 17 respectively (Table 2.).

Table 2. Areas of known high biodiversity mapped on geodiversity map.

Areas of Known High Biodiversity		
Site	Coordinates (UTM 13, Meters)	Geodiversity Score
Montane Subalpine Ecotone	445640, 4472071	17 (High)
Aspen Riparian Zone	441202, 4471373	17 (High)
Ute Pass Alpine Tundra	450127, 4468467	16 (High)

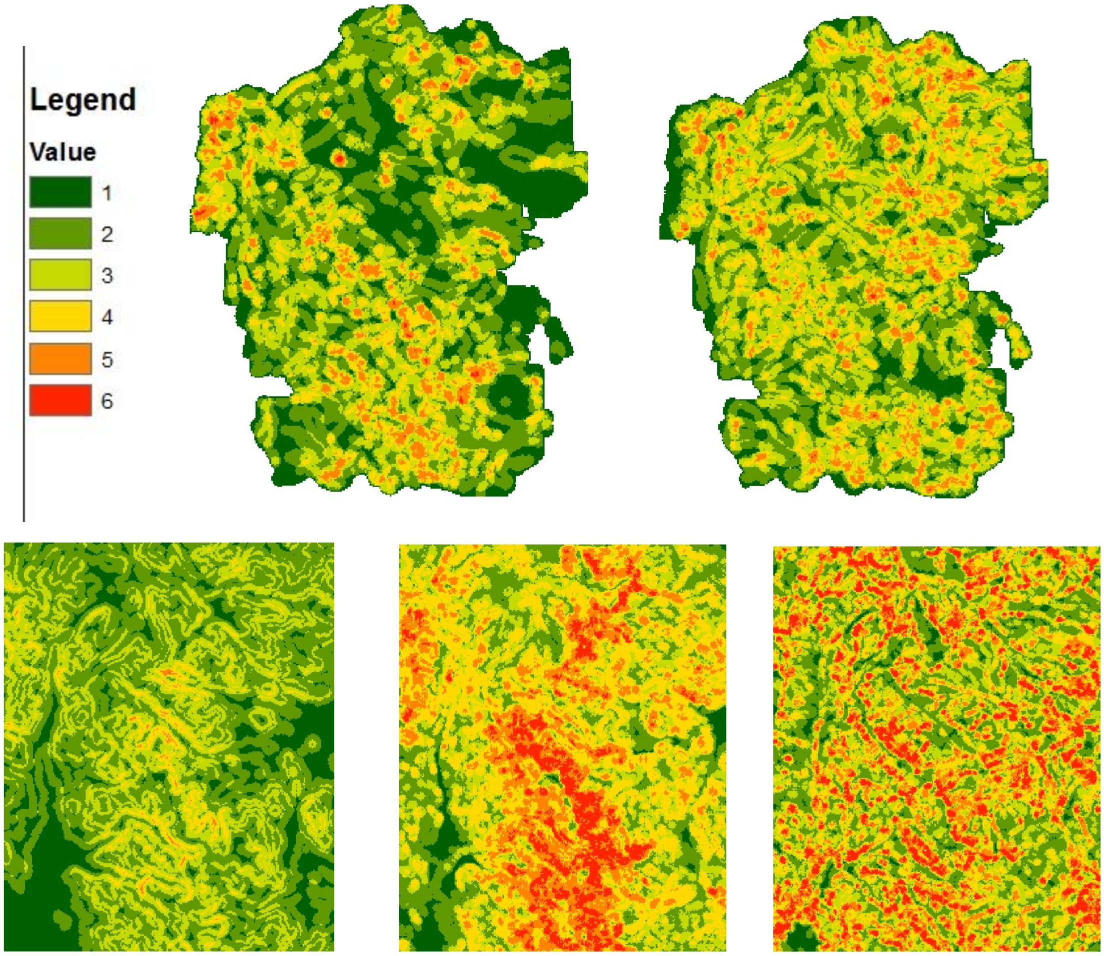

Figure 3. The raster layers after the variety focal statistics (geology, soil, elevation, slope, and aspect, respectively). Red cells are areas that have high diversity of of that speciific class (geology, soil, elevation, slope, and aspect).

