MS Environmental Biology Capstone Project

Emily Ramos
Regis University

MS ENVIRONMENTAL BIOLOGY
CAPSTONE PROJECT

by

Emily R. Ramos

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

REGIS UNIVERSITY
May, 2021

MS ENVIRONMENTAL BIOLOGY
CAPSTONE PROJECT

by

Emily R. Ramos

has been approved

May, 2021

APPROVED:

____________________________________, Tyler Imfeld, Ph.D. (Faculty Advisor)

____________________________________, Amy Schreier, Ph.D. (Chapters 1 & 2)

____________________________________, Tyler Imfeld, Ph.D. (Chapter 3)

____________________________________, Mike Ennis, Ph.D. (Chapter 4)

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

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CHAPTER 1. LITERATURE REVIEW

Impacts on Human Health from Deforestation and Aerosol Pollution in the Brazilian Amazon

Deforestation occurs all around the world due to anthropogenic factors such as human settlement and use of land for cattle and crop agriculture (Pacheco et al., 2014). Following tropical deforestation are deforested fires that are used to burn the remaining biomass (including remaining trees) to clear land for agricultural purposes (Pacheco et al., 2014). Deforestation in the Amazon continues to increase annually due to human encroachment and agricultural expansion (Kramer et al., 1997). Few studies have been conducted to evaluate the human health impacts of deforestation and tropical deforested fires. Tropical deforested fire emissions provide evidence that tropical deforestation and biomass burning impose human respiratory and cardiovascular health risks (de Oliveira Alves et al., 2017). Using methods that increase accuracy in quantifying the number of pollutants released into the atmosphere from deforestation and deforested fires can help further understand what air pollutants are in the atmosphere. Obtaining a greater understanding of aerosol pollutants in the air produced by deforestation and deforested fires can help scientists and health experts understand potential human respiratory and cardiovascular health risks in the Brazilian Amazon.

Tropical Deforestation

Anthropogenic disturbances are leading to rapid rates of deforestation within the Brazilian Amazon. The Amazon represents about 40% of the world's remaining tropical rainforests (de Oliveira Alves et al., 2015). Over 20 million people live in the Amazon region of Brazil. Since 1980, the government has been monitoring deforestation in the Amazon and thus far has recorded that more than half a million square kilometers have been destroyed (Koren et al., 2007). The Brazilian Amazon covers 60% of the country with vast and rich biomes spanning 5.1 million km^2 of the Amazon (Custodio et al., 2019). Of this area, 20,000 km^2 of rainforest is deforested annually with the permanent removal of forest due to agricultural expansion and fire clearing mechanisms. Agricultural expansion and cattle ranching are two main drivers of deforestation and biomass burning (Andreae, 1991; Pacheco et al., 2014).

Since 2001, the cattle industry in Brazil has grown significantly, increasing production annually (Bustamente et al., 2012). In order to install pastures for cattle, deforestation occurs by chopping down trees and is followed by the burning of open native forest areas to clear land for pasture development (Pacheco et al.,2014). In a study conducted in 2012, researchers focused on portions of deforestation that have resulted in pasture establishment and subsequent burning of vegetation (Bustamente et al., 2012). In a given year, burned land cover exceeded 170,000 km^2 to implement pasture areas and agricultural crops. Approximately half of all Brazilian emissions originate from cattle raising (Bustamente et al., 2012). Emissions produced by deforestation and deforested fires for cattle ranching and agricultural expansion impose human respiratory and cardiovascular health risks (de Oliveira et al., 2015).

Biomass Burning

The clearing and subsequent burning of biomass can also be called deforested fires. Deforested fires occur when trees are felled, the vegetation is left out to dry for better burning efficiency and then set on fire (Andreae, 1991). Citizens of Brazil burn large portions of the Amazon to clear land for agriculture, cattle-grazing, or land speculation (Sorrenson, 2000).

These fires are more prominent during the dry season from July – October. Since 1990, Brazil's contribution to global biomass burning is estimated at 50-70% of total biomass burning (Sorrensen, 2000).

Biomass burning is monitored today using satellite data of the Amazon to identify trends in active fires burning and smoke accumulation (Koren et al., 2007). NASA's Terra satellite that was launched in 1999 provides data on biomass burning and measurements of aerosols over land using MODIS and MISR sensors. The time of year and seasonality contribute to ranging trends in biomass burning as the dry season usually produces more deforested fires and smoke accumulation due to a dryer climate and dead vegetation (Koren et al., 2007).

De Oliveira et al. (2020) evaluated the relationship between deforestation, land-use and land-cover (LULC) drivers, and fire emissions in the Apyterewa Indigenous Land in Brazil. Emitted particulate matter with a diameter less than 2.5 micrometers ($PM_{2.5}$) are a primary human health risk as this size of particle can be easily inhaled (de Oliveira Alves et al., 2020). Measured $PM_{2.5}$ emissions increased with growing biomass burning. High rates of deforestation and deforested fires impose human respiratory health risks as a result (de Oliveira et al., 2020).

Aerosol Pollution

Studies more often evaluate and discuss anthropogenic aerosols on climate, neglecting the consideration of natural aerosol particles (Satheesh & Krishnamoorthy, 2005). Natural aerosol particles provide a base level for aerosol impact and consist of sea salt, soil dust, natural sulphates, volcanic aerosols, and those generated by natural forest fires. Along with anthropogenic aerosols, natural aerosol is also increasing from anthropogenic disturbances such as deforestation. Anthropogenic aerosols and natural aerosols interact with one another when processes such as deforestation occur (Satheesh & Krishnamoorthy, 2005). Many studies on aerosol pollution focus on quantifying the number of aerosols in the air due to deforestation and biomass burning while little evaluation occurs of the human health effects of those same produced pollutants. Quantifying aerosol pollution is very important for understanding patterns of gasses released into the atmosphere when deforestation and deforested fires occur (Custodio et al., 2019).

Emissions such as CO_2, CO, O_3, NO, NO_2, HONO, HCN, NHH_3, OCS, DMS, CH_4, non-methane organic compounds (NMOC), and particulate matter (PM) molecules are released into the atmosphere when anthropogenic deforestation and biomass burning occur (de Sá et al., 2019; Guyon et al., 2005; Yokelson et al., 2007). Such molecules are concerning for human health and when inhaled can cause respiratory illnesses (de Oliveira Alves et al., 2015). Pereira et al. (2009) argued that emissions from biomass burning are not correctly measured and current methods to measure aerosol pollution need to be improved. The use of CATT-BRAMS in conjunction with Moderate Resolution Imaging Spectroradiometer (MODIS) has been highly recommended when measuring aerosol pollutants and increases accuracy when identifying and quantifying number of pollutants in the atmosphere (Pereira et al., 2009). Increasing accuracy of known emissions can help in assessing potential pollutants that may cause risk to human health.

A recent study evaluated biomass burning in the Amazon due to deforestation and found that over 10 million inhabitants of the Amazon are directly exposed to high levels of pollutants as a result of deforested fires (de Oliveira Alves et al., 2017). Fine PM molecules are important risk factors for cardiopulmonary disease in humans (Pope, 2009). Epidemiologic studies evaluated the impacts of environmental aerosols on human health and found that different levels of exposure to environmental aerosols produce varying effects on human health (Pope, 2009).

Particulate air pollution can exacerbate illnesses in humans and also increase the number of deaths from cardiovascular and respiratory disease in older populations (Seaton et al., 2003).

While several studies have assessed human health in relation to aerosol pollution, very few evaluate how aerosol pollution produced by deforestation and deforested fires impact human respiratory and cardiovascular health. Increasing accuracy of methods that help quantify aerosol pollution from these processes can help researchers and health experts understand how aerosol pollution, produced by deforestation and biomass burning, impose risks on human respiratory and cardiovascular health.

Human Health Risks

Human lung cells exposed to particulate matter with a diameter less than 10 micrometers (PM_{10}) in the atmosphere significantly increased the level of reactive oxygen species (ROS), inflammatory cytokines, autophagy, DNA damage, and cell death (de Oliveira Alves et al., 2017). Measured concentrations of PM_{10} exceeded the World Health Organization (WHO) upper limits of concentration by 8 to 12 times during the dry season in the Brazilian Amazon. A corresponding increase in asthma, morbidity, and mortality in children and elderly populations occurred as a result (de Oliveira Alves et al., 2017). Despite this known connection between human health risks and aerosol pollution, essentially no published literature has evaluated the effects of deforestation and deforested fires on human health.

