Managing Human-Wildlife Interactions: Ecological and Financial Assessment of Elk Feedground Closure in Teton County

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A Group Project submitted in partial satisfaction of the requirements for the degree of Master of Environmental Science and Management (MESM) for the Bren School of Environmental Science & Management.

Signature Page

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Background and Significance

The Greater Yellowstone Ecosystem (GYE) is one of the biggest, largely intact temperate ecosystems in the world. It is home to an array of wildlife, landowners, hunters, business operators, and Tribal nations, as well as Yellowstone National Park and Grand Teton National Park.[1] Among the wildlife that migrate through the GYE are elk (*Cervus canadensis*), including the Jackson herd, one of the largest elk herds in the country. Within the GYE, multi-generational ranchers and their cattle share the land with the elk and other wildlife, demonstrating that even in wide open spaces like the GYE, human/livestock-wildlife interactions and conflict have created tensions amongst residents, government agencies, and non-governmental organizations (NGOs). One of the main sources of conflict are disease transmission, specifically brucellosis (*Brucella abortus*), which transmits to cattle from elk, and chronic wasting disease (CWD), which is always fatal in elk and other ungulates.[2]

Over 30% of the GYE is made up of private land, much of which is used for ranching operations.[3] The lack of urban development on these lands serves ranchers by providing their cattle with space to graze, ultimately supporting ranchers' livelihoods and food production. At the same time, these low-elevation lands serve as crucial winter-range habitat for migratory species like elk. Across the GYE, 1.88 million acres of easement-free private land overlap with elk ranges. For the Jackson herd specifically, private land overlaps with over 10% of its winter range.[4] Conserving this land is important both from a rancher's perspective and for the GYE ecosystem, especially since 50% of the Jackson elk herd's winter range is currently unprotected (not protected by public conservation areas or conservation easements).[4] On the other hand, the forage competition and disease risk that arises between elk and cattle when they share prime habitat on private land has resulted in the creation of artificial feedgrounds to keep elk and cattle from mingling.

Over a century ago, the National Elk Refuge (NER) feedground was established in southwestern Wyoming to support the Jackson elk herd with hay and alfalfa pellets during harsh winters with poor forage.[5] In addition, the Wyoming Game and Fish Department (WGFD) operates 21 feedgrounds across the state, making Wyoming one of the last western states to artificially feed elk populations.[6] Elk play important ecological and economic roles within the Greater Yellowstone Ecosystem (GYE); they are a source of prey for several large predators and are a major game species for hunters. The establishment of the NER has attracted millions of visitors each year and has reduced elk presence on private ranchland, lessening property damage and disease transmission between elk and cattle.[2] However, the NER and other feedgrounds have altered natural elk behaviors by shifting migration patterns and increasing elk-to-elk disease transmission on the refuge due to increased aggregation of elk.

