ANTICIPATING THE IMPACTS OF THE SOCIAL, POLITICAL, AND BIOPHYSICAL LANDSCAPE ON LONG-TERM CONNECTIVITY FOR REINTRODUCED PLAINS BISON

by

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The following individuals read and discussed the thesis submitted by student Jamie Ann Faselt, and they evaluated the student's presentation and response to questions during the final oral examination. They found that the student passed the final oral examination.

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The final reading approval of the thesis was granted by Matthew Williamson, Ph.D., Chair of the Supervisory Committee. The thesis was approved by the Graduate College.

DEDICATION

I would like to dedicate this research to Iinnii/buffalo/bison and all of the people working to restore this species back to the landscape. To my friends and family, thank you for encouraging me to see this through and for all of your support, especially my mother, Dr. Susan Bodnar, for inspiring me to pursue higher education and follow my passions.

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ABSTRACT

Intense anthropogenic pressures on the natural environment have created the need for implementing strategies that promote or restore habitat connectivity. The ability for animals to move between habitat patches allows animals to find mates, access resources, and shift their range in response to the changing climate and ensures that ecological and evolutionary processes persist. Connectivity conservation typically focuses on biophysical barriers to animal movement, but for many species reintroductions, establishing and maintaining connectivity often requires overcoming both ecological and socio-political barriers. Despite the need to navigate complex socio-political landscapes to implement connectivity conservation plans, datasets depicting those conditions are rarely used in the connectivity models that underlie connectivity conservation plans. In this research, I demonstrate an approach for leveraging social, political, institutional, and ecological datasets to model long-term connectivity for reintroduced Plains bison (*Bison bison*) in part of the Northern Great Plains, where no habitat connectivity currently exists.

Efforts to reintroduce bison, both for cultural and ecological reasons, have been ongoing since their near extirpation in the late 1800s due to colonial forces. There are currently more than 20 international, federal, non-profit, and Tribally-led efforts to reintroduce bison to parts of Plains bison expansive historic range. These reintroduction efforts have occasionally been met with intense socio-political backlash highlighting the need for conservation interventions that address important socio-political obstacles in order to achieve long-term connectivity. Some of the socio-political barriers that

practitioners seeking to restore bison face are a lack of social acceptance, political opposition from the Republican party and cattle ranching industry, and the need to navigate complex jurisdictional boundaries across a large landscape.

I analyzed the impacts of these specific barriers by using responses from an international wildlife governance preference survey, republican voting trends, cattle sales, and parcel density as a measure of jurisdictional complexity. I integrated these datasets with spatial surfaces depicting bison habitat suitability and human modification to develop a suite of resistance surfaces that depict both the challenges of a bison moving through the landscape and the challenges of conserving important movement pathways for the species. I used these resistance surfaces to compare the costs and probabilities for implementing a variety of connectivity conservation plans. My results highlight where social-ecological mismatches and fit occur throughout the landscape. The analysis shows that the most ecologically ideal pathway is also socio-politically costly, and that choosing a slightly less ecologically valuable pathway may cost less in terms of socio-political resistance.

I also analyzed the potential spatial footprints of three commonly used interventions for promoting conservation outcomes by manipulating the socio-political resistance to reflect three hypothetical conservation interventions using the wildlife governance preference survey. I explored the interventions of creating public land tolerance zones (e.g., shift in jurisdictional complexity), economic incentives aimed at promoting social acceptance, and a Tribal and First Nations governance intervention given the cultural importance of bison to Indigenous people in North America. I found that the economic incentive did little to shift the probability of implementing a connectivity plan for bison when compared to the public land tolerance zone and Tribal and First Nations governance scenario, suggesting that those strategies may have a greater impact on bison's long-term connectivity in the region. This approach can help conservation managers make more informed decisions regarding where to implement bison connectivity plans, as well as what levers may lead more successful conservation outcomes. My approach could be applied in research for other wide-ranging, reintroduced, or otherwise controversial species to characterize the potential trade-offs involved with different conservation interventions and ultimately lead to conservation plans that have a higher probability of successful implementation.

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LIST OF ABBREVIATIONS

BCI	Bison Conservation Initiative
BLM	Bureau of Land Management
CSKT	Confederated Salish and Kootenai Tribe
HB	House Bill
HMI	Human Modification Index
HSI	Habitat Suitability Index
IBMP	Interagency Bison Management Plan
ITBC	InterTribal Buffalo Council
LCP	Least Cost Path
MRP	Multi-level Regression with Postr-stratification
MST	Minimum Spanning Tree
NGO	Non-governmental Organization
NPS	National Park Service
UNDRIP	United Nations Declaration on the Rights of Indigenous Peoples

CHAPTER ONE: UNDERSTANDING SOCIAL, POLITICAL, AND BIOPHYSICAL BARRIERS TO LONG-TERM CONNECTIVITY FOR REINTRODUCED PLAINS BISON

Abstract

Strategies that restore, maintain, or enhance habitat connectivity support ecological (i.e., animal movement) and evolutionary (i.e., gene flow) processes that are critical for species' long-term survival. Connectivity conservation strategies are particularly important for reintroduced species as they facilitate recolonization of suitable habitats and help re-establish gene flow to avoid founder effects. Implementing these strategies for reintroduced species is especially challenging, as planners need to reconcile species' habitat requirements and movement behaviors with a complex social and political landscape. Methods that integrate spatial characterizations of the social and political landscape into connectivity models can help planners better anticipate the costs associated with implementation and the probability of success or failure. I demonstrate an approach for integrating ecological and social datasets to model long-term connectivity for reintroduced Plains bison in part of the Northern Great Plains. I leveraged a survey of wildlife governance preferences and a suite of publicly available information on environmental and institutional attributes to develop resistance surfaces depicting both the challenges of moving across the landscape and conserving those movements. I used these resistance surfaces as the basis for both cost-distance based and circuit-theoretic connectivity models to compare the costs and probabilities of movement from the

animal's "perspective" with the costs and probability for implementing a conservation project from the conservation practitioner's "perspective". My results highlight regions in Montana and Northern Wyoming where social-ecological mismatches and fit occur on the landscape. My results show that the biophysical ideal may be more socio-politically costly, and that a slight tradeoff in ecological value may lead to an overall reduction in costs. This integrated approach can be utilized for conservation managers and actors to make more informed and strategic decisions regarding how to balance the social costs of conservation with protecting important movement pathways for a species.

Introduction

Maintaining or restoring habitat connectivity is crucial for conserving species in fragmented landscapes, especially for wide-ranging species that require large and intact habitats (Berger, 2004; Fahrig, 2003; Joly et al., 2019). Connectivity conservation strategies are particularly important for reintroduced species, as they facilitate recolonization of suitable habitats and help re-establish gene flow to avoid founder effects (i.e., a loss of genetic variation from few individuals founding a population) (Sarrazin & Barbault, 1996). Conservation practitioners rely on landscape connectivity models to identify wildlife corridors (i.e., pathways of habitat connecting wildlife populations that are otherwise separated due to human activities) and stepping stones (i.e., semi-natural habitat near corridors that support wildlife movement), and to evaluate the effects of landscape heterogeneity on the ability to move between patches (Beier et al., 2011; Keeley et al., 2019; Rudnick et al., 2012; von Haaren & Reich, 2006). Implementing the plans that result from these modeling exercises can be exceptionally difficult because they require negotiations across complex jurisdictional boundaries (e.g., land tenure), institutional contexts (e.g., legal mandates), and social preferences (Keeley et al., 2019; Niemiec et al., 2021). A failure to include social and institutional barriers alongside biophysical barriers may lead to connectivity plans that are mismatched with the economic, cultural, and governance context (Bennett et al., 2017; Epstein et al., 2015; Niemiec et al., 2021). The alternative is also true, selecting conservation regions only for political expedience may fail to achieve connectivity conservation because those locations may fall outside important habitat requirements. While conservation actors often realize these tradeoffs exist, efforts to understand them prior to implementing a conservation project and doing so in a spatially-explicit way is a gap within conservation science (Dallimer & Strange, 2015). This research utilizes information on the social, political, and biophysical landscape to help conservation managers evaluate the tradeoffs between ecologically important areas for connectivity conservation and locations where implementing conservation actions are more socio-politically feasible. This can lead to better-informed and ultimately more successful conservation actions (Ghoddousi et al., 2021; Niemiec et al., 2021; Williamson et al., *in review*).

Least-cost path (LCP) and circuit-theoretic analyses are two common approaches for modeling connectivity (McRae & Beier, 2007; Zeller et al., 2012). Both modeling approaches rely on resistance surfaces that depict the difficulty of moving across a landscape using a two-dimensional lattice of resistance (or cost) values (Fletcher & Fortin, 2018; Spear et al., 2010; Zeller et al., 2012). Higher costs represent factors that impede movement (e.g., a steep mountain), enhance mortality risk (e.g., a major road crossing), or behavioral aversion (e.g., wildlife hazing) (Etherington & Holland, 2013). Although both LCP and circuit-theoretic models rely on the same resistance surfaces, they differ in their assumptions and outcomes. The least-cost path method identifies an optimal route for an individual animal moving between habitat patches based on the minimum cost-distance, which is a function of distance traveled and the costs traversed. LCP models assume that the animal has complete knowledge of the entire landscape and is able to select the least-cost path (Adriaensen et al., 2003; Etherington & Holland, 2013). In contrast, circuit-theoretic approaches rely on random walk theory to estimate movement probability based on cost-distances and path redundancy, which ultimately highlights locations of high movement probability or potential habitat bottlenecks (McRae et al., 2008). Circuit theory has grown in popularity as it avoids the assumption that an animal has full knowledge of a landscape and may provide a more realistic depiction of how animals disperse across a large landscape (Dickson et al., 2019); however, discrete boundaries produced by LCP can be more amenable to corridor planning and policy development (Keeley et al., 2019). Regardless of the modeling approach, most contemporary analyses emphasize biophysical elements (e.g., topography, vegetation type, productivity, linear infrastructure) (Dickson et al., 2017) with little attention paid to the role that social and political factors may play in constraining connectivity conservation.

Connectivity models may incorporate some impacts of physical human structures (e.g., roads, housing developments, powerlines), but rarely capture the potential impacts of social and institutional structures on animal movement either directly (e.g., variation in hunting regulations) or through their impact on connectivity conservation (e.g., political backlash) (Cumming & Epstein, 2020). There is a growing amount of spatial data on the social, political, and institutional landscape, but efforts to integrate them with biophysical datasets and evaluate their importance has been rare in ecology (Carter et al., 2020; Williamson et al., 2018). The impact of the biophysical landscape can be obvious, such as a steep canyon presenting a barrier to movement for many species. In contrast, the socio-political landscape constrains conservation managers and conservation actions, which can still ultimately impact species movement (Cumming & Epstein, 2020). Extending the idea of resistance surfaces to capture both the elements that impede an animal's ability to move and the elements that impede practitioners' ability to conserve important movement pathways can help conservation managers make strategic decisions regarding the tradeoffs between conservation value and implementation success. The ability to evaluate these trade-offs can be especially important for designing species reintroduction efforts.

Efforts to reintroduce the Plains bison (*Bison bison*) to their historic range provide an excellent opportunity to study the interactions of the social, political, and biophysical landscape on a species' long-term connectivity potential. An estimated 30-60 million bison roamed free from Alaska down to northern Mexico and from parts of California to the Eastern Appalachians (Knapp et al., 1999). By the late 1890s, bison were nearly extirpated with fewer than 100 remaining individuals (Hornaday, 1889; Ewers, 2012). While there have been efforts by Indigenous communities, governments, and environmental non-governmental organizations (NGOs) to restore bison throughout their historic range, they currently occupy 0.05 % of their former range and largely remain in fenced enclosures (Gates et al., 2010; Steenweg et al., 2016). Bison require large, intact grassland habitats and the ability to move across the landscape in order to avoid overgrazing. Additionally, grasslands, their preferred habitat, are among the most endangered ecosystems in North America (Augustine et al., 2019; Samson et al., 2004).

As such, there are two major biological factors that impede bison restoration efforts: a lack of remaining suitable habitat and the genetic isolation of small, fenced-in herds. Identifying and protecting remaining suitable habitat, and planning for long-term connectivity for the species to overcome the issues of genetic isolation, is one strategy to overcome the biological barriers for the species' long-term viability. However, bison expansion is largely considered incompatible with the socio-political landscape and current land uses such as cattle ranching and private property arrangements (Pejchar et al., 2021; Turner, 2020).