In one of the first studies to fill this gap in knowledge, de Oliveira et al. (2020) quantified the amount of pollution exerted in Polycyclic Aromatic Hydrocarbons (PAH), Organic Carbon (OC), Elemental Carbon (EC), and unique tracers of biomass burning such as Levoglucosan. PM_{10} concentrations varied depending on season with increased emissions in the dry season (August-October/2011). As all concentrations of aerosol sources measured in this study significantly increased during the dry season, an estimated corresponding risk of lung cancer during those months exceeded WHO health-based guidelines. More hospitalizations occurred in the dry season due to biomass burning and increased number of aerosol particles in the atmosphere. Infants, pregnant persons, elderly people, and people with pre-existing lung or heart diseases are at high risk and susceptible to the aerosol pollution produced by tropical deforestation and tropical deforested fires (De Oliveira et al., 2020). More knowledge on aerosol particles emitted in the atmosphere by deforestation and deforested fires must be obtained in order to simultaneously assess the impacts on human respiratory and cardiovascular health.

Conclusion and Future Directions

Land clearing and biomass burning for cattle ranching within the Brazilian Amazon region poses human respiratory and cardiovascular health risks (de Oliveira et al., 2015). The human population of the Amazon ranges from 10 million to 20 million people who are exposed annually to aerosol pollution induced by deforestation and biomass burning, which impacts human respiratory and cardiovascular health. Human inhalation of aerosol particles can lead to asthma, lung cancer, other respiratory illnesses, and in some cases mortality (de Oliveira Alves et al., 2017). Little research has been done assessing the impacts on human health from deforestation and deforested fires.

Future directions to monitor aerosol pollution within the Brazilian Amazon should implement methods that increase accuracy in quantifying aerosol pollution such as CATT-BRAMS in conjunction with MODIS. Obtaining a greater knowledge of aerosol particles in the atmosphere and the amount of such particles can help in understanding how they affect human health. Annual monitoring of deforestation and land cover burned by deforested fires and the emissions they produce, while simultaneously monitoring rates of human respiratory and cardiovascular illnesses, can provide scientists and health experts with greater and more accurate data to evaluate how deforestation and deforested fires impact human health.

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CHAPTER 2. GRANT PROPOSAL

Impacts of the 2020 Colorado Wildfires on Human Respiratory and Cardiovascular Health

A proposal submitted to Boulder County Parks and Open Space 2020 Small Grants Program

Emily Ramos

Graduate Student in Environmental Biology

Regis University

November 23, 2020

Section 1. Abstract

The 2020 Colorado Wildfires are the largest wildfires ever recorded in Colorado history. Wildfires are becoming more frequent as a result of climate change and, therefore, there is a need to understand how biomass burning contributes to air quality and human illnesses. Biomass burning produces particulate matter with a diameter of less than 2.5 micrometers ($PM_{2.5}$) that when inhaled can cause human cardiovascular and respiratory health risks. The relationship between human cardiovascular and respiratory health illnesses and the 2020 Colorado Wildfires is unknown. I wish to investigate further the impacts of Cameron Peak and East Troublesome fires on human cardiovascular and respiratory health in affected zip codes regions of each fire. I will collect air quality data and conduct hospital surveys to assess the number of cardiovascular and respiratory cases in impacted zip code regions of each fire. I will then perform statistical analysis that will establish the relationship between air quality and number of cardiovascular and respiratory cases from 2019 to 2020. The information gathered in this project will help health experts and scientists further understand the human health impacts from wildfires.

Section 2. Objectives, Hypotheses, Anticipated Value and Literature Review Section Objectives

This study aims to provide information on aerosol air quality and the potential human respiratory and cardiovascular health effects of Colorado 2020 wildfires. This study will integrate existing air quality data with a public health approach. I plan to synthesize current air quality data and public health surveys to better understand, predict, and adapt to environmentally driven human health illnesses driven by wildfires.

Questions and Hypotheses

Q1: How does biomass burning from wildfires affect air quality?

H1: There will be a negative relationship between air quality and biomass burning.

Q2: What are the trends for Particulate Matter ($PM_{2.5}$) during the 2020 Colorado Wildfires burning season compared to the 2019 Colorado Wildfires burning season?

H2: There will be greater $PM_{2.5}$ levels in 2020 compared to 2019.

Q3: Are there increased cases of human cardiovascular and respiratory illnesses in 2020 compared to 2019 with fewer and less extensive wildfires?

H3: There will be a positive relationship between risk and onset of respiratory or cardiovascular disease and wildfire location. There will be more cases of respiratory and cardiovascular illnesses in 2020 than 2019.

Anticipated Value

Colorado has experienced one of the greatest amounts of biomass burning in recorded history due to the wildfire season of 2020. Wildfires produce aerosol pollution that can have severe impacts on human health (Sellmovic et al., 2018). Among these pollutants, particulate matter with a diameter of less than 10 micrometers can cause human respiratory and cardiovascular health illnesses when inhaled, particularly in young and old populations (de Oliveira Alves et al., 2017). Obtaining baseline data of how much particulate matter is in the atmosphere in regions affected by wildfires plus census data documenting the number of respiratory and cardiovascular hospitalizations can help scientists and public health experts understand the impacts of biomass burning on human health. Monitoring particulate matter and air quality trends in relation to wildfires burning will also aid in understanding how intensity and duration of wildfires are impacted by climate change and as a result impact human health.

Literature Review

Wildfires have a significant impact on air quality in the United States (Sellmovic et al., 2018). Biomass burning from wildfires is the primary source of organic aerosol (OA), black carbon (BC), and brown carbon (BrC) and is the largest secondary source of CO_2, total greenhouse gases, and non-methane organic gases (NMOGs) (Sellmovic et al., 2018). Among these aerosol pollutants released from biomass burning, particulate matter (PM) molecules with a diameter of less than 2.5 micrometers pose the greatest risk to human respiratory and cardiovascular health (Stocker, 2000).

Specifically, fine PM molecules are important risk factors for respiratory and cardiopulmonary disease in humans (Pope, 2009). Particulate matter with a diameter less than 2.5 micrometers can, when inhaled, have extreme impacts that lead to cardio-respiratory disease and mortality (Loria-Salazar et al., 2017). Human lung cells exposed to atmospheric particulate matter with a diameter less than 10 micrometers (PM_{10}) significantly increase the level of reactive oxygen species (ROS), inflammatory cytokines, autophagy, DNA damage, and cell death (de Oliveira Alves et al., 2017). Particulate air pollution can exacerbate pre-existing illnesses in humans and also increase the number of deaths from cardiovascular and respiratory disease in older populations (Seaton et al., 2003). Infants, pregnant persons, elderly people, and people with pre-existing lung or heart diseases are at higher risk and are more susceptible to aerosol pollution produced by biomass burning (De Oliveira et al., 2020).

Colorado has experienced one of the largest wildfire seasons in history during the summer and fall of 2020. At the time of writing this proposal, 1,016 wildfires have been reported in Colorado in 2020, which have burned a combined total of 433,546 acres of land (InciWeb, 2020). Daily data are recorded on air quality and particulate matter levels by the interagency AirNow project, and these data are available for both academic and public use via https://www.airnow.gov. Trends in particulate matter currently show exposure levels that are considered “unhealthy” for humans throughout most of the Front Range (AirNow, 2020). In addition to sampling PM pollution, other aerosol pollution like ozone are monitored. Across 32 sites in Colorado, average ozone values for 2020 range from 58 parts per billion (ppb) to 87ppb, compared to Colorado's standard ozone level of 70ppb. Anytime an ozone level exceeds the standard ozone level, an ozone alert is issued, and people are advised to stay indoors (State of Colorado, 2020). In January 2020, the EPA designated the Denver Metro/North Front Range (DM/NFR) as "serious" nonattainment areas under the 2008 ozone standard (State of Colorado, 2020). Colorado has experienced increased trends in both particulate matter and ozone alerts this year that may be attributed to the 2020 wildfires burning.

While there are known impacts from particulate matter and air quality on human cardiovascular and respiratory health (EPA, 2020), there has been little information collected and fewer inferences drawn on the 2020 Colorado Wildfires' impact on human health within communities in the Front Range. Evaluating trends in human respiratory and cardiovascular illnesses for the year of 2020 in Colorado will catalyze scientists' and public health experts' understanding of both short- and long-term effects of wildfires on human health and livelihoods. It is important to understand the human health effects from environmentally induced cardiovascular and respiratory illnesses as wildfires become more frequent in the future due to climate change (Union of Concerned Scientists, 2020).