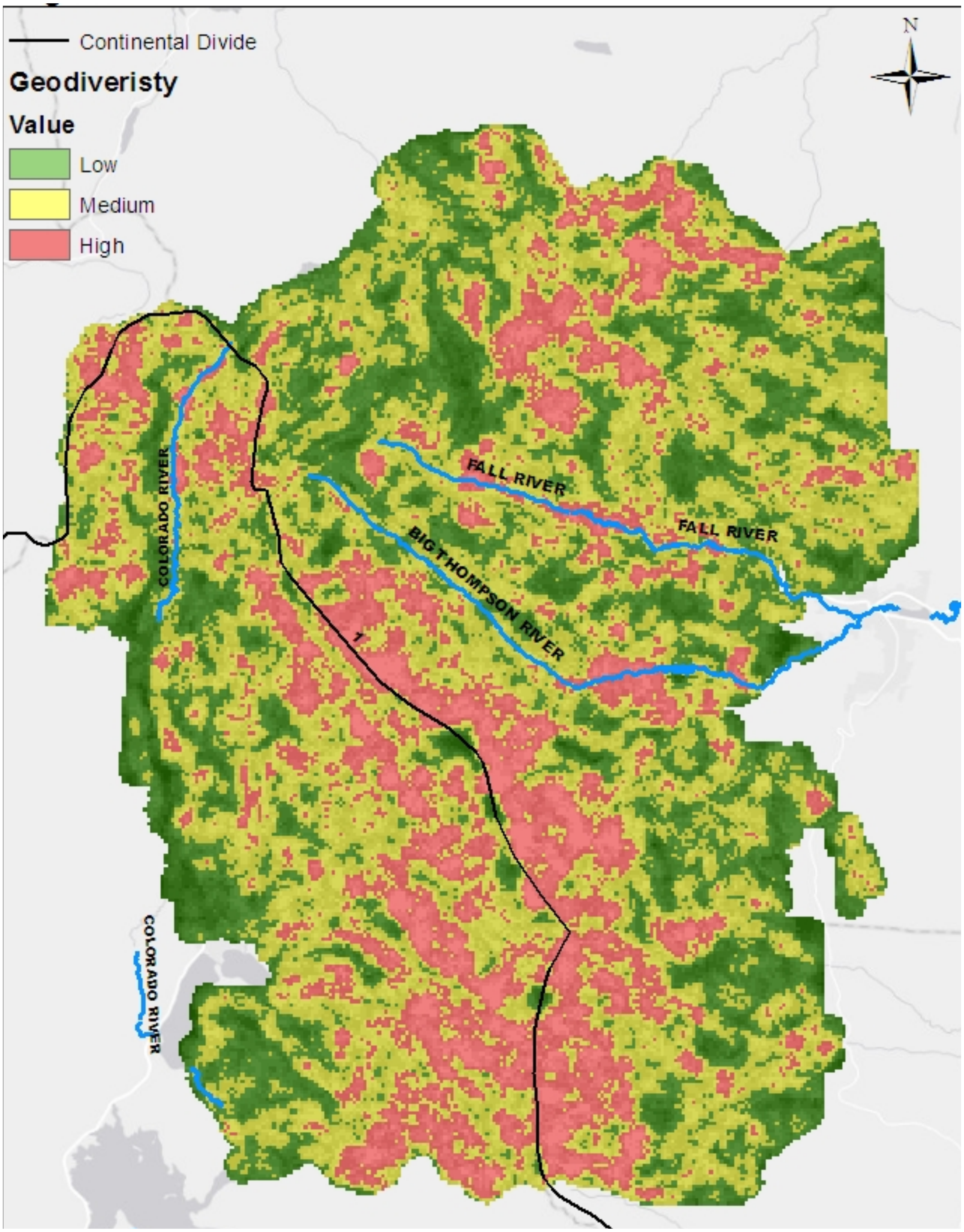

Figure 4. Final geodiversity Map. Geodiversity is classified into low, medium and high geodiversity (5-14, 14-16, 16-26).