A survey of bison experts revealed that other key challenges to bison reintroduction are political resistance, lack of social acceptance, and management across complex jurisdictional boundaries (Pejchar et al., 2021). Despite bison being named the National Mammal in the United States through the National Bison Legacy Act in 2016, there is ongoing anti-bison legislation being pushed at local and state government levels in the Western United States, spearheaded by Republican legislatures (Turner, 2020). Competition with cattle for forage and concern for brucellosis transmission to cattle, a disease that impacts bovines such as bison, elk and cattle, further complicate restoration efforts (Gates et al., 2010; Pejchar et al., 2021; Ranglack et al., 2015; Sanderson et al., 2008; Van Vuren, 2001). The current management strategy of keeping bison in fenced enclosures due to socio-political pressures, eliminates any connectivity between existing bison herds (Gates et al., 2010; Steenweg et al., 2016). Managers need to navigate the tradeoffs between potentially costly campaigns to reduce socio-political resistance and less-costly, but potentially less ecologically effective actions in areas with lower socio-political resistance. However, methods for evaluating these trade-offs spatially and across the entirety of an animal movement path are lacking.

Although social and political constraints on bison reintroduction are widely acknowledged, the impacts on conservation efforts and subsequent biological processes (e.g., connectivity) are less known. This study applies a framework for quantifying social and political resistance (i.e., implementation resistance) to bison in Montana and Northern Wyoming, where nine herds currently exist. I use integrated resistance surfaces in combination with two connectivity modeling approaches to assess the impacts of current socio-political constraints on long-term connectivity for reintroduced bison. This paper illustrates an approach for integrating different sources of socio-political costs into contemporary connectivity models and analyzing trade-offs associated with competing conservation strategies for the restoration of reintroduced bison populations.

Methods

Study Area

I analyzed nine herds in Montana and northern Wyoming (Figure 1.1). There are seven Tribally-owned/managed herds in Montana on the reservations of the Amskapi Piikuni (Blackfeet Reservation), the Sélis, Kootenai & Qlispé (Flathead Reservation), the Assiniboine & Gros Ventre Tribes (Fort Belknap Reservation), the Assiniboine & Sioux Tribes (Fort Peck Reservation), the Apsaalooke Tribe (Crow Reservation), the Tsis Tsis Tas Tribe (Northern Cheyenne Reservation), and Chippewa-Cree Tribe (Rocky Boy's Reservation). The other two herds are the Yellowstone National Park herd in northern Wyoming and Montana and a herd managed as a public-private partnership by American Prairie, an environmental NGO. The largest herd has approximately 5450 bison roaming through parts of the 2.2 million acres in Yellowstone National Park (*Yellowstone Bison*, 2022). The Chippewa-Cree Tribe manage the smallest herd of approximately 14 bison on approximately 1200 acres of the Rocky Boy's Reservation (Stagner, 2021). The remaining herds throughout the region range from approximately 350 to 1400 bison, on approximately 15,000 to 40,000 acres per herd location. This region is a central part of bison's historic range within the Northern Great Plains. Reintroductions have been ongoing since the early twentieth century with the most recent reintroduction occurring in 2020. Most of the herds occur in lower elevation, mixed-grass prairie and in rural communities where livestock production and natural resource development are the dominant industries with an average median income of $50,659 (Walker et al., 2020).

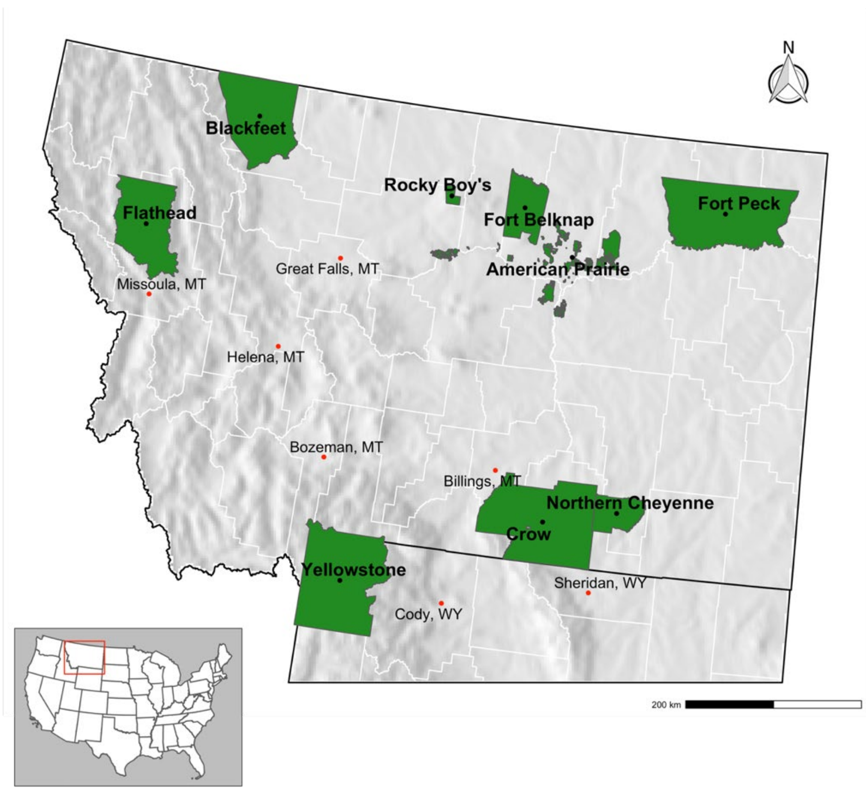

Figure 1.1 Map of current bison herds in Montana and northern Wyoming. The areas with herds are shown in green, with the black points representing the node or herd location used in the analysis. Urban areas throughout the study system are shown as red points. States are outlined in black and counties are outlined in white.

Overview

My methodological approach can be broken down into three distinct phases (Figure 1.2). For the first step, I created two separate resistance surfaces depicting biophysical and implementation costs. Next, I analyzed the resistance surfaces using a combination of LCP and circuit-theoretic connectivity models. Finally, I compared the costs and probabilities of implementing competing conservation strategies.

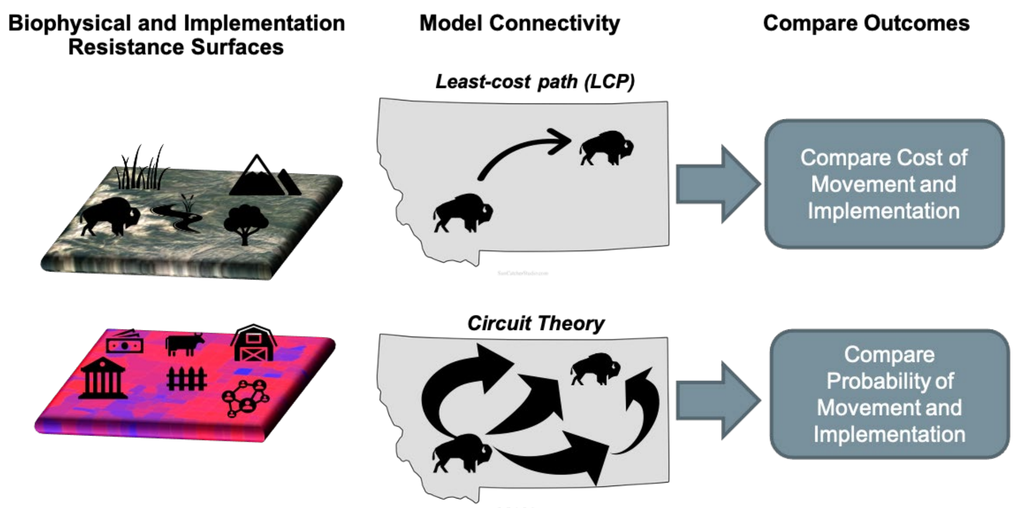

Figure 1.2 Workflow for comparing the impacts of the socio-political landscape for bison connectivity plans. Step I: Create a biophysical resistance surface based on habitat suitability and human modification and an implementation resistance surface based on cattle sales, social acceptability of bison, parcel density, voting trends, and land value. Step II: Calculate the least-cost paths connecting each herd in the study area (i.e., Minimum Spanning Tree) and current flow (circuit-theoretic model) throughout the entire landscape. Step III: Compare the costs of movement and implementation for the top three minimum spanning trees and compare the probability of movement and implementation based on normalized current flow.

I) Build Resistance Surfaces

Biophysical Resistance Surface

I characterized the biophysical elements that impact bison movement by developing a resistance surface based on habitat suitability and human modification. I utilized a Habitat Suitability Index (HSI) developed by Brent Brock of the Wildlife Conservation Society (Shamon et al., 2022). The HSI followed the work of Steenweg et al. (2016) which identified factors known to limit bison distribution and foraging in Banff National Park. Steenweg et al. (2016) utilized previously published data that used landcover and GIS habitat modeling, including radio telemetry data for female bison, to predict the relationship between landscape variables and bison habitat selection. The HSI developed by Shamon et al. (2020) used the same categorization and data on topography and landcover type from the Steenweg et al. (2016) model with the addition of the Enhanced Vegetation Index (EVI) to estimate plant biomass and eliminate areas where the amount of vegetation is too low to support bison regardless of landcover type, including croplands. I took the inverse of the HSI raster (1/HSI) to convert habitat suitability to resistance. I accounted for human-generated biophysical resistance (e.g., linear infrastructure, human settlements) using the Human Modification Index (HMI) for North America (Theobald, 2013). All inputs were scaled from 0 to 1 and combined using a "fuzzy algebraic sum" approach, where the resulting value is at least as high as the highest contributing cell value but does not exceed one (Theobald, 2013). I created a biophysical resistance following the work of Dickson et al. (2017).

$$R_{biophysical} = (fuzzy\ sum\ of\ biophysical\ layers + 1.0)^{10} + \text{slope}/4$$

Baseline Implementation Resistance Surface

I characterized implementation resistance by combining data on cattle sales, voting trends, land fractionation, and the social acceptability of bison (Table 1.1). Competition for forage, impacts to farming infrastructure, and the potential for disease transmission mean that areas that are economically-dependent on the livestock industry are likely to be resistant to the reintroduction of bison (Gates et al., 2010; Pejchar et al., 2021; Ranglack et al., 2015; Sanderson et al., 2008; Van Vuren, 2001). I assumed counties with higher values of cattle sales (in dollars) would be more resistant to bison connectivity conservation (USDA National Agricultural Statistics Service, 2017). Two counties in the study region did not have disclosed cattle sale values. I addressed this by looking at total animal sales for the study region, filtered to those counties most similar to the missing counties, and set the value for cattle sales for the missing counties based on the similar counties' median cattle sales. Due to recent anti-bison restoration legislation spearheaded by the Republican party in Montana (Nicholas, 2021), I assumed that counties with higher percentages of Republican voters (based on the average of presidential election votes from 2000 to 2020 (MIT Election Data and Science Lab, 2018) would be more resistant to bison connectivity conservation. Because land fractionation results in more negotiations with individual landowners and increases the complexity of implementation, I calculated parcel density for each county and assumed that greater parcel density results in greater resistance (Montana State Library, 2019; Wyoming Department of Revenue, 2018). Finally, I included a measure of bison acceptability based on a 30,000-respondent wildlife governance survey that was distributed throughout Mexico, the United States, and Canada in the Fall of 2020 (Sweet et al., *in progress*; Appendix 1). I generated US Census tract-level estimates of the proportion of people that wanted to see bison increase somewhat or increase substantially using multilevel regression and post-stratification (MRP) (Hanretty, 2020; Sweet et al., *in progress*). I took the complement of the bison acceptance responses to calculate social resistance to bison. I followed the same fuzzy sum (Theobald, 2013) and resistance surface calculations (Dickson et al., 2017) to create an implementation resistance layer, where land value was included to mimic slope (Williamson et al., *in review*).

$$R_{implementation} = (fuzzy\ sum\ of\ social\ layers + 1)^{10} + land\ value/4$$

Table 1.1. Landscape variables used to create biophysical and implementation resistance surfaces for bison connectivity conservation in Montana and Northern Wyoming.