Section 3. Methods

Detailed Sampling and Analysis Plan

Study sites

The Cameron Peak Fire and the East Troublesome Fire will be the two focal sites for this research. Cameron Peak Fire and East Troublesome Fire are the largest fires recorded in 2020 and the largest fires ever recorded in Colorado (InciWeb, 2020). The East Troublesome Fire originated north of Hot Sulphur Springs, Colorado on October 14th, 2020. It is currently 193,774 acres in size and only 37% of it is contained. The estimated containment date is December 10th, 2020. The Cameron Peak Fire originated 15 miles southwest of Red Feather Lakes, Colorado on August 13th, 2020 and is currently 208,663 acres in size. Approximately 64% of its perimeter has been contained. The estimated containment date is December 8th, 2020 (InciWeb, 2020).

Specific Aim 1 (See Q1 above): Aggregate air quality data from focal sites for the 2019 and 2020 wildfire season.

Air quality data consist of identifying pollutants present, concentrations of pollutants present, and air quality index scores. I plan to aggregate daily air quality data for every month of 2019 and 2020 in Cameron Peak Fire and Troublesome Peak Fire zip code regions from the databases maintained by the State of Colorado and AirNow. I will also collect smoke accumulation data using satellite imagery from AirNow fire and smoke plumes maps. I will perform a correlation analysis to quantify the relationship between air quality and biomass burning for 2019 and 2020.

Specific Aim 2 (See Q2 above): Identify trends in $PM_{2.5}$ for each focal site in 2019 and 2020

I will use AirNow to evaluate trends in particulate matter for the zip code regions of Cameron Peak and East Troublesome Fires. AirNow provides daily values for ozone and particulate matter along with an air quality index for level of exposure to humans. The air quality index scale includes good (0-50), moderate (51-100), unhealthy for sensitive groups (USG) (101-150), unhealthy (151-200), very unhealthy (201-300), and hazardous (301-500). I will collect daily $PM_{2.5}$ trends for every month of 2019 and 2020 beginning in January for zip code regions of both wildfires. I will complete a regression analysis to infer monthly particulate matter trends for each zip code region impacted by the Cameron Peak Fire and East Troublesome Fire. I will also conduct a t-test comparing particulate matter trends of 2019 to 2020.

Specific Aim 3 (See Q3 above): Identify hospitals within proximity to selected wildfires and collect records of respiratory and cardiovascular cases in 2019 and 2020.

I identified impacted towns by using zip code regions that are in proximity to the Cameron Peak Fire and East Troublesome Fire. Impacted towns are susceptible to fire exposure, smoke accumulation, and potential evacuation. Red Feather Lakes, Fort Collins, and Loveland are all impacted by the Cameron Peak Fire and cumulatively contain nearly 200 health care centers including urgent care centers, medical centers, or hospitals (Figure 1). Estes Park, Hot Sulphur Springs, Grand Lake, Granby, and Parshall are impacted towns by the East Troublesome Fire and include 11 hospitals in total that are identified with similar criteria explained above (Figure 2). I will collect the number of hospitalizations for respiratory and cardiovascular illnesses per hospital within each town for each month of 2020. I will also collect hospital records for 2019 respiratory and cardiovascular hospitalizations from the same identified hospitals in towns located nearest to Cameron Peak Fire and East Troublesome Fire to compare the number of hospitalizations from 2020 and 2019. In order to analyze this datum, I will perform a t-test comparing 2020 respiratory and cardiovascular hospitalizations to 2019 respiratory and cardiovascular hospitalizations. I will quantify the linear distance of each health care center to the edge of its corresponding fire to create one predictor variable that can be used in a one-way analysis of variance (ANOVA) to assess if hospital locations within each town that are in closer proximity to Cameron Peak Fire or Troublesome Fire have a greater amount of cardiovascular and respiratory hospitalizations. After completing both a t-test and ANOVA, I will use multiple regressions to analyze the variation in aerosol pollutants as a function of hospitalizations after accounting for differences in year (2019 vs. 2020) or proximity to each fire.

Project Requirements, Logistics, Timeline and Negative Impacts

In order to collect the annual air quality data for Cameron Peak Fire and East Troublesome Fire exposure regions, I will request access from AirNow and the State of Colorado for 2019 and 2020 air quality data for Specific Aims 1 and 2. I will coordinate with selected hospitals to collect the hospital records needed to evaluate the number of respiratory and cardiovascular hospitalizations in 2019 and 2020 for Specific Aim 3 above. I expect there to be minimal impacts on the study area as I am employing noninvasive techniques to collect air quality data and number of hospitalizations.

Dates	Activities	Deliverables
November 2020 – December 2020	● Aggregate daily air quality data for each month of 2019 and 2020 from AirNow and the State of Colorado ● Evaluate $PM_{2.5}$ trends for each month of 2019 and 2020 from AirNow ● Collect hospital records for each month of 2019 and 2020 in respiratory and cardiovascular cases	● Raw daily data of pollutants present, concentrations of each pollutant, and air quality index scores ● Raw daily data of $PM_{2.5}$ trends for each month of 2019 and 2020 ● Raw data of number of respiratory and cardiovascular hospitalizations for each month of 2019 and 2020
January 2021 – February 2021	● Perform Data Analysis ● Finish Draft Report	● Draft Report
March 2021	● Finish Report Writing	● Final Report

Section 4. Budget

Item	Justification	Cost, units	Quantity	Total Cost
Data Analysis Assistant Stipend	For research assistant to complete data analyses	$15 / hour	165	$2500
MacBook Pro 13-inch	To perform necessary statistical analyses	$1299	1	$1299
Computer Storage (Hard Drive & pCloud Business)	Hard drive to store air quality, particulate matter, and hospital survey data	$120	3	$360
	PCloud Bussiness online database to store large amounts of data that are easily accessible	$30 /month	5	$150
Researcher Stipend	For training data analysis assistant, conducting field surveys, modeling, and report writing	$600 / month	5	$3000
TOTAL PROPOSAL REQUEST				$7309

Appendix Section

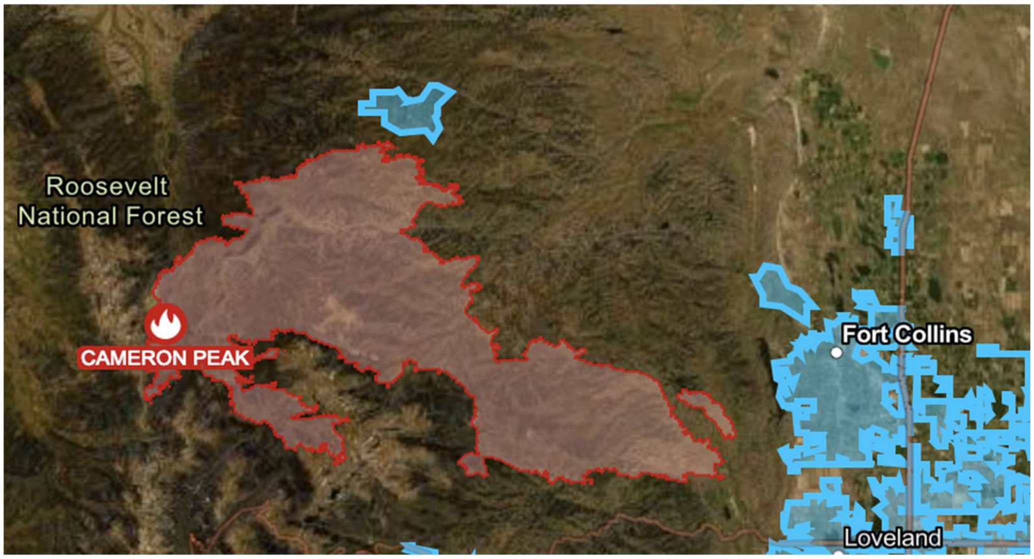

Figure 1. The Cameron Peak Fire (208,663 acres) is outlined and shaded in red, and cities within proximity to the fire are outlined and shaded in blue. Impacted cities include Red Feather Lakes, Fort Collins, and Loveland, which contain 0, 100, and another 100 health care centers, respectively. These maps were generated with ArcGIS online.

Figure 2. East Troublesome Fire (193,774 acres) is outlined and shaded in red. Cities within proximity to the fire are outlined and shaded in blue. Impacted cities include Estes Park, Hot Sulphur Springs, Grand Lake, Granby, and Parshall; 9 hospitals in Estes Park, 0 hospitals in Hot Sulphur Springs, 0 hospitals in Grand Lake, 2 hospitals in Granby, 0 hospitals in Parshall. These maps were generated with ArcGIS online.