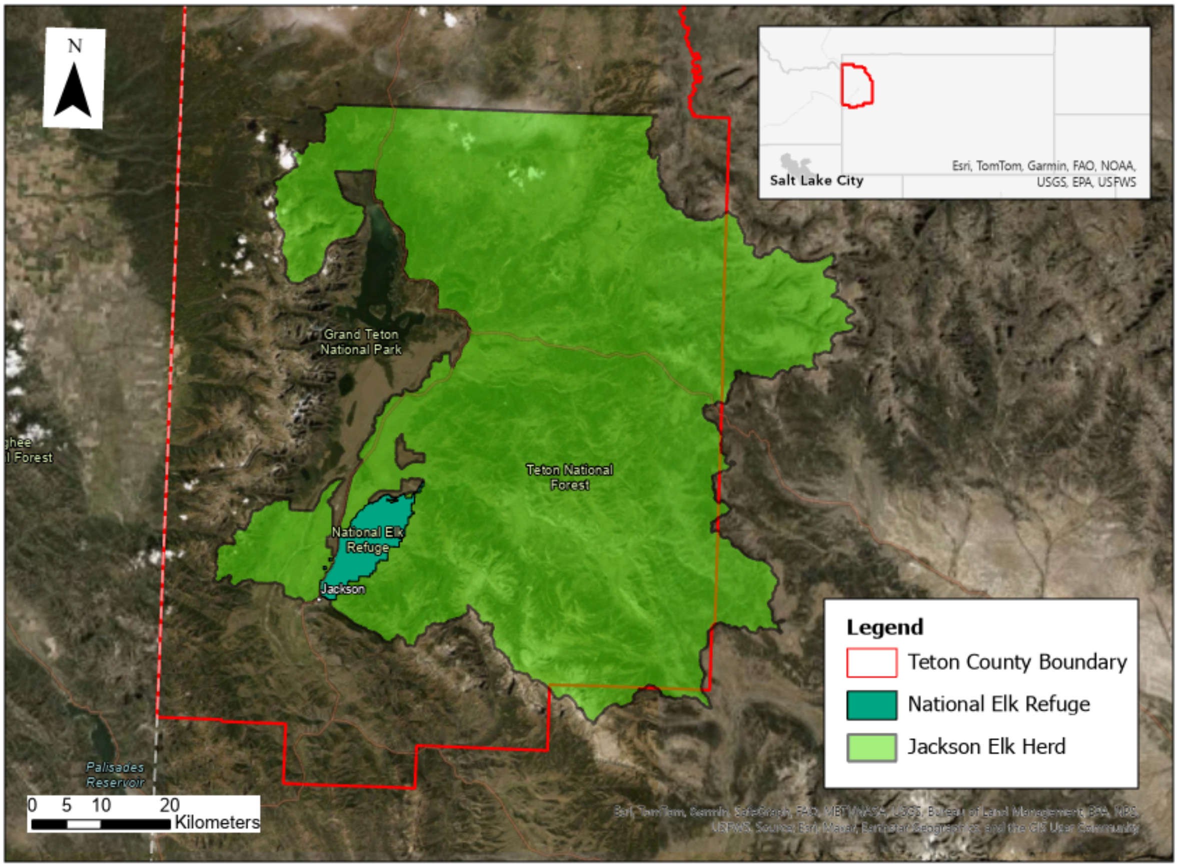

Figure 1. The location of the National Elk Refuge within the Jackson elk herd unit and Teton County boundaries in western Wyoming.

Brucellosis is a bacterial and zoonotic disease of particular concern within the GYE. While the disease rarely results in mortality, it can cause infertility and induce abortions in elk and cattle, resulting in economic losses for cattle ranchers.[7] Brucellosis transmits through direct contact and has been found to persist in fetal tissues, soil, and vegetation for 21 to 81 days in temperatures of less than or equal to 4 degrees Celsius.[8] High elk density on feedgrounds has resulted in increased brucellosis prevalence among fed elk herds, with an average seroprevalence of 28% within the NER in particular.[9] Between 2002-2014, 21 livestock herds in the GYE were infected with brucellosis from elk transmission.[10] From 1985-2015, the WGFD vaccinated 97% of feedground elk with a vaccine developed for cattle, but there was "no reduction in seroprevalence or abortion events."[11] If a new vaccine were developed, over 50% of the female elk population would need to be vaccinated, which is only potentially feasible in elk feedgrounds, and is expensive and difficult to track. In 2016, it was estimated that the distribution of brucellosis among elk herds in the GYE is increasing by 3-8 km/year. This spread is occurring across elk herds, including herds that are fed and not fed.[12]

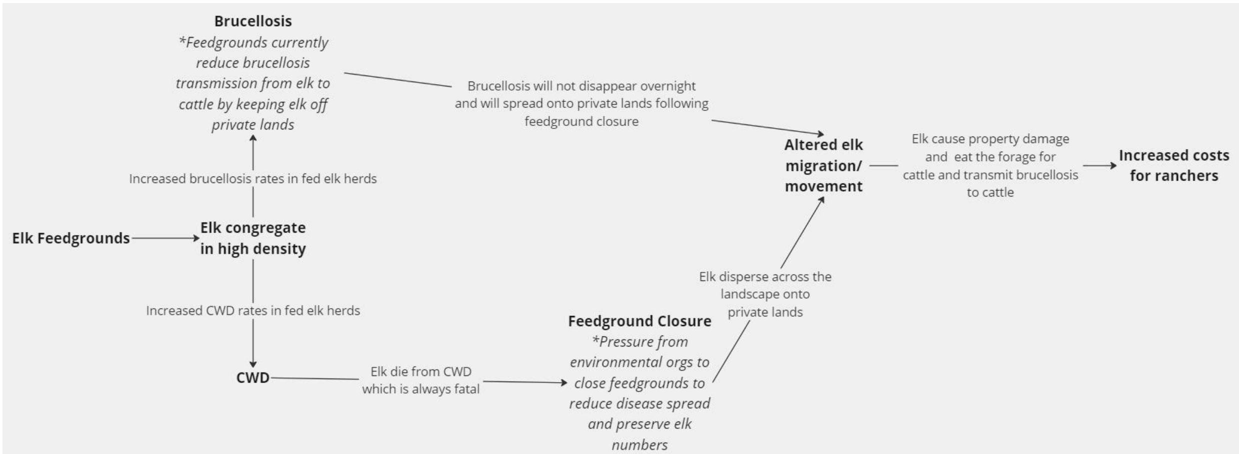

Figure 2. Flow chart displaying the social, economic, and disease interactions at play both broadly in Wyoming and specifically in Teton County.