Layer Type	Variable	Description	Source
Biophysical	Habitat Suitability Index	Habitat suitability model based on bison habitat requirements	Brock (2020) adapted from Steenweg et al. (2016)
	Human Modification Index	Degree of human modification for conterminous United States	Theobald (2013)
Implementation	Parcel Density (PD)	Number of private land parcels per 100 hectares for each county	Montana State Library (https://msl.mt.gov/geoinfo/data/msdi/) Wyoming Statewide Parcel Viewer (https://www.arcgis.com/apps/webappviewer/index.html?id=4bb9a66f7287402b8f650aa9f21d3fa5)
	Cattle Sales	Cattle sales per county in dollar amount including calves	USDA National Agriculture Statistics Service (https://quickstats.nass.usda.gov)
	Land Value	Market-value of private lands in US	Nolte (2020)
	Percent Republican Presidential Vote by county average 2000-2020	Average percent of Republican presidential voters from 2000-2020 per county	MIT Election Data and Science Lab (https://doi.org/10.7910/DVN/VOQCHQ)
	Bison increase preference	Proportion of people per US Census tract-level estimated to have answered they want bison numbers to increase from international wildlife governance preference survey	(Sweet et al., *in progress*)

II) Model Connectivity

Minimum Spanning Tree

A minimum spanning tree (MST) is an extension of the LCP approach that identifies the shortest pathway that connects every node (i.e., herd) for a given graph (Urban & Keitt, 2001). The MST is analogous to the LCP in that it identifies the lowest-cost, single pixel-wide path, but results in the suite of lowest cost paths that connect the entire network. The graphs were constructed by treating the existing herds as nodes and assigning the least-cost path between nodes based on the biophysical resistance surface to incorporate both biophysical traversal costs and distance traveled (Adriaensen et al., 2003). In order to generate three different MSTs, I iteratively identified the MST, buffered that by 4000m, and updated the resistance surface by assigning the maximum resistance value to pixels within the MST. This approach maintains a focus on minimizing biophysical costs of movement while eliminating path redundancy (Williamson et al., *in review*).

Cumulative Current Flow

I also used a circuit-theoretic analysis of the implementation and biophysical resistances surfaces to characterize the probability of successfully implementing a conservation plan and the probability of bison movement. Circuit-theoretic analysis also treats the landscape as a graph with nodes defined by the herds and resistance distances based on the appropriate resistance surface. The current flow produced from the biophysical resistance surface can be interpreted as the probability of movement and ultimately represents the potential for gene flow throughout the landscape (McRae & Beier, 2007). Current flows resulting from the implementation resistance surface reflect the probability that a conservation practitioner seeking to conserve a route between two nodes is successful (i.e., higher current flow means higher probability of a successful conservation action) (Williamson et al., *in review*).

III) Compare Outcomes

Costs of Movement and Implementation

To compare the costs of movement and implementation within the minimum spanning trees, I extracted and summed the accumulated cost for both the biophysical and baseline implementation resistance surfaces from Yellowstone National Park along the entire MST. I estimated the median value for the biophysical and implementation costs for an estimate of the "typical" values per each route; I also assessed the maximum biophysical and implementation costs for each route to compare the magnitudes of the greatest biophysical and implementation barriers for each route. Finally, I calculated the Euclidean distance for each path to better understand how length impacts the overall costs associated with each pathway.

Probabilities of Movement and Implementation

To compare the probabilities of movement and implementation, I created a bivariate choropleth map. Bivariate mapping is a strategic approach for analyzing potentially divergent data (Teuling et al., 2011). I applied a two-dimensional color scheme that shows the spatial distribution of the relationship between the probabilities of bison movement and implementation success (Williamson et al., *in review*). I compared these probabilities by normalizing the quantiles of cumulative current flow for both the biophysical and implementation cumulative current flow outputs.

Execution in R and Julia

I conducted all data manipulation and spatial data preparation in R to develop a suite of 540m resolution rasters as inputs for the resistance surfaces (i.e., took all of the implementation variable datasets individually and turned the tabular data into respective raster layers). I used the centroid of each reservation, park, or reserve (n=9 centroids) as the nodes to be connected as I did not have fine resolution data on specific herd locations. I used the *igraph* package (Csardi & Nepusz, 2006) to estimate the MST and the *gdistance* package (van Etten, 2017) to estimate accumulated costs. I ran all circuit-theoretic analyses using Circuitscape (Anantharaman, 2020) for the Julia language (Bezanson et al., 2017). The code for the analysis and visualization is available at: https://github.com/jamiefaselt/jf-bison-thesis.git.

Results

Landscape Conditions

The Habitat Suitability Index (HSI) for the study region ranged from 8.89 to 73.00 with a median value of 39.82. Values for human modification were generally low, with a median value of 0.19. Preferences for bison ranged from 42% to 50% of a tract supporting increased bison populations. Cattle sales ranged from $310,000 to $93,478,000, with a median value of $28,434,000. The study area generally votes for Republicans, with highly conservative areas in the central and eastern parts of the state, and more liberal voting trends in counties with Tribal communities and urban centers. Most of the study area had low parcel density: the median was 1.92 parcels/hectare, with the highest parcel density occurring in the western part of Montana with a maximum of 142.11 parcels per hectare.

Cost of Movement and Implementation

I used the biophysical resistance surface to determine the locations of the corridors and visualize them over the biophysical current flow to assess overlap between the top pathways and landscape current flow (Figure 1.3). The lengths of the paths were approximately 3500km, 4200km, and 6100km for the first-, second-, and third-ranked paths respectively. The cumulative, maximum, and median biophysical costs were lowest for the top ranked path (Figure 1.4). Whereas the implementation costs (cumulative, maximum, and median), were lowest for the second ranked path.

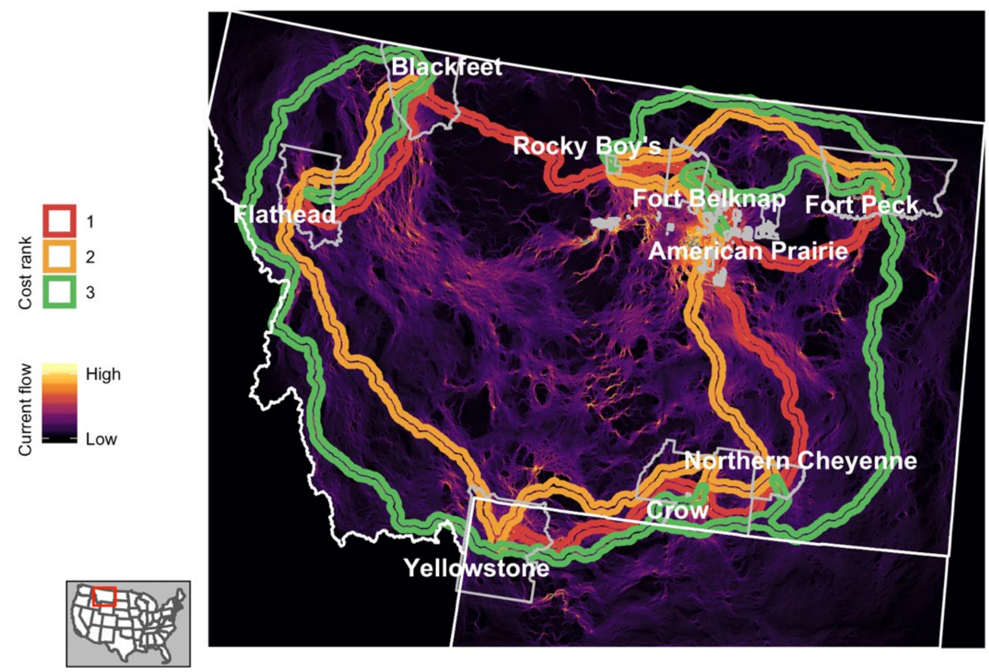

Figure 1.3 Top three pathways for bison connectivity corridors (based on the minimum spanning tree (MST) path and buffered by 4000m) connecting each herd in Montana and Northern Wyoming, USA, originating from Yellowstone National Park and current flow from circuit-theoretic connectivity model in the background. Both the MST and current flow outputs are based exclusively on biophysical resistance. The states are outlined in white and the general herd boundaries are shown in grey (note: the American Prairie has multiple parcels south of Rocky Boy's, Fort Belknap, and Fort Peck).

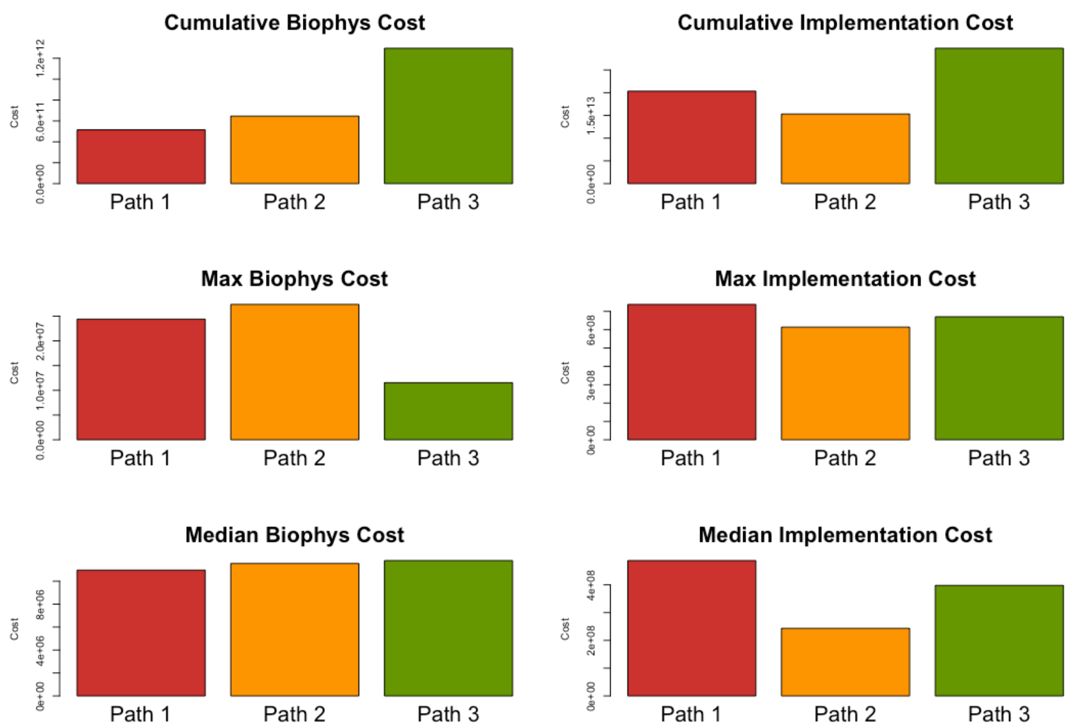

Figure 1.4 Comparison of the biophysical and implementation costs for the top three ranked-pathways connecting each herd in the study system. Cumulative costs are an estimate of the sum of the cost-distance values from both the respective biophysical and implementation cost surfaces within each buffered MST. Maximum costs are an estimate of the greatest cost along each ranked-pathway for biophysical and implementation cost surfaces. Median biophysical and implementation costs are an estimate of the central tendency for each pathway.

<u>Probability of Movement and Implementation</u>

The comparison of bison movement and implementation probabilities revealed that there are areas that are suitable for bison movement but have low implementation probability (i.e., social-ecological mismatch), including the area just south of the American Prairie and the western and southeastern parts of the study system (Figure 1.5). The comparison also reveals a potentially important corridor that has both high movement and implementation probability between the Blackfeet herd and the other northern Tribal herds (Rocky Boy's, Fort Belknap, and Fort Peck). The Rocky Mountain Front region (extending south from the Blackfeet Nation) and some east-central parts of the study system had discrete regions with high biophysical and implementation probabilities (i.e., social-ecological fit).