Section 5. Qualifications of Researcher

Emily Ramos

2908 E 135th Pl
Thornton, CO 80241
(720) 323 3322
Eramos003@regis.edu

EDUCATION

M.Sc. Environmental Biology **- Regis University, CO**
August 2020 - May 2021
Currently pursuing a M.Sc. in Environmental Biology

B.S. Environmental Science & B.A. Biology **- Regis University, CO**
August 2016 - May 2020

RESEARCH EXPERIENCE

Grant Proposal, Regis University
October 2020 – Current
Write a mock grant proposal to assess the human cardiovascular and respiratory health effects due to biomass burning from the 2020 Colorado wildfires

Denver Rocky Mountain Parks, CO
August 2020 - Current
Collect baseline data to be used towards conservation and restoration efforts
Conduct vegetative quadrats to calculate species richness and abundance
Evaluate Dung Beetle population density and diversity

Mote Marine Laboratory & Aquarium, FL — *Intern Student*
June 2020 - August 2020
Evaluating hatching success and larval survivorship among ovigerous female stone crabs with exposure to moderate levels of red tide
Conducted cell counts, measured and dosed red tide treatment groups, evaluated environmental data, and completed monitoring tasks

Marine Biology Field Work, Belize- *Student*
March 2020
Completed field observations and underwater fish identification in coral reef species
Created a conservation project focusing on ways to improve coral reef ecosystem productivity

SKILLS

Statistical Analysis in R

Excel

Research Design

Report Writing

AWARDS

Brechler Award for Outstanding Academics (2016-2020)

First Team All-RMAC (2019)

Second Team All-RMAC (2018)

Elected Captain of Regis University Women's Soccer Team (2019-2020)

Third Team All-Region Selection by United Soccer Coaches (2019)

Nominated for Student Athlete of the Year (2019)

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CHAPTER 3. JOURNAL MANUSCRIPT

A Quantitative Analysis on How Mechanical Thinning Impacts Pinyon Jay (*Gymnorhinus cyanocephalus*) Occupancy in Southern Colorado

Abstract

Forestry and natural resource management extract usable resources from forests while maintaining adequate wildlife habitat. This is especially true for piñon-juniper woodlands in the United States southwest, but little is known how this management strategy impacts the presence of pinyon jays (*Gymnorhinus cyanocephalus*), an important seed disperser of piñon-juniper species. I hypothesized that mechanical thinning management alters the quality and quantity of piñon-juniper habitat and thus affects the occupancy of this landscape by this species. Pinyon jay occupancy surveys took place on the Bureau of Land Management (BLM) in Colorado from October to September 2020. Observers collected presence-absence data along with environmental characteristics of each site during field surveys. Bayesian occupancy models were used to determine the odds of observing pinyon jays after accounting for several covariates. In mechanically thinned areas the odds of observing pinyon jays increased significantly, in striking contrast to previous work in this system. Future research building off this study may yield similar outcomes to other studies with denser data and multiple years of collection. Piñon-juniper habitat management must consider the ecological impacts of mechanical thinning's on bird species as such management strategies can negatively impact bird occupancy and the entire ecosystem.

Introduction

The management of natural resources is crucial in maintaining the consumptive needs of society while also supporting the integrity and function of natural ecosystems. A large number of resources come from forests as they are home to wildlife, produce fisheries, and provide recreational and other social activities for humans (Bettinger et al., 2016). Forest management plans must consider the character of the forest, any environmental risks involved, the long-term vision of the land-manager, and the desires of stakeholders (Korjus, 2014). Typical forest management integrates silvicultural practices and economic concepts to meet the land-managers objectives at the regional scale in the United States (Bettinger et al., 2016).

One forest of particular interest in the United States are piñon-juniper woodlands. Piñon-juniper forests are classified as being dominated by one or more piñon species and one or more juniper species (Shaw et al., 2005), and approximately 40 million hectares of piñon-juniper habitat cover the western United States (Romme et al., 2009). Piñon-juniper habitats have been threatened since the 1900s due to forest thinning and tree reduction mechanisms practiced by land managers to meet ecological, social, and economic goals (Magee et al., 2019). These forests are managed with the priority of improving habitat for game species, creating wildlife corridors, and mitigating fire hazards (Boone et al., 2020). Management strategies also include mechanical thinning, or the clearing entire tree stands. These strategies help land managers reduce fuel loads and increase tree health and growth of understory shrubs. Current land management strategies do not fully take into consideration the specific ecological impacts on bird species that inhabit these pinyon-juniper woodlands.

The pinyon jay (*Gymnorhinus cyanocephalus*) is an important short-and long-distance seed disperser for pinyon-juniper woodlands and therefore is of special interest in understanding how forest management strategies impact avian populations (Johnson et al., 2016). Pinyon jays share a mutualistic relationship with pinyon trees - pinyon trees provide highly nutritional seeds that pinyon jays store for use in the winter and use in support of nesting success (Ligon, 1978).

Pinyon trees benefit from long-distance seed dispersal by pinyon jays. Pinyon jays nest primarily in piñon-juniper habitats and are highly social, nesting colonially at traditional colony sites and sometimes breeding cooperatively with helpers at the nest (Johnson et al., 2006; Marzuluff and Balda, 1992; Balda, 2002). When pinyon jays are not nesting, they travel over large landscapes often in groups that range up to several hundreds of individuals (Balda, 2002). While pinyon jay dispersal patterns overlap consistently with piñon-juniper forests, there has been little research investigating how land management strategies impact pinyon jay populations.

Despite its critical ecological roles, the pinyon jay is one of the most rapidly declining bird species assessed in the Western Breeding Bird Survey (BBS; Boone et al., 2020). Since 1966, the pinyon jay population has decreased by 3.6-4% annually (Sauer et al., 2017). The pinyon jay is also classified as vulnerable on the International Union for Conservation of Nature (IUCN) Red List (IUCN, 2018), is on the Partners in Flight Watch List (Partners in Flight, 2017), and is a US Fish and Wildlife Service (USFWS) Bird of Conservation Concern (USFWS, 2008). Decline of the pinyon trees' primary long-distance seed disperser is problematic for redistribution of seeds in high mortality areas, higher elevations, and is a limiting factor to climate resiliency of piñon habitats (Johnson et al., 2016). The reasoning for decreasing pinyon jay populations is poorly understood, but the primary hypotheses from the literature point to decreasing habitat quality (Somershoe et al., 2020).

The goal of this study was to determine the effect that landscape-scale management of piñon-juniper woodlands has on occupancy by pinyon jay populations. To better understand region-specific information on pinyon jay populations and the effects commonly used in habitat management practices, data was collected to evaluate occupancy on the Bureau of Land Management lands in central Colorado. A significant portion of piñon-juniper ecosystems occur on Bureau of Land Management (BLM) lands in the western United States and provide an ideal context in which to study the interplay between forestry management and pinyon jay occupancy trends (McNitt et al., 2020). The main question I sought to answer is how piñon-juniper thinning treated areas on piñon-juniper habitats impact pinyon jay occupancy. I hypothesized that mechanical thinning management alters the quality and quantity of piñon-juniper habitat and thus affects the occupancy of this landscape by this species. I predicted that occupancy probability of pinyon jays will be low when piñon-juniper thinning is present. The results of this occupancy probability modeling will provide information on landscape-scale processes and details of silvicultural treatments such as piñon-juniper thinning that can inform conservation management of these habitats and their constituent species.

Methods

2.1 Region and Selection of Study Site

Royal Gorge Field Office (RGFO) lands managed by the BLM occur within or near Arkansas River Valley and to the south of the Wet Mountains (Figure 1). The majority of piñon-juniper ecosystems within this region occur on BLM lands. Areas surrounding the Arkansas River were managed with mechanical thinning using heavy machinery and hand thinning techniques. Topographically, the area is characterized as steep, rocky terrain with semiarid climate that produces little precipitation, hot summers, and mild winters. Survey sites were created using LANDFIRE existing vegetation type data to determine piñon-juniper ecosystems within RFGO (McNitt et al., 2020). A total of 53 sites were surveyed for this study.