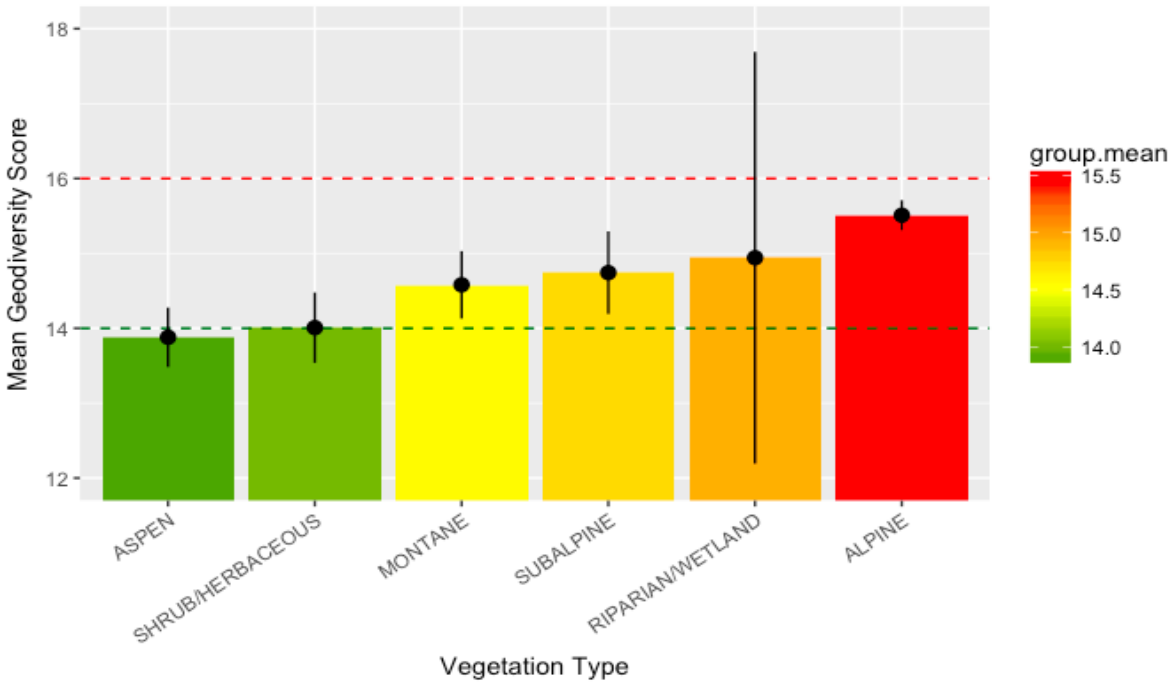

Figure 5. Mean geodiversity scores in each coarse-scale vegetation type. The dotted lines indicate the range of low, medium, and high geodiversity classes. The error bars indicate the standard error of the averages.