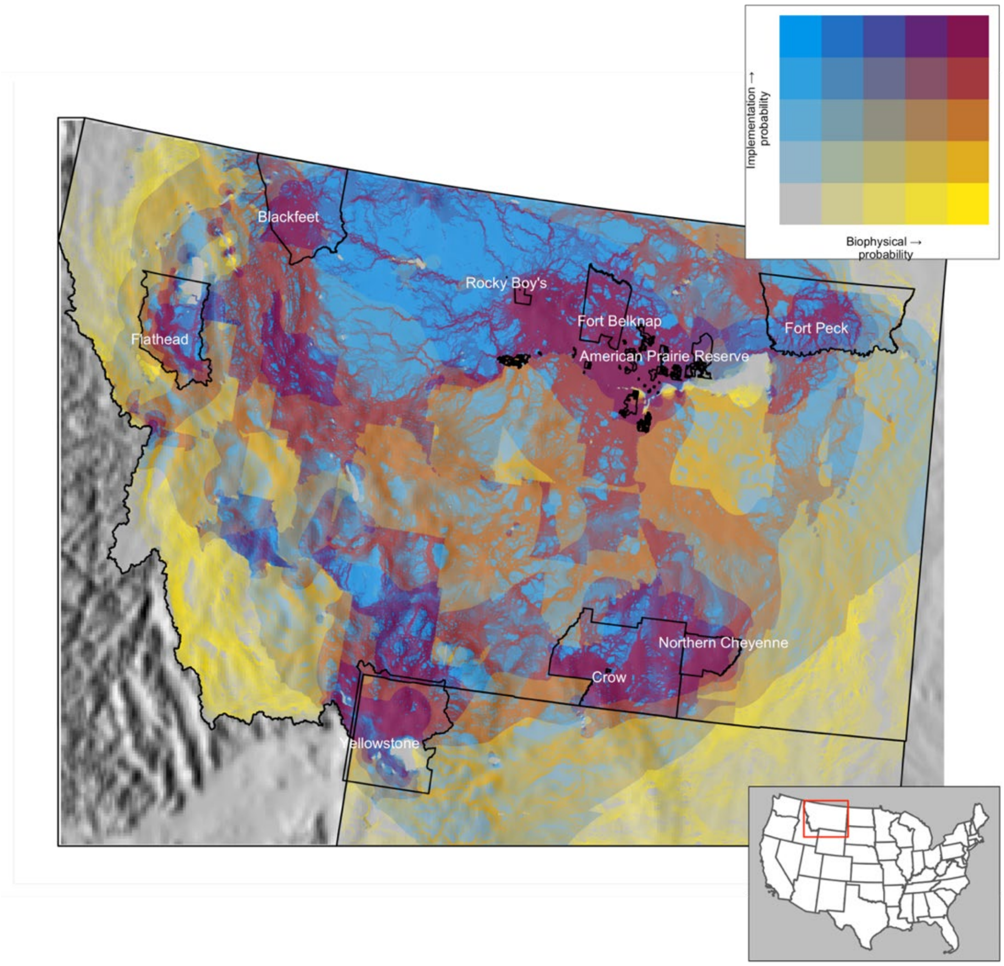

Figure 1.5 Bivariate Choropleth Map. Map comparing the divergence and convergence of the biophysical and socio-political circuitscape outputs. Ecological value or movement probability by a species is on the x-axis and socio-political willingness or implementation probability is on the y-axis. The outlines of the herd locations are shown in black. The resulting map shows the interaction between socio-political willingness and ecological value for a joint probability map of ecological value and implementation likelihood.

Discussion

Integrating both biophysical and implementation resistance into connectivity models for bison in MT and northern WY highlights the importance of incorporating the socio-political landscape in connectivity conservation planning. I use LCP/MST models to identify potential corridor locations illustrated that, although the top-ranked path was the most expedient from a biophysical perspective, the second-ranked path indicated lower overall socio-political costs associated with it. Results from my circuit-theoretic analysis highlight areas of social-ecological fit and social-ecological mismatches that occur both within and outside the identified corridors from the MST approach. This research addresses the need to evaluate the importance of socio-political factors within conservation plans (Carter et al., 2020; Niemiec et al., 2021; Walker & Hurley, 2004), and does so in a spatially-explicit way. Conservation practitioners can utilize this methodological approach to better anticipate implementation hurdles and make informed decisions regarding competing conservation strategies.

Conservation managers often need to make decisions with incomplete or imperfect information and many of these decisions are often based on anecdotal evidence, long-standing traditional management strategies, and personal experience (Pullin & Knight, 2003; Pullin et al., 2004). Further complicating matters, managers may not be trained in understanding the complex socio-political context of a landscape (Hemming et al., 2022; Wright et al., 2020). Spatial analyses that explicitly include social-ecological components can help address these gaps in conservation decision making (Bennett et al., 2017; Epstein et al., 2015; Niemiec et al., 2021). I show how analyzing the social, political, and biophysical landscape within connectivity models highlights areas that may be chosen based on biophysical value, but are mismatched with the social and political landscape. For example, the bivariate choropleth map indicates that the area southeast of the American Prairie has a high biophysical value, but a low probability of implementation success (Figure 1.5). The bison restoration efforts by the

American Prairie Reserve, similar to the region just north of Yellowstone, have seen social and political backlash from the local, predominantly ranching, communities (Turner, 2020). Therefore, including social and political datasets in the conservation planning process may help conservation practitioners better anticipate similar implementation hurdles in the future.

Conservation managers also need to evaluate the tradeoffs between competing values, objectives, and lines of evidence, such as different modeling approaches (Barnett & Belote, 2021; Etherington & Holland, 2013; Keeley et al., 2019; McRae & Beier, 2007; Rayfield et al., 2016). This research highlights how managers can compare socio-political and biophysical tradeoffs both within and between connectivity models. For example, the MST comparisons highlight how the biological ideal in the top-ranked path is only slightly less costly from a biophysical perspective, but that the second-ranked path is a greater magnitude less costly from an implementation perspective (Figure 1.4). There are regions where paths one and two follow similar courses, and potentially piecing together some of the lower biophysical and implementation connections from pathway two could be a strategy for creating a full network of connectivity that is less costly overall. These comparisons could be used to not only identify the top three, but also understand the movement and implementation costs associated with each. Combining the LCP approach with current flow outcomes from a circuit-theoretic approach allows conservation managers to compare discrete corridors with the entire landscape. The cost metrics from the MST comparisons give conservation managers a metric that may be more amenable to policy planning, whereas the probability metrics from the circuit-theoretic approach can help free managers to visualize otherwise missed regions of interest. As such, analyzing both current flow through the entire landscape and the top least cost-corridors gives conservation planners valuable tools for more informed decision-making. Given advances in computation efficiency, rather than researchers trying to decide which approach is best, I suggest integrating them, especially when including social datasets.

The purpose of this analysis is not to highlight precisely where bison connectivity conservation should be focused. Rather the analysis provides a proof of concept for conservation practitioners to make more informed decisions in connectivity planning. I used Plains bison, a cultural and ecological keystone species, as the case study in Montana and Northern Wyoming because there is currently no connectivity between herds in the region. However, this should not preclude envisioning what connectivity may look like in the future, especially if the goal of bison conservation is to have wild, free-ranging herds within their historic range (Buffalo Treaty, n.d.). It is important to consider that the social survey results utilized in this study are estimates based on the post-stratification and are not data from the exact census tract. However, MRP is found to have greater accuracy than other statistical disaggregation results (Zahorski, 2020). Additionally, I did not consider every potentially relevant social, political, or biophysical factor due to data availability. Future studies regarding bison in the region could use these results to make decisions about where to gather data on missing variable, or gather finer-scale data. A possible way to identify what other variables to consider and to make more nuanced decisions about the weighting of variables could be to utilize the Delphi technique (e.g., more structured expert opinion pools) (Hemming et al., 2018; Mukherjee et al., 2015).

Connectivity plans for large landscapes are increasingly utilized to maintain healthy ecosystems and species populations (Keeley et al., 2019). At the same time, there is growing recognition that the social and political landscape needs to be more explicitly acknowledged and addressed for conservation success (Epstein et al., 2015; Ghoddousi et al., 2021; Keeley et al., 2019; Williamson et al., *in review*). Social science datasets may be utilized in conservation plans but often only at the end of the planning process to promote stakeholder buy-in; a more advantageous approach can be to utilize social data to inform decisions in the initial planning stages (e.g., connectivity models) and throughout implementation (Niemiec et al., 2021; Walker & Hurley, 2004; Welch-Devine & Campbell, 2010). This analysis fills a valuable gap for developing quantitative steps for including non-biological variables to inform decisions about wildlife connectivity management, enabling conservation actors to spatially identify and strategizing where and how to implement conservation plans based on biological value and socio-political willingness/resistance. Such an integrated approach can assist conservation planners in identifying areas where conservation projects are more likely to be successful and in identifying barriers or bottlenecks to movement on the landscape. This framework may be especially important for controversial species such as wide-ranging species or carnivores (Dickson et al., 2017; Esmaeili et al., 2019).

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CHAPTER TWO: EVALUATING THE EFFICACY OF POTENTIAL CONSERVATION INTERVENTIONS TO PROMOTE CONNECTIVITY FOR BISON IN THE NORTHERN GREAT PLAINS

Abstract

Conservation managers need to make decisions regarding where and how to achieve conservation amidst complex socio-political and ecological landscapes, often while balancing competing objectives and with imperfect or inaccessible information. While there is wide acknowledgement that social science should inform conservation actions, utilizing social science datasets to design and implement conservation interventions from the planning stage remains rare in practice. In this study, I analyze socio-political and biophysical data to assess the spatial impacts of three commonly used interventions on long-term connectivity for Plains bison, a culturally and ecologically important species. I demonstrate an approach for comparing the impacts of conservation interventions on bison connectivity by manipulating socio-political resistance to bison connectivity based on three hypothetical scenarios of: 1) creating federal "tolerance zones" for bison movement, 2) providing economic incentives, and 3) increasing Tribal/First Nations governance of wildlife. I compared the relative impacts of these intervention scenarios on long-term connectivity for Plains bison. I found that the scenario of an economic intervention had a minimal change in projected implementation success. The hypothetical interventions of increasing Tribal/First Nations governance and creating public land tolerance zones had a greater overall effect on bison connectivity

throughout the study system. This research can provide conservation planners insight into the tradeoffs associated with strategies aimed at promoting long-term connectivity for Plains bison and other wide-ranging or reintroduced species.

Introduction

Staggering pressures on the natural environment from human activities necessitate the need to develop effective conservation interventions that improve the outcomes of conservation actions (Di Marco et al., 2016; Lorimer et al., 2015; Mills et al., 2019; Steffen et al., 2015). Conservation managers need to make decisions regarding where and how to achieve conservation amidst complex socio-political and ecological landscapes, often while balancing competing objectives and with imperfect or inaccessible information (Cook et al., 2010; Hemming et al., 2022; Pullin & Knight, 2003). Deciding on competing intervention strategies is challenging; managers may lack resources, adaptive capacity, or an adequate understanding of the socio-political context of a place (Bull et al., 2015; Constantino et al., 2021; Cook et al., 2010; Ferraro & Pattanayak, 2006; Law et al., 2017; Pullin et al., 2004). Despite calls to utilize social science to inform conservation plans (Bennett et al., 2017; Niemiec et al., 2021), non-biophysical datasets are rarely used in early planning stages for designing or implementing conservation interventions in practice (Niemiec et al., 2021; Walker & Hurley, 2004). According to the International Union for Conservation of Nature (IUCN) Red List of Threatened Species, there are six major types of conservation actions or interventions: land/water protection, land/water management, species management, education and awareness, law and policy, and livelihood, economic and other incentives (*Conservation Actions Classification Scheme*, n.d.). In this study, I utilize social science datasets to impose and anticipate the spatial impacts of three commonly used conservation interventions: changes in land-use tenure (e.g., protected areas), economic incentives, and changes in governance.

Establishing protected areas is an important and long-used conservation intervention (Colchester, 2004; Elsen et al., 2020; Gray et al., 2016; Montesino Pouzols et al., 2014). In the United States, protections can range from strict restrictions on hunting, harvesting, and human use of an area (e.g., National Parks), to multi-use landscapes such as Bureau of Land Management (BLM) and National Forest lands, where extractive practices can still exist. For wide-ranging species, protected areas can be critically important (Barnett & Belote, 2021; Saura et al., 2017). However, adequately protecting a migration corridor likely requires species-specific conservation policies on multi-use public lands (Tack et al., 2019), especially policies that balance land-use and biodiversity conservation (Montesino Pouzols et al., 2014). Shifting land tenure policies on public lands can enhance wildlife connectivity within protected area networks, which are currently insufficiently connected (Saura et al., 2017). At the same time, establishing wildlife connectivity across large landscapes also requires working with private land-owners (Keeley et al., 2018; Niemiec et al., 2021; Tanguay et al., 2021) and balancing federal protections for land with local politics (Sullivan & McDonald, 2020). Ultimately, conservation interventions aimed at enhancing the social-acceptance for conservation actions are necessary.