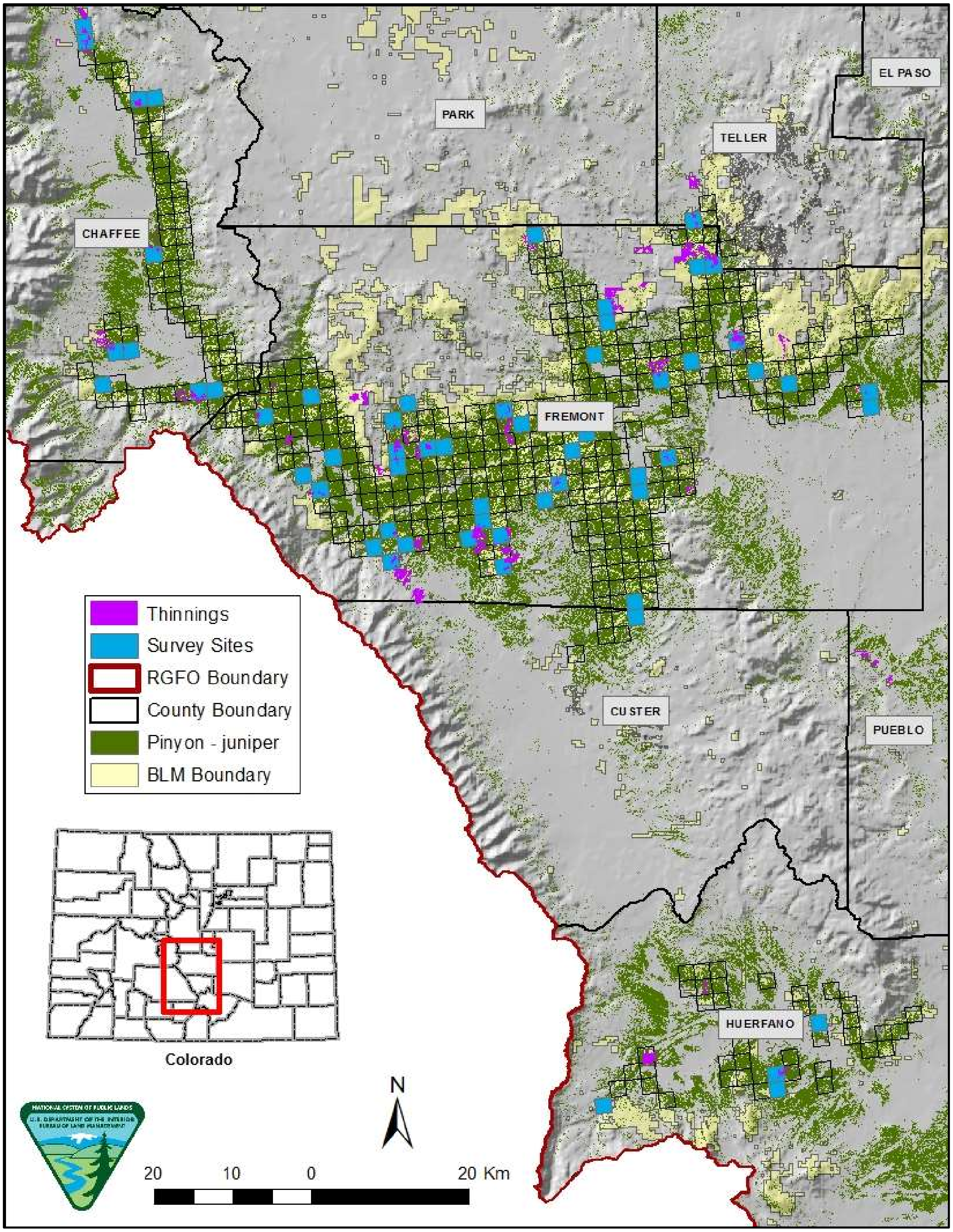

Figure 1. RFGO Boundary that overlaps with BLM boundary for the project area derived from LANDFIRE existing vegetation type data including pinyon jay occupancy survey sites, and piñon-juniper thinning treatments. This map was generated by technicians of the BLM field office.

2.2 Data Collection & Field Surveys

Pinyon jay occupancy surveys took place from sunrise to 10:30am from September to October in 2020, only visiting each site once total. Grid cells containing piñon-juniper habitat were created with 500m-by-500m borders. In each grid there were four survey points. At each survey point in a grid cell, observers looked and listened for 3 minutes before playing a pinyon jay call, after which an additional 3 minutes of observing took place. Observers recorded start time and end time of visit, observer name, wind speed, temperature, weather, and occupancy status of pinyon jays. If pinyon jays were present, then observers recorded the flock size, direction of movement, and if able to, note the presence and type of breeding behavior. An entire gid cell counts as one survey. Observers visited each survey point within a grid cell and repeated this same procedure identically. Surveys were deemed completed when all four survey points were visited by the observer in the grid cell or pinyon jays were observed at any of the survey points, whichever occurred first.

2.3 Bayesian Analysis

2.3.1 Bayesian Occupancy Modeling

To model occupancy patterns of pinyon jays across this landscape, I performed single-species, single-season occupancy modeling in a Bayesian framework. (Mackenzie et al., 2017). This methodology was chosen because it is an appropriate tool to use for the one year of data collection has taken place thus far. A total of 53 sites that were visited in 2020 were used in these models. All models were fit using Just Another Gibbs Sampler (JAGS; Plummer, 2003), with specific commands featured in the *jagUI*, *rjags*, *unmarked*, and *lubridate* packages in the *R* programming language (R v4.0; R Core Team, 2021). Given that this and subsequent analyses are based on a single years' worth of data, I set uniform prior distributions for each parameter of interest, ranging from 0 to 1. JAGS sampled the posterior distribution of the important parameters using independent Markov Chain Monte Carlo (MCMC) chains that were run for 10,000 iterations. Early values of the MCMC chains can be highly dependent on the initial values produced, therefore, the first 5,000 iterations of the MCMC chain were discarded as 'burn-in.' The last 5,000 iterations were subsequently thinned by 1/5 to ensure that posterior samples were independent. The posterior distributions were sampled and post-processed to calculate summary statistics including means and 95% credible intervals in the *MCMCvis* package (Youngflesh, 2018).

2.3.2 Detection Probability Null Model

In order to establish a simple null model that estimates the probability of pinyon jay observations in 2020, I analyzed the data for this year in a Bayesian model framework with no covariates included and perfect detection assumed (Kery & Schaub, 2012). This model assumed that the probability of detecting a pinyon jay on the landscape followed a Bernoulli distribution, with an underlying observation probability (*p*). Because this is the first year of this study being conducted, no priors have been established to use, therefore I assumed a uniform prior on the detection probability (*p*) using an interval of 0 to 1.

2.3.3 Detection Probability with Covariates

In order to assess how probability of observation was influenced by different covariates I created three models derived from the simple null model above. Credible intervals were conducted to determine the interval in which there is a 95% chance of the true effect of a variable occurring. The first model was an observer effort model which included start time of survey, time to observation of pinyon jays in each survey, and Julian date as covariates. The second model is an environmental model which included altitude, thinning treated sites, ruggedness of terrain, and occupancy as covariates. For the third model I created a combined covariate model of the observer effort model and the environmental model by including each model's significant covariates on pinyon jay occupancy. All models assumed that whether a pinyon jay was observed at site *i* followed a Bernoulli distribution, with an underlying detection probability (*pi*) where β0 represents the baseline log odds of observation. Priors for β0, β1, and β2 were assumed to be normal with mean 0 and precision 0.1

Results

The simple null Bayesian model of observation probability resulted in the absence of any other covariates there's a 26.8% chance (40% odds; Table 1) of observing pinyon jays within BLM lands. Developed from the null model, the observer effort model indicated two variables that influenced pinyon jay occupancy. Julian date had an effect on the occupancy of pinyon jays, but its estimate was low, and its 95% CI spanned 0, while time to observation on pinyon jays and start time of survey did indicate influence on pinyon jay occupancy. As time to observation of pinyon jays in a survey has a one-unit increase of decimal time, a 63% decrease in the odds of pinyon jay occupancy occurs (95% CI: 22%- 84% decrease; Table 1). With every one hour increase in start time of survey, a 22% decrease in the odds of pinyon jay occupancy occurs (95% CI: 48% decrease, 18% increase; Table 1). The start time and survey length indicate that when surveys took place earlier pinyon jays were more likely to be observed and when observers spent more time searching pinyon jays were less likely to be observed.