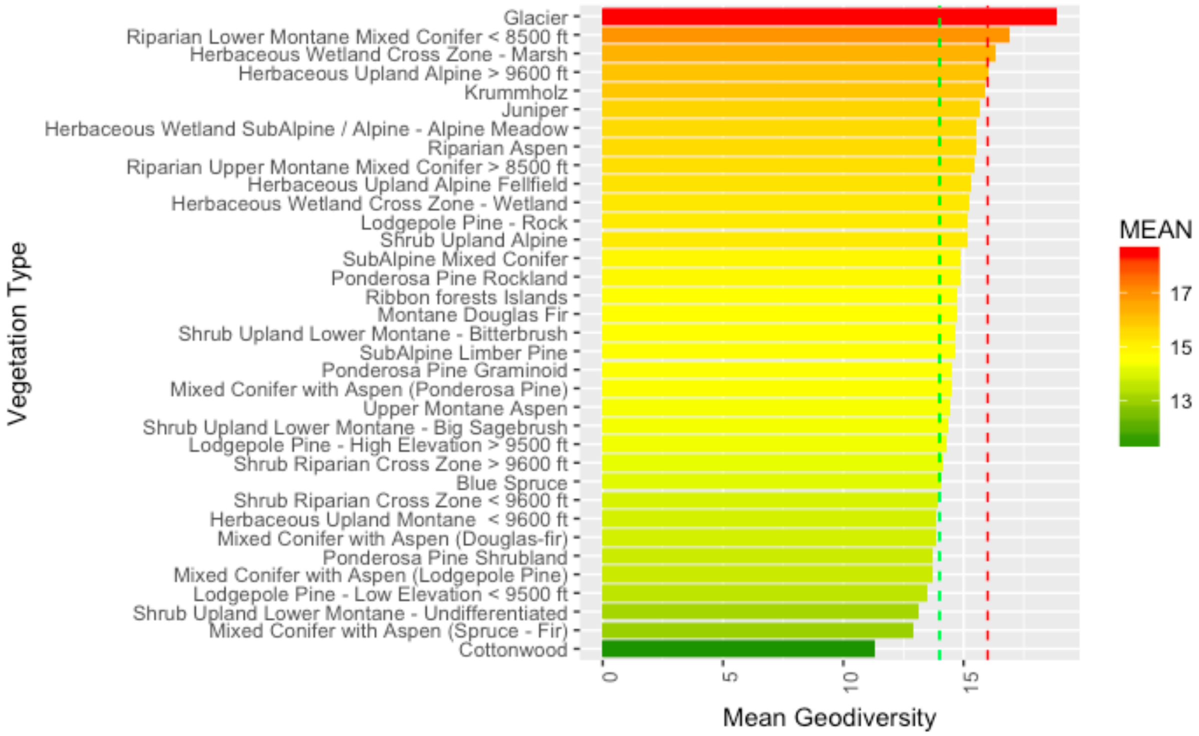

Figure 6. Mean geodiversity scores of each fine-scale vegetation type. The dotted lines indicate the range of low, medium, and high geodiversity classes.

Discussion

The methods detailed in this project successfully predict biodiversity. The model used in this research was based on the work of Melelli et al. (2017), where geodiversity was calculated as the sum of the diversity of five different components: slope, aspect, elevation, soil and geology. Other research has used components of roughness, drainage density, climate, and hydrology (Melelli et al., 2017; Parks & Mulligan, 2010). Inclusion of some of these components could have made the model more comprehensive, and made the geodiversity index more robust; however, these components were not available for our study area. Sufficient research has found high success rates in using geodiversity as a predictor of biodiversity at larger scales (Tukiainen et al., 2016; Anderson & Ferree, 2010). Little research has found substantive success at the smaller park scale, and the results of this research were congruent with that.

When sites of known high biodiversity were mapped on the geodiversity index, they scored in the high geodiversity range, suggesting that the model was relatively accurate. The model successfully identified a wide range of geodiversity scores. While there were no sites that scored the maximum of 30, the large range indicates that there are areas in the park are far more diverse in terms of our five components compared to others.

The model showed strong discriminatory ability on a cell to cell basis. When average geodiversity scores were calculated across vegetation types the model became less distinct with all of the vegetation types having similar mean geodiversity scores. The small range of mean geodiversity scores indicates that the 6 different vegetation types had no clear distinction in their average geodiversity scores. In addition, when averaged out, none of the coarse vegetation types scored in the high geodiversity range. This is due to the variation of the geodiversity scores which caused the high geodiversity cells to be evened out my the low scoring geodiversity cells.

Riparian/wetland vegetation types had high variation in mean geodiversity driven by the low geodiversity score of cottonwood vegetation areas (Figure 4.). While other riparian/wetland areas scored high geodiversity, cottonwood scored lowest score of all vegetation types park wide. The low score could be attributed to the fact that they represent a relatively small spatial area in context of the whole park (0.02%), and typically only grow in relatively recently disturbed areas (Colorado State Forest Service, 2015).

On the flip side, glaciers had the highest mean geodiversity score. Similar to the cottonwood, some of this could be due to their small relative area (0.10%) of the whole park. One reason glaciers may have had such high geodiversity scores could be because all of the glaciers at RMNP are cirque glaciers (Hoffman et al, 2005). This means that they are relatively small glaciers that are in bowl-shaped basins (Hoffman et al, 2005). Because of their unique bowl shape, the glaciers have rapidly changing aspects over short distances, possibly giving them much higher diversity scores in the aspect layer and impacting their overall high geodiversity scores.

High geodiversity scores of Alpine and Riparian/Wetland vegetation types (Figure 5.) are visible in the map of geodiversity with noticable geodiversity hotspots occurring near the continental divide and along Fall River and Big Thompson (Figure 4.). High riparian and wetland geodiversity scores suggest that the presence of water could be an important factor contributing to high geodiversity. Future research could analyze and quantify how proximity to water (lakes, ponds, streams, and rivers) is correlated with geodiversity scores. Another interesting question that arises from this research is how close the high geodiverse areas are to recreation areas like campgrounds, trails, or roads. Understanding these relationships could aid in management decisions and areas of suggested protection, especially in areas where tourists have high impact. Additional research could investigate how geodiversity is correlated with specific biodiversity, for example are there specific species that utilize these areas of high biodiversity. Answering this question could futher validate the use of geodiversity as an indicator of biodiversity on a park level.