There is a longstanding history of using economic interventions to enhance the acceptance of wildlife conservation (Bulte et al., 2003; Naughton-Treves et al., 2003; Nyhus et al., 2003; Pirard, 2012; Treves et al., 2009; Zabel & Holm-Müller, 2008), however, as with most conservation interventions, there is a lack of empirical evidence regarding their efficacy (Bulte et al., 2003; Ferraro & Pattanayak, 2006; Rode et al., 2015; Selinske et al., 2017). For example, an economic incentive is unlikely to shift deeply entrenched values held among livestock producers (Naughton-Treves et al., 2003) and may have unintended negative consequences such as ultimately serving as a subsidy to convert natural habitats into agricultural lands (Bulte & Rondeau, 2007). While economic incentives for conservation can be complicated, insufficient, and expensive (Pirard, 2012; Treves et al., 2009), important distinctions between the type of economic incentive are worth considering (Karlsson & Sjöström, 2011; Nyhus et al., 2003). Economic incentives in the form of compensation for livestock losses due to depredation may have unintended negative consequences, but broader financial incentives for proactive mitigation and land-use changes may be a more promising approach (Karlsson & Sjöström, 2011; Nyhus et al., 2003).

Land-use changes and overall increases in social acceptance for conservation can also be a result of governance shifts, such as through community-based and collaborative conservation (Jupiter et al., 2014; Leeuw et al., 2012; Bixler et al., 2015; Simms et al., 2016). Governance relates to the institutions (e.g., policies, tenure systems, cultural contexts, social norms), structures (e.g., co-management bodies, decision-making authorities), and processes (e.g., negotiations, mandates, law-making, policy-application) that dictate decisions on who makes the decisions and how, and what actions are taken by whom (Lockwood et al., 2010). Community-based conservation involves bottom-up governance and collaboration with cross-scale governance networks (Berkes, 2004). A focus on local, bottom-up governance can enhance conservation successes because the scale of management may be more likely to match the scale of the ecosystem service (Berkes, 2004; Cumming et al., 2006). Additionally, community-based conservation, especially Indigenous-led environmental governance, can be both a justice and efficacy oriented conservation intervention (Artelle et al., 2019; Tran et al., 2020). Indigenous-led wildlife governance is exceptionally important when considering sacred landscapes and culturally important species; centering Indigenous governance structures can help biodiversity conservation on a whole by imagining new alternatives rather than merely upholding the status quo (Turner et al., 2008).

Ultimately, shifts to the status quo regarding a lack of social acceptance for conservation and incompatible land uses need to occur for societies to reach global biodiversity targets, one of which is enhancing habitat connectivity (Belote et al., 2020). Not only do conservation interventions need to occur in important places ecologically, they also require a certain level of socio-political acceptance and institutional support (Epstein et al., 2015). This can be especially true for large landscape conservation and/or conservation of highly mobile species (e.g., Plains bison) where conservation interventions may succeed in one location but fail in another and thus require spatial understanding and coordination (Runge et al., 2014; Williamson et al., *in review*). Plains bison present an optimal focal species for assessing which conservation interventions may result in a spatially coherent path for wildlife connectivity. There are international, federal, and Indigenous-led efforts to restore bison to parts of their historic range, but due to socio-political constraints, there is virtually no connectivity between existing herds. Some groups involved in bison restoration include the Buffalo Treaty, the InterTribal Buffalo Council, the United States Department of the Interior, and non-profit organizations such as the American Prairie; these entities state that wild, free-roaming bison is an ultimate goal for their ecological and cultural restoration (*Buffalo treaty*, n.d.; *Building the Reserve*, 2016; *InterTribal Buffalo Council*, n.d.; United States Department of the Interior Bison Working Group, 2020). Bison restoration, and subsequent connectivity, is a priority for both revitalizing Indigenous communities' cultural connection to bison and for ecological resilience, especially in imperiled grassland ecosystems like those of the Northern Great Plains (Augustine et al., 2019; Samson et al., 2004).

<u>Bison Case Study</u>

Bison are an ecological keystone species; they impacted the structure, composition, and stability of plant and animal communities throughout their historic range (Gates et al., 2010; Knapp et al., 1999; Truett et al., 2001). Bison are also a significant cultural keystone species; no other wildlife species is considered to have a more significant influence on North American human culture (Garibaldi & Turner, 2004; Gates et al., 2010; Zontek, 2007). Some key challenges to bison restoration are: political resistance, competition with the cattle ranching industry, management across jurisdictional boundaries, and an overall lack of social acceptance (Gates et al., 2010; Pejchar et al., 2021; Sanderson et al., 2008). Interventions aimed at increasing social acceptance of bison will likely play a role in any future connectivity for the species.

<u>Political Resistance and Management Across Complex Jurisdictional Boundaries</u>

Bison are the national mammal of the United States, and the federal government manages 11,000 Plains bison throughout 19 federally-managed herds (*Yellowstone Bison*, 2022). The federal government has been working on a Bison Conservation Initiative

(BCI) and an Interagency Bison Management Plan (IBMP), which were established in 2008 and 2000, respectively. One of the aims of the Bison Conservation Initiative is to promote large, free-ranging herds of bison (United States Department of the Interior Bison Working Group, 2020). The herd in Yellowstone National Park is the largest and one of the most politically controversial (Bidwell, 2009). While the Yellowstone herd is considered free-roaming wildlife inside of the park, when they leave federal land and venture into the state of Montana, their designation transitions to livestock with oversight from Montana Fish Wildlife and Parks and the United States Department of Agriculture through the Animal and Plant Health Inspection Service. Despite ongoing efforts towards the goal of maintaining wild, healthy bison herds, the federal herds remain either fenced in or killed, captured, or hazed if they exit federal lands (Bidwell, 2009). State-level anti-bison initiatives stand in contrast to recent federal efforts to reintroduce bison. For example, the Montana State Legislature passed House Bill (HB) 302 and HB 318 into law in 2021. HB 302 gives county commissioners the power to veto any proposal for bison restoration, even on federal lands. HB 318 alters the definition of wild bison to any that has not been held in captivity, owned by a person, or taxed as livestock. Since the vast majority of conservation herds are fenced in, and the unfenced herds have often been "in captivity" for quarantine purposes, HB 318 disqualifies nearly all Plains bison for use in restoring public herds throughout Montana (Bailey, 2021). The federal government needs to navigate the tensions between local and state governments with their efforts to support wild bison conservation. One way to overcome the state-level political obstacles, and "soften" some of the jurisdictional boundaries that need to be navigated for connectivity, could be to leverage federally owned public land as bison friendly "tolerance zones".

Competition with the Cattle Ranching Industry

Cattle industry proponents argue that bison pose a threat due to competition for forage with cattle, especially in drought years (Ranglack & du Toit, 2016). Additionally, ranchers fear brucellosis transmission from bison to cattle. Brucellosis is a reproductive disease that causes abortion in female bovids (Bidwell, 2009). While there have been no known cases of bison transmitting brucellosis to cattle in the wild, this fear further complicates bison conservation efforts (Gates et al., 2010). As such, if ranching communities are predominantly concerned with the economic implications of bison moving through the landscape due to the possibility of disease, forage competition with cattle, and infrastructure damage, economic interventions may be an effective conservation strategy. Experts on bison conservation identified economic incentives as a strategy for overcoming barriers to bison conservation (Pejchar et al., 2021), but the efficacy of economic incentives to promote conservation and areas where constituents will respond to them remains in question.

Indigenous Sovereignty as a Conservation Mechanism

Many of Tribally-led bison (or buffalo as they are commonly referred to in this context) reintroduction programs embody bottom-up collaborations such as the InterTribal Buffalo Council (ITBC), the Buffalo Treaty, and the Iinnii Initiative. It is important to note that Tribally-owned herds can play multifaceted roles, where bison's return to the landscape enables Indigenous communities to reestablish their relationship to bison, derive economic benefits from bison (e.g., tourism, sale of bison meat), and support ecological resilience on their lands (Shamon et al., 2022). The ITBC assists Tribes in restoring bison through grants, education and training programs, and surplus NPS bison transfers to Tribal lands (*InterTribal Buffalo Council*, n.d.). The Buffalo Treaty has 31 signatories and was established in 2014 with an objective “to honor, recognize, and revitalize the time immemorial relationship we have with BUFFALO… and recognize BUFFALO as a wild free-ranging animal and as an important part of the ecological system” (*Buffalo treaty*, n.d.). The Iinnii (Blackfeet word for “Bison”) Initiative is working to establish an internationally free-ranging herd that can travel along the Rocky Mountain Front within Blackfoot Confederacy land in Montana and Alberta, and into Waterton-Glacier International Peace Park (*Blackfeet Buffalo Program*, n.d.). The Confederated Salish and Kootenai Tribes (CSKT) of the Flathead reservation also recently gained management over the formally managed DOI National Bison Range. This recent transfer to Indigenous management is in line with the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP), which “establishes a universal framework… for the survival, dignity, and well-being of Indigenous peoples” (Champagne, 2013). UNDRIP and United Nations are declarations may not have substantive enforcement power, but they hold moral ground and the cases where they are used as a legal instrument are growing (Gómez Isa, 2020; Goolmeer et al., 2022). Implementing an intervention aimed at enhancing Tribal and First Nations governance of bison has grounding as a moral justification. Additionally, there is evidence that focusing on culturally important species (e.g., bison) can increase social acceptance of conservation actions (Freitas et al., 2020).

Methods

Overview

I analyzed the nine restoration herds in Montana and Northern Wyoming that included seven Tribally-owned/managed herds, one NPS herd in Yellowstone National Park, and one public-private partnership in the American Prairie (Faselt, 2022). This research builds upon an analytical comparison of the probabilities of bison movement and conservation action (e.g., implementation) and used a circuit-theoretic connectivity modelling approach (Faselt, 2022). The biophysical and baseline implementation resistance surfaces for bison represented resistance from habitat variables and human modification and socio-political resistance, respectively (Faselt, 2022). I then manipulated the baseline implementation resistance surface to create several resistance surfaces that reflect the impacts of conservation interventions aimed at enhancing social acceptance of bison on the species long-term connectivity potential. The first hypothetical intervention reflects the scenario that two protected areas in the study region become bison “tolerance zones”, where bison would be permitted to freely move throughout them. The second hypothetical intervention reflects an economic incentive and is based on the long-standing history of an economic approach to conservation. The third hypothetical intervention reflects a Tribal and First Nations governance scenario based on UNDRIP guidelines and the cultural significance of bison among Indigenous communities in the study region. I quantified the potential impacts of each intervention by comparing the changes in relative importance or rank of each region and assess areas that have more or less channelized/impeded current flow, to the baseline implementation resistance. Both metrics reflect relative changes in the importance of locations throughout the study system based on the interventions.

Biophysical and Baseline Implementation Resistance Surfaces

I characterized the biophysical landscape elements that affect bison movement by combining data on a habitat suitability index (HSI) (Shamon et al., 2021) and human modification (HMI) (Theobald, 2013), and slope. I characterized implementation resistance by combining data on known socio-political forms of resistance to bison restoration. This included data on cattle sales, Republican voting trends, parcel density as a measure of jurisdictional complexity, the social acceptability of bison from an international wildlife governance preference survey, and land value (Faselt, 2022). The inputs for each resistance surface were scaled from 0 to 1 and combined using a “fuzzy algebraic sum” approach (Theobald, 2013), then I created the resistance surfaces following the work of Dickson et al. (2017) (Faselt, 2022). Each of the subsequent resistance surfaces were created following these methods.

Modifications for Intervention Scenarios Resistance Surfaces

For scenario one, I created a public land “tolerance zone” intervention on federal lands, due to the DOI efforts to restore wild, free-roaming bison as stated in the Bison Conservation Initiative. I identified potential tolerance zones by considering all proclaimed and designated protected areas in the study region larger than ~20,000 hectares and selected those whose bison habitat suitability scores were in the upper 75th percentile and whose social resistance values were below the median, based on a 5km buffer around each protected area. This filtering approach resulted in Nine Pipe Wildlife Refuge and the Rocky Mountain Front Conservation Area as the two most suitable tolerance zones. I selected Nine-Pipe Wildlife Refuge and the Rocky Mountain Front Conservation Area as suitable tolerance zones and added them as a short-circuit region (i.e., an area given zero resistance).

The second scenario was based on a hypothetical economic intervention. Using the wildlife governance preference survey, I analyzed the question "Which of the following actions do you feel would be most appropriate to ensure stable numbers of bison in the future?" and looked at those who responded, "financial incentives to encourage people to take actions that benefit bison." I generated US Census tract-level estimates of the proportion of people that wanted to see economic incentives using multilevel regression and post-stratification. The output from the economic incentive model was an "economic incentive preference" layer. I then added this with a "bison increase preference" layer (Faselt, 2022) based on the same wildlife governance survey and methods stated above. I assumed that if an economic incentive were implemented to promote bison conservation, that would raise the amount of social acceptance of bison. Since the circuitscape inputs are resistance surfaces, I took the complement of the "bison increase layer + economic incentive preference" to represent overall social resistance to bison after the hypothetical economic intervention.