The environmental model was also developed from the null model and indicated two variables that influenced pinyon jay occupancy. Altitude did affect the occupancy of pinyon jays, but its estimate was low, and its 95% CI spanned 0 (95% CI: 33%decrease, 14% increase, Table 1). For every one-unit increase in altitude the odds of pinyon jays occupying the site increased by

5% (95% CI: 0.77, 1.41; Table 1). Treated sites and ruggedness of terrain had significant influence on pinyon jay occupancy. When a site has undergone thinning pinyon jays are 3 times more likely to be observed (95% CI: 10% decrease, 1028% increase; Table 1), and for everyone one-unit increase in ruggedness of terrain there is a 63% decrease in the odds of observing pinyon jays (95% CI: 10% - 86% decrease; Table 1). As ruggedness of terrain increased, pinyon jays were less likely to be observed and in treated areas with piñon-juniper thinning pinyon jays were more likely to be observed than in untreated areas.

When fitting a third combined covariate model of the significant predictors above, all predictors remained relatively the same with little variance from original posterior estimates (Table 1). The best fitting model was the combined model as it had the lowest AIC value (AIC = 68.308, Table 1) when compared to the other models. ΔAIC values lower than 4 proved that the observer effort model and the environmental model were not significantly different from the combined model. The null model had a ΔAIC value greater than 4 (ΔAIC: 4.866) indicating significant difference from the combined model.

Table 1. Pinyon jay occupancy modeling results support an influence in the odds of observer effort and environmental factors. Model parameters, their effect size, and 95% CI are reported below for each of the four models fit to these data. Bolded parameters indicate significant predictors that were retained in the combined model.

Null Model – AIC = 73.174		
Variable	*Effect Size*	*95% CI*
Odds of Occupancy	40%	28%, 53%
Observer Effort Model – AIC = 70.571		
Variable	*Effect Size*	*95% CI*
Time to Observation	**63% decrease**	**22% - 84% decrease**
Start Time	**22% decrease**	**48% decrease , 18%increase**
Julian Date	35% decrease	86% decrease, 190% increase
Environmental Model – AIC = 71.065		
Variable	*Effect Size*	*95% CI*
Mechanical Thinning Treatment	**3.01**	10% decrease, 928% increase
Altitude	5% increase	33% decrease, 41% increase
Ruggedness	**63% decrease**	**10% - 86% decrease**
Combined Model – AIC = 68.308		
Variable	*Effect Size*	*95% CI*
Treated	155% increase	27% decrease, 888% increase
Time to Observation	48% decrease	76% decrease, 14% increase
Start Time	21% decrease	48% decrease, 21% increase
Ruggedness	54% decrease	84% decrease, 17% increase

Discussion

Mechanical thinning of piñon-juniper habitats is used to lower the risk of high severity fires (Ross et al., 2012). As climate change is becoming more predominate, management of these dense habitats is increasingly important for fire mitigation (Magee et al., 2019). However, the ecological impacts of these management strategies on bird populations, especially those of species that specialize on these habitats, are not fully understood. In this study I sought to answer how mechanical thinning of piñon-juniper habitats impact pinyon jay occupancy and whether this effect was mediated by landscape features or by metrics of observer effort. My hypothesis, that in areas of the BLM that are treated with mechanical thinning, pinyon jay presence will be low due to less habitat availability, was soundly rejected as the odds of pinyon jay occupancy were 3 times greater in areas with mechanical thinning treatments. Ruggedness of terrain, start time of survey, and time to observation all also indicated influence on pinyon jay occupancy, but to a lesser magnitude than thinning treatments.

The best fitting model of this study was the combined model that accounted for thinning treatment, time to observation, survey start time, and ruggedness of terrain. This study accounts for knowing that pinyon jays are observed more frequently in the morning but not allowing any surveys to take place after 10:30 am. Even after accounting for this, survey start time still influences the odds of observing a pinyon jay. Pinyon jays prefer lower elevations and a mixed density of piñon-juniper habitat. When pinyon jays are nesting, a denser piñon-juniper habitat is favored. But, when pinyon jays are foraging, a less dense piñon-juniper habitat is preferred. As observers search for pinyon jays, treated areas will vary in habitat density and may also impact if an observer can physically observe a pinyon jay present. This model suggests that all of the covariates included should be considered in future studies and subsequent modeling approaches.

Even in the best fitting model, treated areas still increased the odds of observing a pinyon jay at each survey site. Results of this study differed strikingly from other studies evaluating bird species occupancy and mechanically thinned areas.

Previous work on BLM lands asked a similar question to the question posed by this study, evaluating how mechanical thinning impacts bird species occupancy (Magee et al., 2019). This study was conducted from mid-May to early July 2014 and 2015. Magee et al. (2019) found that numerous bird species were negatively impacted by thinning mechanisms including pinyon jays. Along with pinyon jays, occupancy of the mountain chickadee (*Poecile gambeli*), Clark's nutcracker (*Nucifraga columbiana*), white-breasted nuthatch (*Sitta carolinensis*), Virginia's warbler (*Oreothylpis virginiae*), and gray flycatcher (*Empindonax wrightii*) all decreased when thinning mechanisms had occurred. A total of 19 bird species had negative coefficients associated with landscape- and/or local-scale occupancy when areas were treated (Magee et al., 2019). Other studies have also documented short- and long-term negative impacts on bird communities when piñon-juniper treatments occur (O'Meara et al., 1981; Sedgwick and Ryder, 1986; Crow and van Riper, 2010; Bombaci et al., 2017; Gallo and Pejchar, 2017). In my present study I found the opposite effect of mechanical thinning increasing the odds of observing pinyon jays within BLM lands.

This study's design and its use of a single season's worth of data may have impacted my findings that pinyon jay occupancy increased in mechanically thinned areas. Single-season occupancy models assume perfect detection which can be problematic because a species may not be detected 100% of the time (MacKenzie et al., 2018). Having limited data for one season worth of pinyon jay occupancy and observers visiting each survey only once within the season may be misleading, as inferences are being drawn from a small set of data. When multiple years of data are collected for this study more accurate measures of occupancy and more informative priors for modeling can be obtained. Another limitation to consider is that each grid cell was visited once but the data contained an amalgamation of four observations. In future studies when each grid cell contains many visits with separate observations the data could be more parsed out and allow for better determination of pinyon jay occupancy probability. Finally, when observers recorded surveys, pinyon jay presence was noted variably based on the observer skill set to record a pinyon jay presence by auditory calls or by visually identifying the species. Consistency in recording pinyon jay presence in future data collection based on both auditory calls and visual identification will allow for more reliable measures of pinyon jay occupancy. Pinyon jays are loud birds and can be distinctly identified by auditory survey methods (Robins et al., 1986). Results of this study might change with denser sampling as more dense data will produce a finer-grained landscape perspective of occupancy and weather variables. Along with denser data, audio observation could contribute more frequent observations as a whole and potentially reduce the effect mechanical thinning has on pinyon jay occupancy currently.

Despite the present limitations of single-season occupancy models, this study is being expanded on in the future to have multiple seasons and visitations to each survey point within each season to resolve some of the current limitations of single-season occupancy modeling for pinyon jays. While current results suggest that pinyon jay presence increases significantly within mechanical thinning treated areas, future research on this topic may yield more accurate effects and potentially align with previous studies. Thinning of piñon-juniper habitat is crucial for fire management practices but having a combination of thinned areas and forested-dense areas may be more beneficial for pinyon jay survivorship than highly thinned areas solely. Piñon-juniper habitat management must take into consideration the impacts of silvicultural treatments such as thinning on bird communities as such activities can negatively impact the ecosystem as a whole (Magee et al., 2019).

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CHAPTER4.

Resolving Environmental, Economic, and Political Tensions of the Controversial Keystone XL Pipeline

Introduction

The Keystone XL Pipeline has been an energy infrastructure project in the spotlight for the past decade mired on controversy given the diversity of stakeholders at play in its development. The Keystone Pipeline comprises two segments: the existing southern segment known as the Keystone Pipeline and the proposed northern segment, the Keystone XL Pipeline. The Keystone XL Pipeline was proposed by the energy infrastructure company TC Energy in 2008 to transport fossil fuel to market or refineries at a fast rate within the United States. The Keystone Pipeline System has been operating since 2010 and the Keystone XL Pipeline would extend the system and increase flow rates to process 168 billion barrels of crude oil from underneath Canada's boreal forest. However, construction and permitting of the Keystone XL Pipeline has varied tremendously since 2010, due largely to federal policy changes. Different political administrations have taken into consideration key economic benefits the pipeline extension could produce but also the potential significant environmental impacts that could occur as a result of the pipeline.