There were some limitations to the breadth of this study. For example, I was unable to use climate data due to its coarseness. In future research, incorporating climate variables like precipitation or temperature into the geodiversity calculation could provide more meaningful results. A second limitation of this study is the use of a GIS-based approach. The geological and biological processes cannot be fully explained at a 140m cell sized scale. True understanding of the relationship between geology and biology must be done observing their interaction on the ground. Finally, the non-randomization of the areas identified as high biodiversity, and the fact these areas were based off of empirical data lead to limitations in the conclusions that can be made about the model's success. To more accurately quantify the ability of geodiversity to predict biodiversity, future researchers would need to quantify biodiversity on the same scale as the geodiversity is quantified, and then calculate the correlation between the geodiversity and biodiversity. My approach is adventageous as a first step in understanding the geo- and biodiversity of an area, but the results of this type of study should be used to lead future research in the correct direction.

Some of the decisions made in the geodiversity calculation process could have impacted the results in significant ways. Using Jenks natural breaks to classify the diversity of the 6 components (Figure 3.) meant that components like slope that had low mean diversity scores were given very few cells with a score of 6, in comparison slope and aspect had high diversity scores and there were far more cells given a score of 6. This meant that when all six layers were summed together, slope and aspect had more weight in the final model. Changes in the classification of the 6 geodiversity components (slope, aspect, elevation, geology, and soil) could change the weight each component contributes to the final geodiversity scores. Further, when calculating geodiversity scores, all six of the components were given equal weight. If we thought that soil or geology had a greater impact on the geodiversity of an area we could have made the decision to weight that layer higher, which would have change the final geodiversity scores. Another classification that could have been changed is the low, medium, and high geodiversity classification. We chose to use Jenks natural breaks, but we could have classified these differently, for example classifying high geodiversity as any cell within the 90th percentile, etc.

Overall, the methods of this paper can be applied for geodiversity calculations worldwide. Small modifications to the methods are suggested on an individual basis, making the model appropriate for specific geodiversity questions. The results of this give substantive evidence that the model accurately predicted areas of high biodiversity, and that geodiversity could be used at a park level small-scale. Geodiversity maps, like the one produced in this study are good coarse identifiers of biodiversity. Knowing this, areas of high geodiversity should be protected to provide habitat for future species and could therefore be used by park management to determine areas of conservation need, and make decisions about where to build new trails and infrastructures. By creating new ways to indentify areas of high geodiversity, we can effectively conserve areas of high geodiversity, and in essence protect the stage that is protecting the actors.

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CHAPTER 4. ENVIRONMENTAL STAKEHOLDER ANALYSIS: DRAINAGE BASINS INCORPORATED INTO CITY PARK GOLF COURSE REDESIGN TO DECREASE CITYWIDE FLOODING ISSUES

Introduction

From the days where Denver was a mining town to today, the city has struggled with flooding issues. Shortly after the city's founding in 1858, a large flash flood swept through Cherry Creek (a tributary to the South Platte River), killing 20 people and causing $1 million dollars in damage (VISIT DENVER, 2017). Despite this clear lesson about the location of the city, the residents remained and rebuilt with some water management facilities established to protect the city. Almost exactly 100 years after the first flood decimated the city, another large flood swept through downtown Denver in 1965, killing 8 people and costing approximately $508.2 million dollars in damages in the Denver metropolitan area (Colorado Parks and Wildlife, 2017). This event lead to the creation of the Chatfield Reservoir and dam with construction beginning in 1967. The Chatfield Reservoir dramatically decreased the prevalence of destructive flooding throughout the Denver area, but some amount of flooding persists even today. A major reason for the continued flooding is that as the city developed, all of the natural waterways to the North and East of downtown Denver were eliminated and built over as the city expanded.