The third scenario was based on a hypothetical scenario that promotes Tribal/First Nations governance of wildlife. I analyzed the question "How appropriate do you feel it is for the following group to regulate wildlife populations and habitats?" and looked at those who responded "Tribal/First Nations Governments." I generated US Census tract-level estimates of the proportion of people that wanted to see Tribal/First Nations governing wildlife using multilevel regression and post-stratification. The output from the Tribal/First Nations governance model represented a "Tribal governance incentive preference" layer, based on the estimated probability of each census tract that responded that Tribal/First Nations governments are the most appropriate entity for managing wildlife and habitat. I then added this with a "bison increase preference" layer (Faselt, 2022) based on the same wildlife governance survey and methods stated above. I made the assumption that increasing Tribal/First Nations governance as the method for promoting bison populations could ultimately increase the amount of social acceptance for bison. For both the economic incentive and Tribal and First Nations governance scenarios, the adjusted social acceptance layers were added to the remaining implementation resistance layers (cattle sales, voting trends, parcel density, and land value) and converted to resistance surfaces using the methods stated above.

Comparing Probability of Movement with the Projected Implementation Changes from Intervention Scenarios

To compare the probabilities of movement and implementation, I normalized the quintiles of cumulative current flow for both the biophysical and implementation outputs (Faselt, 2022). In order to assess the potential impacts from the hypothetical interventions, I calculated the changes in the implementation quintiles based on changes in current density with each intervention scenario and ranked the shifts based on the difference from the implementation baseline quintiles. I also identified how the intervention scenarios shift areas of current flow that are channelized (i.e., flowing) or impeded throughout the landscape. I normalized the current flow outputs for the baseline implementation and intervention scenarios by dividing current flow by each respective current surface by a "null" current flow output, where the resistance values were the minimum implementation resistance value (McRae et al., 2016; Williamson et al., *in review*). Low current flow can result from diffuse pathways or where resistance values are high enough that current flow is impeded. I classified locations where the ratio between the null and the implementation/intervention current surfaces was less than 20% of the null as impeded and locations where the ratio is greater than 20% of the null as channelized (Williamson et al., *in review*).

Execution in R and Julia

All data manipulation and spatial visualizations were conducted in R (R Core Team & Others, 2021). Each of the input rasters (Chapter 1, Table 1) and intervention scenario rasters had a resolution of 540m. For the connectivity analyses, I used the centroid of the reservations, national park, and reserve as the nodes to be connected because fine-scale data on herd locations is sparse (n=9 nodes). Circuit theoretic connectivity analyses ran in the Julia language (Bezanson et al., 2017) using the Circuitscape program (Anantharaman, 2020). For reproducibility and transparency, the code for the analysis and figures are available at: https://github.com/jamiefaselt/jf-bison-thesis.git.

Results

Intervention Conditions

The areas selected for the "tolerance zone scenarios" were Nine-Pipe Wildlife Refuge (area = 33201.6241 ha), which had a mean habitat suitability index of 56, and social resistance value of 414; and the Rocky Mountain Front Conservation Area (Area = 371965.1893 ha) which had a mean HSI of 47, and implementation resistance of 414. Preferences for economic incentives were generally low, ranging from 5.8% to 8.8%. In contrast, preferences for Tribal/First Nations governments managing wildlife were high, ranging from 60% to 69%.

Intervention Scenario Comparisons

The comparison of biophysical and baseline implementation probabilities revealed locations of social-ecological fit and mismatches (Faselt, 2022) (Figure 2.1a). The ranked changes ranged from -3 to +3, representing a negative or positive change in relative importance. The changes in rank (Figure 2.1b,c,d) highlights how the intervention scenarios change the relative importance of parts of the landscape. The public land "tolerance zone" scenario (Figure 2.1b) resulted in a negative change in rank for a large portion of the landscape and a positive change in rank (i.e., greater relative implementation probability in comparison to the baseline) along the short-circuit region or tolerance zone of the Rocky Mountain Front. The economic scenario (Figure 2.1c) resulted in minimal changes to implementation probability throughout the landscape. The Tribal and First Nations governance scenario (Figure 2.1d) produced some positive changes in rank, especially among more urban areas including Bozeman, Helena, and Great Falls, and between the Flathead and Blackfeet Reservations; this governance scenario also produced some negative changes in rank in the region south of the American Prairie and northeastern Reservations, extending south to the Crow Reservation.

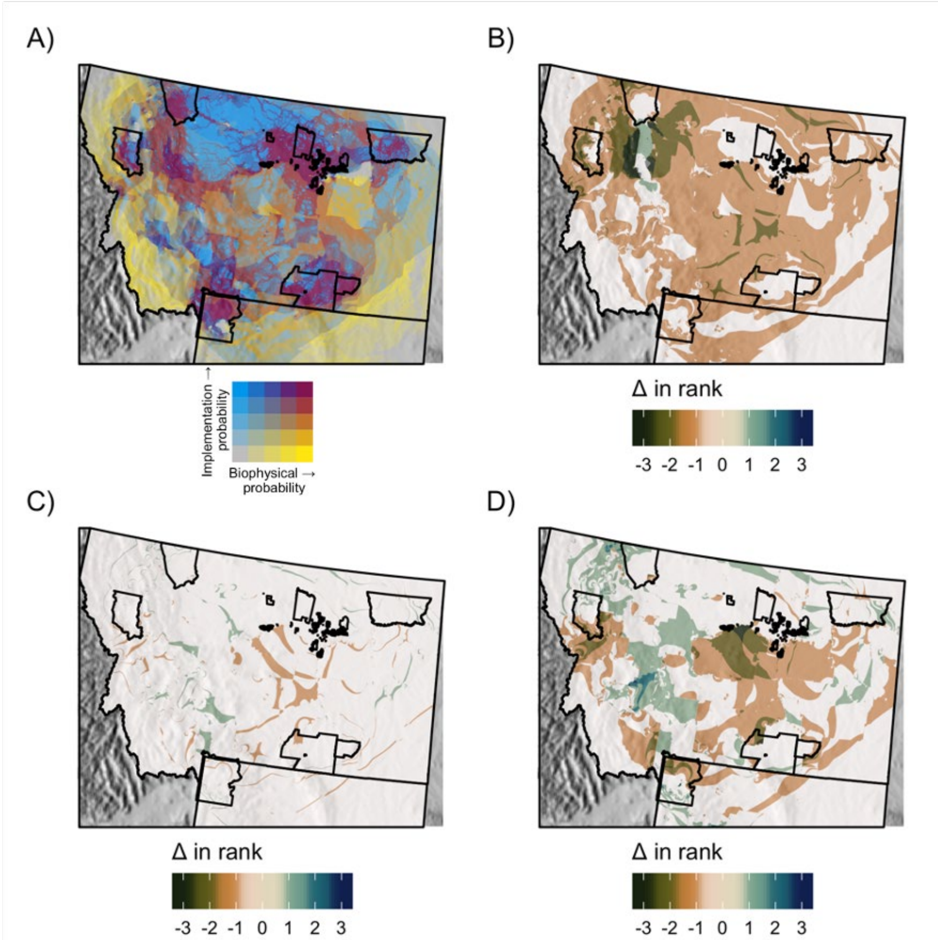

Figure 2.1 Bivariate choropleth map (A) depicting the joint probability of movement and implementation and the hypothetical shifts in probability of implementation based on: (B) public land "tolerance zones", (C) an economic intervention scenario, (D) an intervention scenario aimed at enhancing Tribal and First Nations governance of wildlife.

The comparison of channelized and impeded current flow (Figure 2.2) revealed that the public land tolerance zone (Figure 2.2b) had more regions now considered impeded in the western part of the study system. The economic incentive scenario (Figure 2.2c) showed minimal changes from the baseline implementation (Figure 2.2a). The Tribal and First Nations governance scenario (Figure 2.2d) yielded both an increase in channelized and impeded current flow throughout the study system.

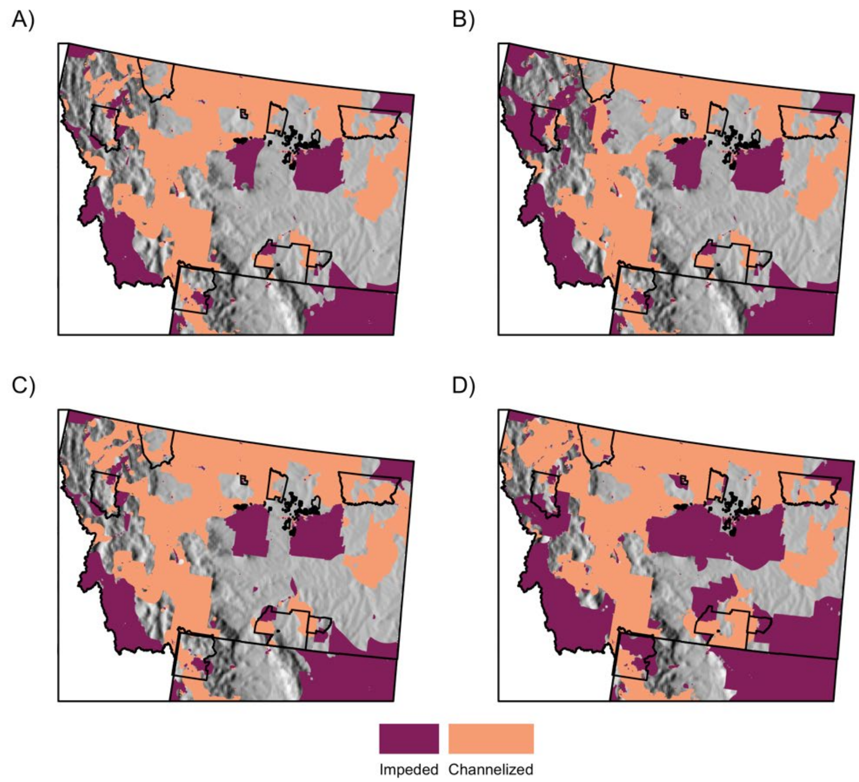

Figure 2.2 Channelized (i.e., current flow greater than expected given a null resistance surface) and impeded (i.e., areas where the landscape restricts current flow) locations base on baseline implementation resistance (A), public land "tolerance zone" intervention scenario (B), economic intervention scenario (C), and Tribal and First Nations governance scenario (D).

Discussion

I analyzed potential intervention scenarios aimed at enhancing social acceptance for bison connectivity, based on 1) creating "tolerance zones" for bison movement on federal public land, 2) establishing economic incentives, and 3) promoting Tribal/First Nations governance of wildlife. I used Plains bison as a case study because of their status as a cultural and ecological keystone species and the myriad efforts to reintroduce them throughout their historic range. Anticipating the performance of potential interventions to promote conservation is challenging due to the complex ecological, economic, social, and political contexts of a region (Law et al., 2017). This research provides conservation managers a way to impose hypothetical interventions that explicitly include social, political and institutional datasets. Conservation interventions can be costly and time-consuming to implement, so anticipating the outcomes for interventions provides a valuable contribution for bison conservation and other reintroduced and wide-ranging species.

While economic incentives are a common conservation strategy (E. H. Bulte et al., 2003; Naughton-Treves et al., 2003; Pirard, 2012), I found that the economic incentive scenario had a minimal spatial impact on implementation probability. Despite the uncertain or potentially detrimental side effects from economic incentives, they still have seemingly broad-scale support (Naughton-Treves et al., 2003), including specifically for bison conservation (Pejchar et al., 2021), which is a sentiment I did not find based on the wildlife governance preference survey used in this study. As such, economic incentives may not be a particularly effective option for Plains bison in the study region.