There are serious environmental concerns for transporting tar sand oil in pipelines across the Canadian border and through the United States. A tar sands oil spill would contaminate nearby watersheds such as rivers and wetlands; wildlife and people exposed to the spill will be vulnerable to toxic chemicals. The Keystone XL Pipeline would cross hundreds of rivers, streams, aquifers, and water bodies and would lead to greater greenhouse gas emissions through the transport and consumption of fossil fuels. Despite these concerns, the pipeline would benefit Americans by creating jobs and providing fossil fuel energy upon which the national infrastructure presently depends. Given these competing interests, there is an ongoing debate between environmentalists and the oil industry about whether the Keystone XL Pipeline should be constructed. To reconcile opposing views, I propose a solution as the United States moves away from the oil industry, the Biden administration targets repairing existing pipelines and provides TC Energy with construction rights to build sustainable energy plants within the United States as part of Biden's new infrastructure plan.

Background Information

The Keystone XL Pipeline Construction

In 2020, TC Energy awarded six U.S. union contractors $1.6 billion in contracts to build the Keystone XL Pipeline in 2021 (Mannion, 2020). Construction of the Keystone XL Pipeline has been long-delayed and controversial since 2008 (Mannion, 2020). The existing Keystone Pipeline runs between Alberta and the Dakotas, splitting and ending in Texas and Illinois and stretches over 2,600 miles (Figure 1). The Keystone XL Pipeline segment is proposed to run southeast from Alberta through Montana and South Dakota to Nebraska. This segment is projected to be 1,209 miles long (Figure 1). The pipeline would require a 50-foot-wide permanent right-of-way passage that paves way for tar sand oils. Approximately 88% of that route is on privately owned land with the remaining 12% owned by local, state, or federal governments (Ramseur et al., 2014).

Figure 1. The Keystone Mainline (solid green line) and proposed Keystone XL (dotted green line) running from Canada to Texas. Map generated by keystonexl.com.

Crude Oil and Environmental Impacts

Oil sands, the primary product transported by the pipeline, are heavy oils with a high viscosity. A key study has indicated that oil sands crude has a higher greenhouse gas (GHG) emission intensity than other forms of crude oil because oil sands crude requires more energy- and resource-intensive activities to extract (Ramseur et al., 2012). Oil sands crude is thicker, more acidic, and more corrosive than lighter conventional crude oil and is more difficult to clean up when an oil spill occurs (Denchak, 2021). A large oil spill by the Enbridge Energy Partners' Alberta Pipeline in 2010 highlighted concerns among environmental groups and communities pertaining to the nature of heavy crude oil (Parfomak et al., 2013). Approximately 1.1 million gallons of crude oil were released and resulted in over 220 areas of moderate-to-heavy contamination, including over 200 acres of submerged oil on the river bottom and over 300 solidified oil deposits in Marshall, MI (Parfomak et al., 2013). Clean-up of this oil spill cost $700 million and used benzene and other hazardous constituents to dilute the spill (Parfomak et al., 2013). Oil spills are a major concern of all pipelines. Oil spill data from 2010 through October 2019 indicate that TC Energy's existing pipelines caused large oil spills, releasing between 1,000 and 10,000 barrels of oil (Allen, 2021; State Department's EIR, 2019). While these spills did not release as much crude oil as the Enbridge spill, the potential of a spill occurring is concerning for the environment and communities that surround these areas. Therefore, the proximity of the pipeline to surrounding communities is crucial in assessing oil spill risks (Gravelle and Lachapelle, 2015). Currently, the Keystone XL pipeline is proposed to cross hundreds of rivers, streams, aquifers, water bodies, and farms, ranches and indigenous communities (Denchak, 2021). However, without a pipeline to transfer oil-sands, alternative means of transportation may be considered by oil companies in the forms of using railcars and barges (The Atlantic, 2013).

These forms of transportation provide their own challenges as railcars and barges are not the safest transportation form of oil-sands. Transporting oil-sands in pipelines is argued the safest way to transfer this product by TC Energy, but all forms of transportation of this product yield carbon emissions and risk of accidents leading to oil spills (TC Energy, 2021; The Atlantic, 2013).

Crude Oil and Economic Benefits

The Keystone XL Pipeline extension of the Keystone Pipeline would provide the United States with greater energy security by transporting 1.1 million barrels of Canadian crude oil to U.S. markets each day (The Perryman Group, 2010). Obtaining crude oil from Canada provides a supply of oil in reliable quantities from a more stable and predictable source than volatile regions which currently dominate the global market. As a result, the Keystone XL Pipeline would generate long-term increase in marginal supply, which will have a modest price effect in permeating the entire economy. Local economies within the route of the Keystone XL Pipeline would benefit from increases in tax revenues and business activity associated with temporary construction work in the area and local property taxes paid on a continuing basis. Construction of the pipeline would generate $20.931 billion in total spending, $9.605 billion in output, and 118,935 person-years of employment. The gains in US business activity stemming from a permanent increase in stable oil supplies range from $100.144 billion to $221.305 billion in total spending, $29.048 billion to $64.193 billion in output, and 250,348 to 553,235 permanent jobs depending on oil price per barrel. This infrastructure investment would have substantial positive economic outcomes both during its construction and for years to come (The Perryman Group, 2010).

United States Administrative Policies Through the Years

Despite the potential economic benefits to its construction, the Keystone Pipeline's status has varied tremendously due to the political climate of the United States in the last decade. The Obama administration halted the Keystone XL Pipeline in 2015 as under this administration it would not serve the interests of the United States (Abdullah and Chadwick, 2015). President Obama argued that the pipeline would not produce long-term jobs nor reduce gas prices. The Obama administration emphasized combating climate change as a global leader and did not believe that authorizing the Keystone XL pipeline construction of the Cushing Extension would support combating climate change. Instead, this administration believed in transitioning the United States to a clean energy economy, which meant reducing the nation's reliance on fossil fuels from unstable parts of the world (Abdullah and Chadwick, 2015).

President Trump was elected to office in 2017 on promises of restoring and supporting the fossil fuels industry. The Trump administration decided the U.S. would leave the Paris Agreement (a global agreement to combat climate change) in 2017 with the belief that climate change is neither empirically backed nor a threat to global society (Jung, 2020; Briggs, 2021). This administration believed that leaving the Paris Climate Agreement would stimulate economic growth (Jung, 2020). In March of 2017, the State Department approved the Keystone XL pipeline's Presidential Permit to construct the Keystone XL Pipeline (Allen, 2021). The Trump administration was in support of the Keystone XL Pipeline as they believed it would provide energy security and economic growth (CBS News, 2017).

The Biden administration revoked the Keystone XL pipeline in January 2021, shortly after his inauguration. Like the Obama administration, the Biden administration found that the Keystone XL pipeline would not serve the U.S. national interest for many of the same reasons (Allen, 2021). On the same day, President Biden signed executive orders to rejoin the Paris

Climate Agreement and to revoke the Keystone XL pipeline (9News, 2021). President Biden believes that the Keystone XL pipeline would not be consistent with the Administration's economic and climate imperatives (9News, 2021). President Biden's priorities remain in tackling the climate crisis while empowering American workers and businesses in the transition to clean energy (White House, 2021).

Stakeholders

TC Energy and Oil Workers

TC Energy and oil workers hold a big stake in the construction of the Keystone XL pipeline as the pipeline would produce an economic boost, providing jobs for both Canadians and Americans (Parfomak et al., 2013). TC Energy argues that the Keystone XL Pipeline offers a safe, reliable, and environmentally responsible way to enhance market access by delivering crude oil to markets in the United States (TC Energy, 2021). Proponents of the pipeline argue that pipelines are the safest way to transport fuel (Nickel and Volcovici, 2021). TC Energy supports the construction of the Keystone XL pipeline as it increases the security and diversity of the U.S. petroleum supply (Parfomak, 2013). The Canada Energy Regulator has approved the Keystone XL Pipeline segment in Canada by issuing a certificate in 2010 (TC Energy, 2021). For the Canadian portion of the Keystone XL Pipeline, 2,800 construction jobs are anticipated during peak construction periods for Canadian citizens. In total, the project would generate $1.6 billion in employment income during construction. Once the Keystone XL Pipeline is in service in Canada, an estimated $7 million in additional annual property taxes to municipalities is projected. The anticipated increase in GDP for Canada associated with the construction of the Keystone XL Pipeline is $2.4 billion. In May 2019 this segment was approved for outstanding pre-construction conditions by the board of National Energy for the Canada project, but construction has been halted since the United States has not approved the project in their nation (TC Energy, 2021).