The city of Denver sits within a large natural geologic basin, aptly named The Denver Basin. The primary waterway through the Denver Basin is the South Platte River, which flows from South to North through the area. Within the city of Denver, there are smaller drainage basins that dictate the flow of water towards the South Platte River. Two of these basins are the Montclair Basin and the Park Hill Basin, which lie to the North and East of downtown Denver, respectively. The Montclair Basin covers 10.9 square miles and is the city's largest basin without a defined waterway. Directly adjacent to the Montclair Basin, the Park Hill Basin covers approximately 5.75 square miles. Stormwater naturally flows through these two basins, towards the South Platte River, but is not confined to specific channels so the waters flow along the roads instead (Colorado Parks and Wildlife, 2017). The City of Denver designates both of these drainage basins as high priority basins due to their relatively flat topography, complete urban development, and lack of an adequate stormwater drainage system. The Platte to Park Hill Stormwater Program encompasses these two basins and works to address flooding throughout the neighborhoods that sit within each basin (City and County of Denver, 2016).

The City of Denver started the Platte to Park Hill Stormwater Systems Program in the summer of 2015 to address ongoing flooding throughout the city. Extending east from the South Platte River, the program addresses issues in multiple neighborhoods: Elyria, Swansea, Cole, Clayton, Skyland, Whittier, Five Points, and Northeast Park Hill (Figure 1. Due to the lack of available waterways in the Montclair basin, low-lying areas throughout these neighborhoods frequently flood during storms. The flooding is only projected to get worse as weather patterns shift and more extreme weather events increase in frequency (Nicholls, 1999). The program serves as a comprehensive approach to stormwater management throughout the Denver metropolitan area and includes numerous proposals for drainage basins and other flood protection projects (City and County of Denver, 2016).

There are three main proposed solutions to this problem, first to construct a stormwater detention basin within the City Park Golf Course to hold excess stormwater (Figure 2). The next option would be regular maintenance of the existing drainage system that would serve to prevent structural instability throughout the affected area. This option would take extensive money and resources, and would only mitigate the flooding events, not prevent them in the first place like the other two proposed options would. A third proposal is to create stormwater detention basins within the Cole neighborhood, this is similar to the City Park Golf Course redesign, but would impact 50 homes in the proposed basin site.

Of the flood protection projects, one stands out as the clear choice, the addition of a stormwater detention system at City Park Golf Course to prevent flooding in the Cole, Clayton, Skyland, Park Hill, and City Park neighborhoods (Figure 1; Figure 3). The floodwaters that put these neighborhoods at risk, will be collected into the stormwater detention basins where the water will be held temporarily and slowly released. The benefits of this are two-fold, as it will both prevent flooding and also improve water quality through the natural filtration processes that the detention basins provide. City Park Golf Course provides the perfect area for drainage basin incorporation, as it is already a manufactured natural area, and through a redesign process could be home to multiple drainage basins that protect surrounding neighborhoods from flooding issues.

Stakeholders, Their Interests and Values

In the event of the golf course redesign, some long-standing, old trees will be taken down to make space for the drainage basins. The loss of trees and intermittent construction will have a negative impact on wildlife in the area as the golf course is in a sense a wildlife refuge in a big city for many of these animals. Additionally, there will be job shortages at the golf course through the duration of the construction and these seasonal workers will need to find other sources of work. The greatest impact will be the effect on the local businesses that benefit from the City Park Golf Course, as noise pollution from the construction will drive away customers from local businesses. This impact could include local golf shops, or local restaurants that benefit from the recreational and leisure opportunities supplied by the City Park Golf Course.

Many local homeowners are passionate about these proposed actions. Residents in the City Park neighborhood are upset because they are not the ones that are affected by the flooding, but they will be the ones impacted by the construction occurring in their neighborhood. The noise pollution from the construction would be a nuisance and could impact residents' daily lives. In contrast, homeowners in Elyria, Swansea, Cole, Clayton, Skyland, Whittier, Five Points, and Northeast Park Hill neighborhoods are elated that the city is finally doing something to protect them from the flooding events that could potentially destroy their houses (Kennedy, 2016). The City Park Golf Course option is by far the most ethically sound. The neighborhoods affected by the flooding are lower income neighborhoods than the Golf course neighborhood. The tradoff in this proposal is protection of lower income housing, for noise disturbance in higher income neighborhoods.