The public land tolerance zones intervention yielded greater spatial changes for implementation probability when compared to the economic incentive. The results from the delta and channelization maps indicate the tolerance zone region of the Rocky Mountain Front yielded such a greater probability shift for implementation that the rest of the landscape was relatively less important or considered impeded. The Nine-Pipe Wildlife Refuge tolerance zone did not shift the implementation probability immediately near it, likely because of its size and proximity to the Bison Range managed by the CSKT of the Flathead Reservation. This suggests that for “tolerance zones” to be impactful, managers may consider larger ones and/or ones some distance from established herds. While protected areas are an important conservation tool (Elsen et al., 2020; Gray et al., 2016), less than a third of them are sufficiently connected (Saura et al., 2017). Establishing something like a tolerance zone within protected areas that have multiple uses, may enhance wildlife connectivity for controversial species. Additionally, making wildlife friendly zones within multi-use protected areas overcomes part of the jurisdictional complexities that connectivity projects face. Both the Rocky Mountain Front Conservation Area and Nine-Pipe Wildlife Refuge fall under the jurisdiction of the United States Fish and Wildlife Service (USFWS), which has stated its cooperation with the DOI BCI and has a goal to "work to conserve existing bison herds in the United States" (*American Bison (Bison bison)*, n.d.). Other regions, that the chosen thresholds did not capture, could also be suitable for tolerance zones that aim to enhance wildlife connectivity, for example, the US Forest Service (USFS) requires connectivity plans within individual forests as of 2012 (Keeley et al., 2019). However, one major critique of protected area conservation (and conservation more broadly) in the United States and abroad, is the legacy of Native Land dispossession (Craig et al., 2012; Finegan, 2018; Sillitoe, 2015; Youdelis et al., 2021).

Implementing a Tribal/First Nations led governance scenario could be a step towards reconciling historical wrongdoings imposed upon Indigenous communities throughout the history of conservation. There are specific rights related to conservation and land stewardship set out by UNDRIP; for example articles state that "ownership, use, and management of territory, land, and resources, including collective ownership and stewardship, restitution of land taken without consent, no forced removals, access to natural resources and their own means of subsistence and development, and engagement in traditional and other economic activities", and "maintaining and protected sacred and other cultural sites; and maintaining their spiritual relationship with their territories" (Stevens, 2014). Even though United Nations guidelines are "soft law" mechanisms with no substantive enforcement power (Goolmeer et al., 2022), it is considered an increasingly robust legal instrument (Gómez Isa, 2020). While this research does not proport to provide directives for how to achieve these conservation interventions, one thought-provoking actualization for the Tribal/First Nations governance scenario could be for the US government to formally recognize culturally important species for protection under existing legal frameworks such as the Endangered Species Act (Goolmeer et al., 2022). Additional literature suggest that a focus on culturally important species can stimulate community engagement and subsequently increasing buy-in and the likelihood of conservation initiative success (Freitas et al., 2020). Ultimately any directive for how to achieve enhanced Tribal and First Nations led governance scenarios for bison restoration can and should be Indigenous-led with support from chosen partners (Artelle et al., 2019; Goolmeer et al., 2022).

As these interventions currently exist in the abstract and not as a formal directive for how to achieve them, conservation planners, managers, rightsholders and stakeholders could come together to discuss the actualization of interventions and create a deeper understanding of how the tradeoffs might exist on the landscape. The short-circuit locations for "tolerance zones" were based on high habitat suitability and low social resistance, and no locations were consulted. However, this approach can provide the federal government with insights into potential locations to focus on establishing tolerance zones for bison. It is important to note that Tribal and First Nations communities (and individuals) are not a monolith and this research is not aiming to suggest that there would be a one-size-fits-all approach to managing wildlife between Tribal and First Nations governments. Additionally, the wildlife governance preference survey results were downscaled and are not data generated from the exact census tract, however the approach used in this analysis is shown to have higher accuracy than other statistical disaggregation approaches (Zahorski, 2020). Still, it may be beneficial to gather finer-scale and/or more targeted social data prior to attempting to actualize any of the interventions assessed in this analysis. Finally, I approach this research from a Western Science and Governance lens, but given the diversity of rightsholders and stakeholders involved in bison conservation, the interventions may not be the most appropriate when considering different world views.

In this case study, I identified the importance of integrating space into assessments of the potential effectiveness of conservation interventions. Bison are a contentious yet incredibly important cultural and ecological keystone species. Finding ways to restore them on a landscape scale has many merits, ranging from carbon sequestration and seed dispersal (Hillenbrand et al., 2019; Knapp et al., 1999), to food sovereignty and reconciliation (Hisey, 2021; Shamon et al., 2022). Efforts to reintroduce or recover politically contentious and culturally important species such as caribou and salmon are increasing, suggesting that there may be opportunities for using this approach for future studies. The groups involved in promoting the conservation of contentious species, such as bison, will need to understand and evaluate tradeoffs, and be strategic about where, when and how to impose interventions, especially given increasing political pressures, climate change, and limited resources. This analysis could be utilized to answer those questions, and ultimately support more effective, transparent, and just conservation.

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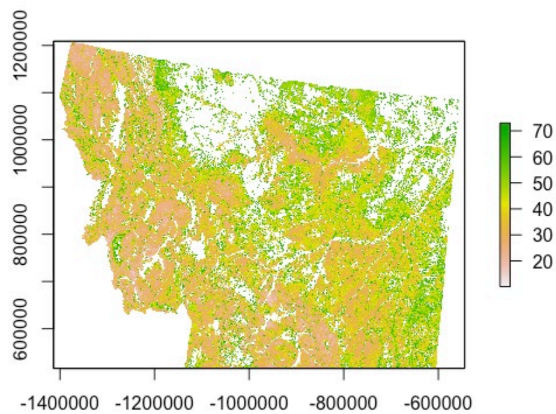
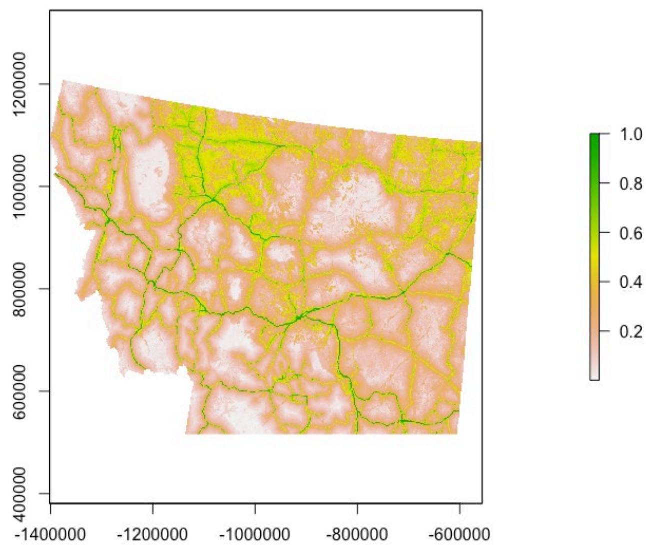
APPENDIX A

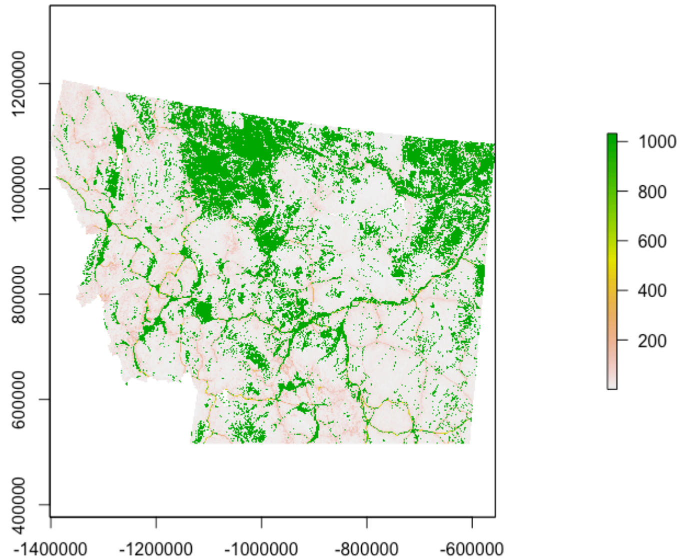
Chapter One Supplementary Figures



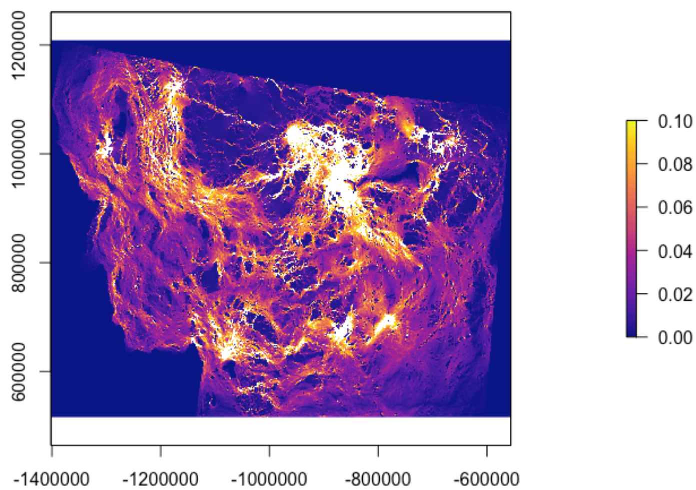
Appendix A.1 Habitat Suitability Index for plains bison cropped to study area used in the biophysical resistance surface (Shamon et al., 2021).



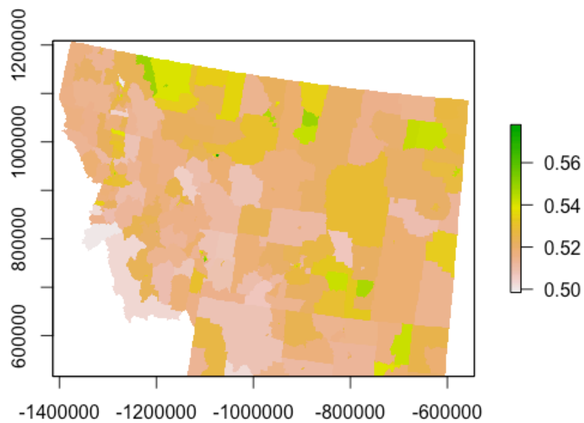
Appendix A.2 Human Modification Index for study area used in the biophysical resistance surface (Theobald et al., 2020).



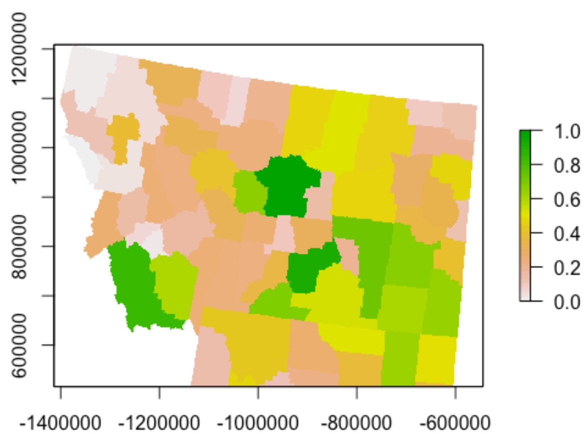
Appendix A.3 Biophysical resistance surface created by combining the HSI and HMI layers.



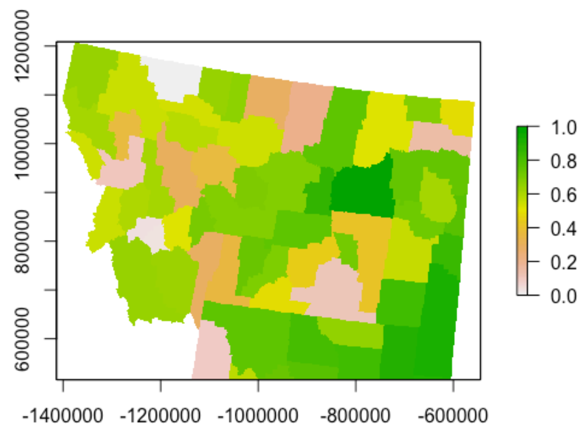
Appendix A.4 Cumulative current flow from circuit-theoretic connectivity model of biophysical resistance surface.



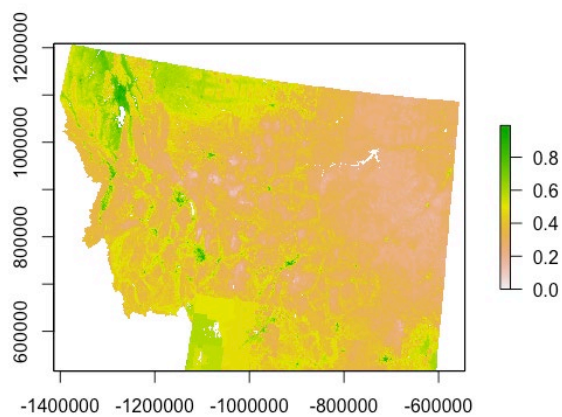
Appendix A.5 Multi-level regression with post stratification outputs for portion of census tract that are resistant to bison, inverse used in the implementation resistance surface.