Halting the Keystone XL Pipeline has had implications for TC Energy as they have had to eliminate more than 1,000 construction jobs for the Canada segment. For many oil workers, the oil and gas industry provide financial stability (Chiarello, 2021). Without the Keystone XL pipeline many people who relied on the pipeline for employment are now jobless and unable to find another form of work (Chiarello, 2021). As a result of President Biden's decision to cancel the Keystone XL Pipeline permit, TC Energy will now have to find new ways to increase its earnings in the next coming years. TC Energy has been caught in a decade of legal battles and shifting project outcomes with changing presidents in office for the United States (Nickel and Volcovici, 2021). It is projected that, with Biden’s decision to halt the Keystone XL Pipeline, this will be the death of the project moving forward (Nickel and Volcovici, 2021). TC Energy still owns the existing Keystone Pipeline and that will remain in operation even with Biden’s decision about the Keystone XL Pipeline.

Environmentalists

The Keystone XL Pipeline had become a rallying point for environmental activists confronting government and industry failure to mitigate climate change (Bradshaw, 2015). Environmental groups are opposed to the Keystone XL pipeline and have consistently protested against its construction (Zanotti, 2021). Major concerns for environmentalists involve the potential environmental impacts such as increased pollution and oil spill consequences to important ecosystems (Denchak, 2021). In particular, environmentalists object to the global environmental impacts associated with the lifecycle of greenhouse gas emissions found with the development of oil sands crude (Parfomak et al., 2013). Environmentalists such as Smandych and Kueneman (2010) argue that ecological destruction is occurring through the disturbance of boreal forest, natural gas depletion and air pollution, and water depletion and groundwater pollution from tar sands development. In 2011, a protest was organized by Bill McKibben, a well-known environmental activist, calling upon citizens to participate in a direct-action campaign to stop the Keystone XL Pipeline. During this protest in Washington D.C., 1253 people were arrested, including prominent scientists, celebrities, civil rights organizers, environmentalists, and Native American activists, making it the largest act of disobedience in the history of the North American climate movement (Klein, 2014; Bradshaw, 2015). When President Biden halted the Keystone XL Pipeline in 2021, environmentalists rejoiced in this substantive and symbolic victory in the movement against climate change (Bradshaw, 2015).

Indigenous Nations and Landowners

The proposed Keystone XL pipeline path would have crossed the plaintiff tribes' homelands (NARF, 2021). Many of these tribes, including Red Sioux Tribe, believed that, under the Trump administration, the federal government ignored treaty rights, tribal sovereignty and widespread opposition of the Keystone XL pipeline (NARF, 2021). The Trump administration was pushing for the pipeline to be built and as a result, in 2020, the Rosebud Sioux Tribe and the Fort Belknap Indian Community filed a federal lawsuit against the United States Department of Interior (DOI) and the Bureau of Land Management (BLM) over the illegal Presidential Permit provided by Donald Trump that violated tribal consultation and treaty obligations (NARF, 2021). Despite these tribal nation's efforts for adherence to the law and tribal rights, in 2020 a judge ruled against the tribes' claims (NARF, 2021). Throughout the rest of 2020, the Native American Rights Fund, which represents Fort Belknap Indian Community and Rosebud Sioux Tribe, continued their fight against illegal permitting of the Keystone XL Pipeline by filing in the

United States District Court of Montana (NARF, 2021). When President Biden signed the Executive Order revoking the Keystone XL Pipeline permit issued by the Trump administration, the Rosebud Sioux Tribe, the Fort Belknap Indian Community, the Gros Ventre, and the Native American Rights Fund all supported the Biden's administrations actions (2021).

Like Indigenous Nations, landowners oppose the Keystone XL pipeline out of fear that an oil spill would occur and release heavy crude oil onto their land impacting any farming or livestock (Parfomak et al., 2013). Another concern among landowners and communities along the proposed pipeline path is the potential for their land or water to be contaminated by an oil spill (Parfomak et al., 2013). In 2015, TC Energy filed court documents in Nebraska for eminent domain to take easement for the pipeline from landowners who did not want to willingly sell their land rights (The Hill, 2015). Many landowners in Nebraska vocalized that they would have filed individual challenges to their eminent domain filings as a way to stop the pipeline (The Hill, 2015). This has been an ongoing conflict until President Biden's decisions to halt the pipeline. Both Indigenous Nations and landowners have been combatting the Keystone XL pipeline construction by conducting protests at construction sites in the United States (Chakraborty, 2021). Specifically, in Philip, South Dakota, prior to Biden's decision to halt construction of the pipeline, protestors consisted of landowners, the American Civil Liberties Union, and the Cheyenne River Grassroots Collective. Indigenous Nations believe it is their duty to protect the Earth and sacred indigenous sites within the candidate construction site (Chakraborty, 2021).

Biden Administration

The Biden administration has decided to move away from fossil fuels and pursue clean energy (White House, 2021). More specifically, President Biden issued an executive order on

January 20, 2021 on protecting public health and the environment by restoring science to tackle the climate crisis. This executive order included revoking the March 2019 permit for the Keystone XL Pipeline. Since then, President Biden has proposed a new infrastructure plan that includes a $3 trillion investment in American jobs (White House, 2021). This plan invests in rural communities and communities impacted by the market-based transition to clean energy (White House, 2021). Biden includes in this plan fixing highways, rebuilding bridges, upgrading ports, airports, and transit systems in hopes that these investments will include good-quality jobs. The Biden administration is focused on combatting climate change while also producing jobs for the American economy (White House, 2021).

Proposed Solution

I propose that President Biden include funding for repairing and upgrading existing pipelines in his infrastructure plan. The repair of existing pipelines tackles the crisis of aging infrastructure while not contributing further to the climate crisis (Sheeran et al., 2011). Targeting investments in repairing existing water and natural gas pipelines along proposed Keystone XL Pipeline states (Montana, Nebraska, Oklahoma, South Dakota, Texas) is projected to create more than 300,000 total jobs across all sectors and nearly five times more long-term jobs than the Keystone XL Pipeline (Sheeran et al., 2011). This solution would help in aiding to the Americans that have lost jobs as a result of the Keystone XL Pipeline being halted by President Biden.

In order to mitigate TC Energy's financial loss from the halt of the Keystone XL Pipeline, I also propose that President Biden's infrastructure plan provide permitting for clean energy to TC Energy to allow the company rights to build for more sustainable energy in the same states that would have originally had the Keystone XL Pipeline run through them. TC

Energy plans to expand its portfolio in natural gas, crude oil, nuclear, hydro, wind solar, and other emerging technologies in its near future (TC Energy, 2021). As part of the United States infrastructure plan, I propose the solution that TC Energy be given construction rights to build clean energy plants of either hydro or wind solar within the United States in the same states that would have had the Keystone XL Pipeline constructed in. This would help create new short-term and long-term jobs for Canadian and American citizens with construction and maintenance of these sustainable energy plants.

Environmentalists, landowners, and Indigenous Nations are accounted for in this solution as no further climatic or aquatic risk is present in the absence of the Keystone XL Pipeline. TC Energy plant building will take place on federal lands or with the consent of landowners' private property. A shift to clean energy particularly in hydroelectric, wind, or solar satisfies environmentalists and Indigenous Nations values to combat climate change and eliminate the risk of air and water pollution. While there are still environmental concerns with these renewable energy resources, these concerns are nowhere in magnitude as the concerns with the Keystone XL Pipeline (EIA, 2021; Energy Efficiency & Renewable Energy, 2021). These environmental impacts can be mitigated to decrease species disturbance with innovative technology and scientific understanding of ecosystem dynamics (Energy Efficiency & Renewable Energy, 2021). My proposed solution accounts for all stakeholders and adheres to their positions pertaining the Keystone XL Pipeline.

Conclusion

The conflict between oil/gas and clean energy has been an ongoing battle for the last decade. The Keystone XL Pipeline is a primary example of this, and the conflicting views society holds in the economic benefits and the environmental impacts of crude oil. Climate change is an ongoing crisis that impacts all humans and ecosystems on Earth. Economic development can still come from clean energy while also reducing environmental impacts.

I proposed a solution to mitigate opposing views of the Keystone XL Pipeline that satisfies all stakeholders involved. The proposed solution to repair existing pipelines and provide TC Energy with permitting of clean energy plants in the United States supports all stakeholders' views while coming to a reasonable and realistic resolution.

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