Members of the City Park Golf Course are in opposition to the changes coming to their golf course. Many of them feel as though this golf course is a historic landmark in Denver that has been unchanged for years, and are upset to see the nostalgic course changed. On top if this, the members will not be able to visit their golf course throughout the construction process. Not only are the course employees affected by the short-term closing of the golf course, but the golf course workers will also be out of a job for a season. The decreased traffic through the area, and overall decrease in tourism, along with the increase in noise pollution will decrease potential business for local restaurants and shops, giving them reason to oppose the golf course reconstruction project.

Beyond the anthropogenic effects that the golf course redesign will have, the plants and animals that call City Park Golf Course home will be impacted. Activist groups have not let this go unnoticed; art activists in town placed flowers and photographs under the 260 trees that were scheduled to be taken down if the construction were to happen. Groups like the Denver Audubon protested the construction, as City Park Golf Course is not only home to many birds, but also provides a stopover point for many migrating birds who will no longer be able to make their stop if all of these trees are taken down.

Recommendation

All things considered, the City Park Golf Course redesign is the best option to solve the flooding issues in Denver Neighborhoods. While local businesses, neighborhoods, and those invested in the City Park Golf Course may be negatively impacted, these impacts will be short term. The benefits of the added drainage basins will be long term, and protect far more people in more significant ways than those being negatively impacted. Much of the habitat being taken out of the golf course during the reconstruction will be re-planted, and the historic trees will be rehomed in areas around Denver. While 260 trees are planned to be taken out of the golf course, many more are being protected, and 1,013 trees are planned to be planted in the ten years following the golf course redesign (United States, City and County of Denver, City Planner, 2016). The golf course was never a native natural area; the nature there is engineered by golf course architects, and is the product of unnatural amount of water resources, and lawn care. If the golf course were an area home to more native species, the protection of it would be more vital. Further the water retention basins will add to the overall biodiversity at the course, as they will provide a unique habitat that will be intermittently flooded and be home to wetland species that were not previously present. The Golf Course will not only be returned to its previous habitat, but it will also serve as flood protection to many Denver Citizens with no long term detriments.