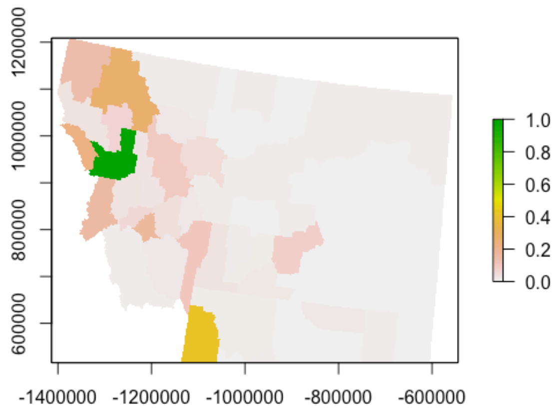
Appendix A.6 Relative cattle sale amounts in dollars (NASS, 2017) used in the implementation resistance surface.



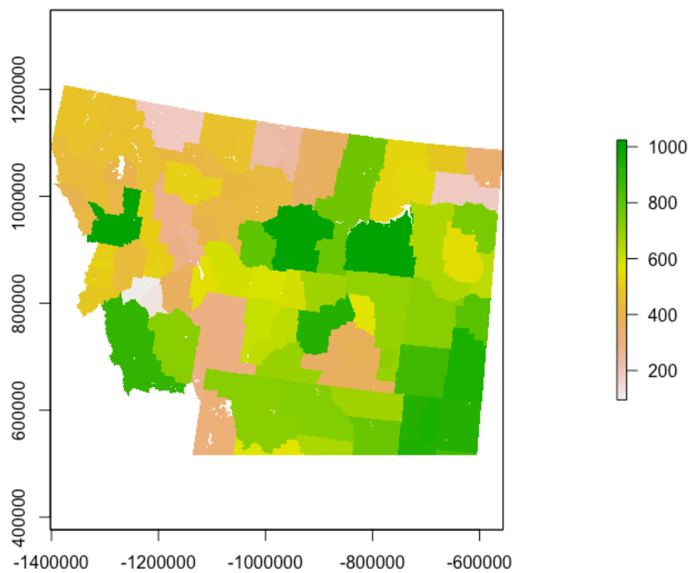
Appendix A.7 Average proportion of votes for Republican Presidential candidates from 2000-2020 (MIT Election Data and Science Lab, 2018) used in the implementation resistance surface.



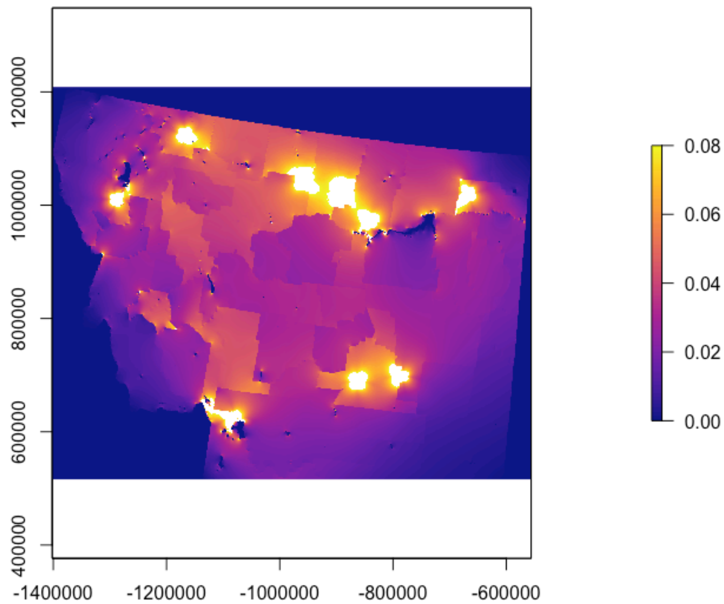
Appendix A.8 High-resolution maps of the estimated value of private lands in the contiguous United States (Nolte, 2020) used in the implementation resistance surface.



Appendix A.9 Parcel density map (parcels/100 hectares) (Montana Cadastral Framework, 2019) used in the implementation resistance surface.



Appendix A.10 Implementation resistance surface created by combining the social survey data, cattle sales data, republican voting data, parcel density, and land value.



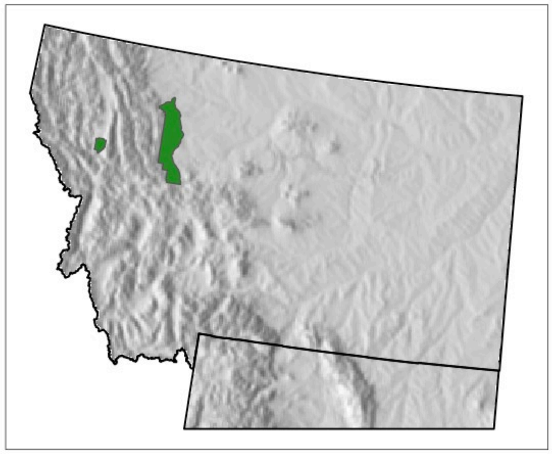
Appendix A.11 Cumulative current flow from the implementation circuit-theoretic connectivity model.

Multilevel Regression with Poststratification supplemental information

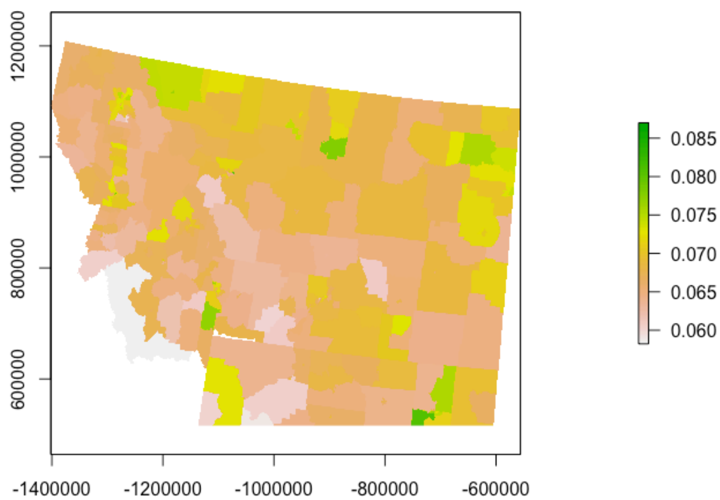
I used rstanarm in R version 4.1.3, I fit a Bayesian binomial regression with a logit link function (Goodrich et al. 2020). I coded the response variables as bison increase somewhat and increase greatly as 1's with all other responses coded as zero and used varying intercepts for the predictors of state, gender, country, education, age, and mean distance to bison's range (Gates et al., 2010). The model showed successful convergence and mixing based on R-hat values and effective sample sizes. The model was fit with priors from the normal distribution between 0 and 1, run on four chains, with 2000 iterations (Sweet et al., *in progress*).

APPENDIX B

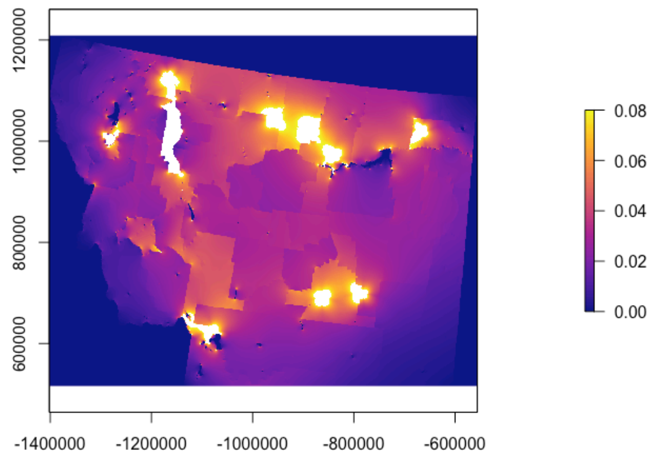
Chapter Two Supplementary Figures



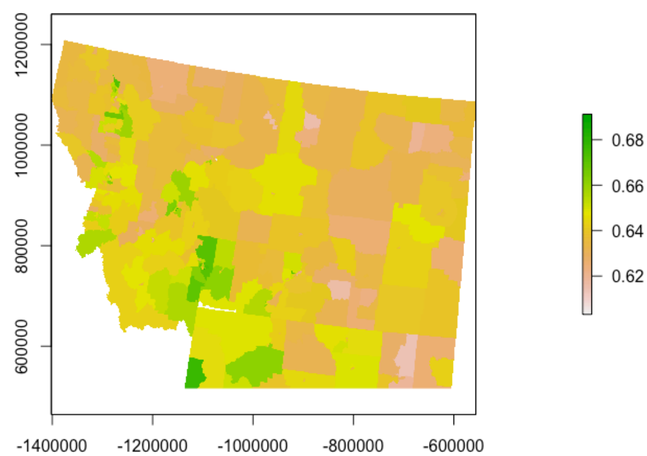
Appendix B.1 Map showing public land tolerance zone locations, Nine-Pipe Wildlife Refuge further west and Rocky Mountain Front Conservation Area.



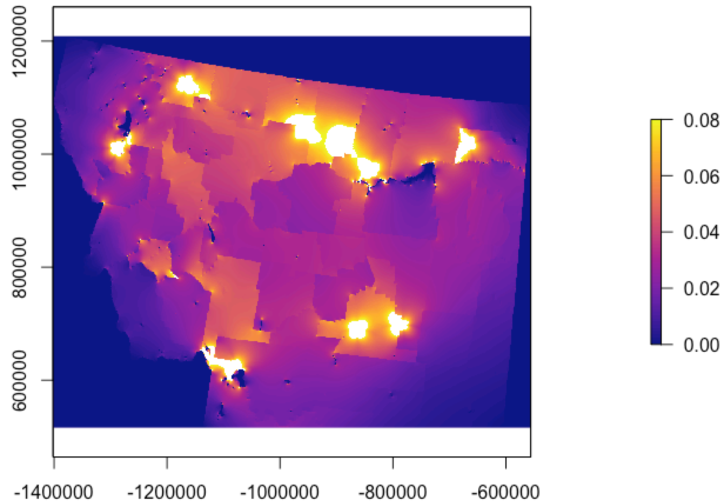
Appendix B.2 Multi-level regression with post stratification outputs for portion of census tract that support economic incentives for bison conservation.



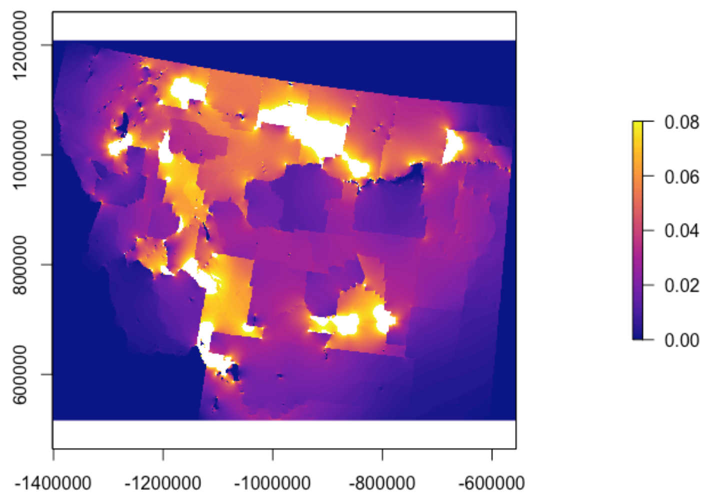
Appendix B.3 Cumulative current flow for the economic incentive intervention scenario.



Appendix B.4 Multi-level regression with post stratification outputs for portion of census tract that responded that Tribal/First Nations should manage wildlife.



Appendix B.5 **Cumulative current flow for Tribal/First Nations governance scenario.**



Appendix 1 B.6 **Cumulative current flow for public land tolerance zone intervention scenario.**

Multilevel Regression with Poststratification supplemental information

I used rstanarm in R version 4.1.3, I fit a Bayesian binomial regression with a logit link function (Goodrich et al. 2020). For the economic incentive scenario I coded the response variables as economic incentive preference as 1's with all other responses coded as zero and used varying intercepts for the predictors of state, gender, country, education, age, and mean distance to bison's range (Gates et al., 2010). For the Tribal/First Nations government scenario I coded Tribal/First Nations should manage wildlife as one's, with all other responses as zero. The models showed successful convergence and mixing based on R-hat values and effective sample sizes. The models were fit with priors from the normal distribution between 0 and 1, run on four chains, with 2000 iterations (Sweet et al., *in progress*).