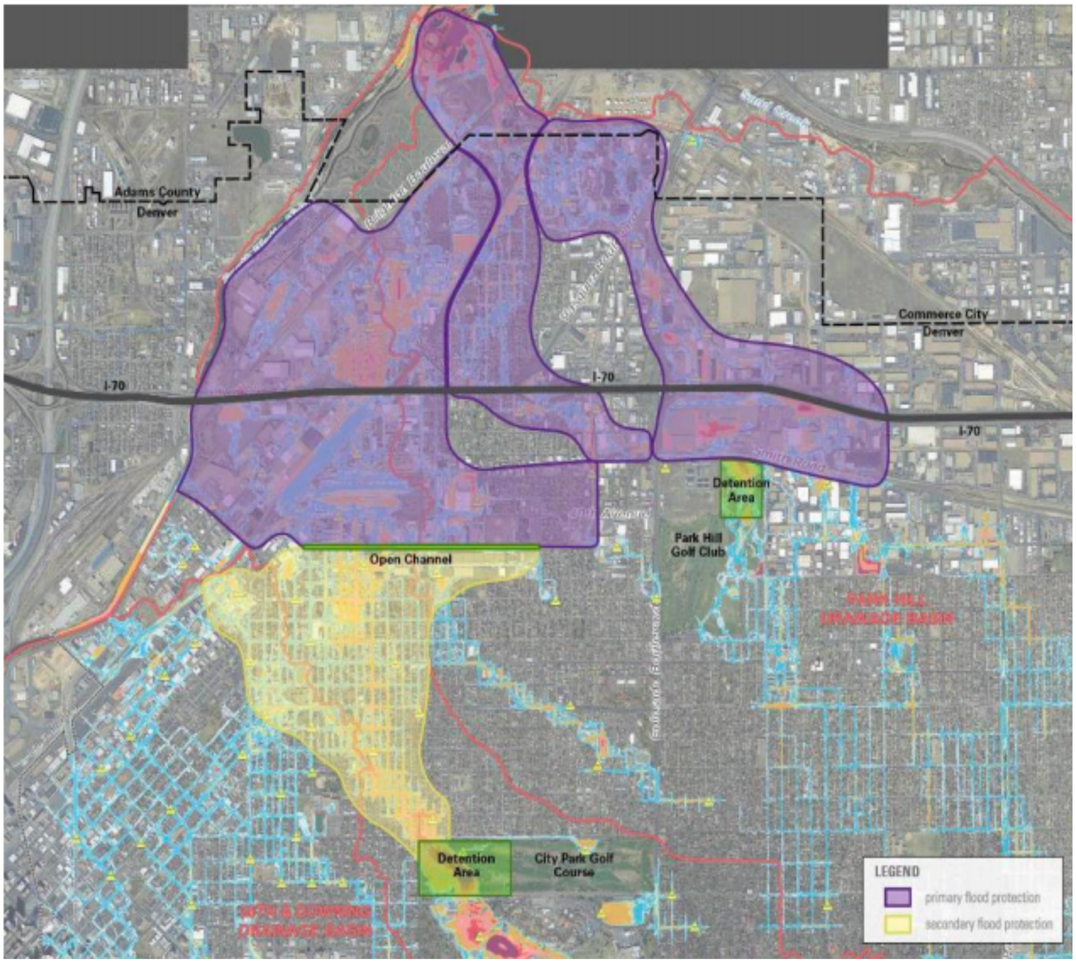

Figure 1. Map indication the areas that would experience reduced flooding with the Cole Neighborhood or City Park Golf Course alternatives (City and County of Denver, 2017).

Figure 2. Shows where the stormwater detention pond will be located on the City Park Golf Course (City and County of Denver, 2017).

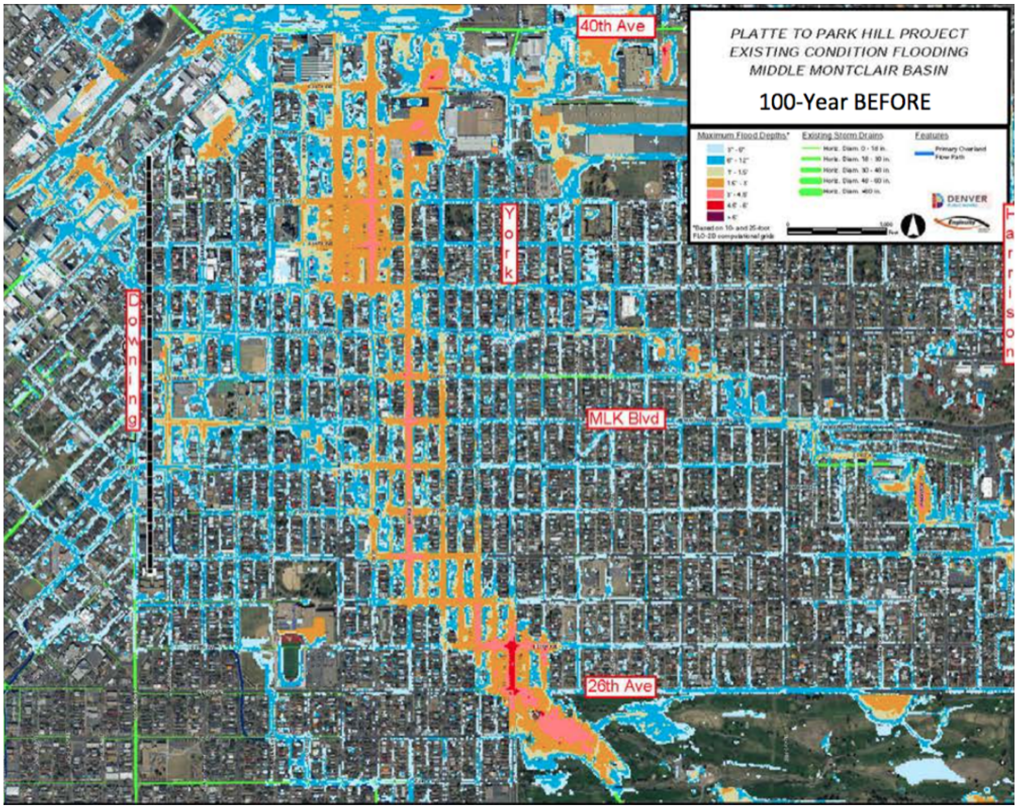

Figure 3. Map of current maximum flood depths predicted for a 100-year flood across the Platte to Park Hill drainage system (City and County of Denver, 2017).

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