While the NER and other Wyoming feedgrounds currently limit brucellosis transmission from fed elk to cattle by keeping elk off private land, feedgrounds increase the prevalence and elk-to-elk transmission of other diseases, including CWD.[13] As such, there is mounting political and legal pressure from environmental and conservation groups to close the feedgrounds.[14] This would result in the disbursement of elk across the landscape, likely leading to increased interactions with cattle and higher rates of brucellosis transmission to livestock.[12] In addition, there are concerns about the natural carrying capacity of the NER and surrounding lands due to the fact that the refuge currently supports an additional 2500 elk that the natural habitat is not equipped to serve.[5] As it stands now, the closure of at least some feedgrounds is a strong possibility, with lawsuits pending to close certain feedgrounds permanently.[14] This political pressure and a recent lawsuit that forced the closure of one feedground operation indicate that a broader shift in feedground policy may be on the horizon.

Federal brucellosis policies by the United States Department of Agriculture Animal and Plant Health Inspection Service (USDA APHIS) give ranchers the option to depopulate infected cattle herds (which they are compensated for) or otherwise require them to adhere to a mandatory quarantine period that can last up to one year.[7] The GYE is the only place in the country that still has positive cases of brucellosis, thereby triggering mandatory vaccinations in the Designated Surveillance Areas (DSA) of Idaho, Montana, and Wyoming. Each state develops its own Brucellosis Management Plan (BMP) in accordance with the guidelines set by USDA APHIS. Wyoming's BMP involves WGFD, USDA APHIS, and the Wyoming State Livestock Board.[15] Within Wyoming's BMP, all cattle within the boundary of the DSA must be tested annually for brucellosis. In addition, any time cattle leave the DSA or re-enter, they must be tested for brucellosis.[15] As such, ranchers in the GYE face unique risks associated with brucellosis, which causes the cattle to not only abort their calves, but could also result in infertility, weight loss, and decreased milk production.[7] The disease creates financial challenges for ranchers through quarantine costs and depopulation. These challenges can increase ranchers' intolerance for wildlife on their land and can make it difficult to maintain the large, working landscapes that support habitat for elk and other species.[6, 16] While feedgrounds did decrease the number of brucellosis cases in nearby cattle,[17] the disease has increased tremendously in elk populations within the feedgrounds due to the elk being in such close proximity to one another.[18] This in turn increased brucellosis among both fed and unfed elk due to their co-mingling in the spring and summer seasons. While brucellosis cases in cattle have decreased, they have not totally disappeared due to the interaction between fed and unfed elk.[10] The closing of these feedgrounds will not only create disease management problems for ranchers, but could heighten other financial issues for them, such as property damage and grazing issues. The concept of elk foraging and competing with hay meant for cattle or sale in the winter months is not a new one but it risks being exacerbated if the NER feedground were to close.

As seen in Figure 3, the Jackson herd congregates in and around the NER, especially in the winter months. With the potential closure of the NER, elk will likely disperse throughout the landscape.[5] Understanding future elk movement as well as their biology will be crucial in estimating the amount of elk that could reside on public and private lands; this could be done through the evaluation of migration barriers, protected areas, land use, and topographic variations. Barriers to migration cause major disruption to both elk movement and habitats. Evaluating anthropogenic barriers like energy development, roads, housing; and natural barriers, such as elevation, weather, and water bodies, could provide insight into where elk may migrate and identify locations with ideal habitat. This past year, increased snowpack forced elk to lower-elevation areas for feeding, increasing interactions with cattle.[19] If elk are already being pushed to private land by the weather, then it is important to understand how their crucial habitats could also be altered by the potential closure of the NER. Climatic changes are a fundamental issue, changing elk migrations every year, further pressing the importance of conserving private lands for elk winter ranges. Understanding elk migration barriers could provide insight into where elk may go following a change in their core habitat, such as the operation of the NER. Because the NER has been in operation for over a century, it is difficult for biologists to determine where elk may move if the feedground closes. An estimate of how elk movement might shift will help prepare feedground managers, ranchers, and other stakeholders to balance elk herd health with stakeholder financial well-being.

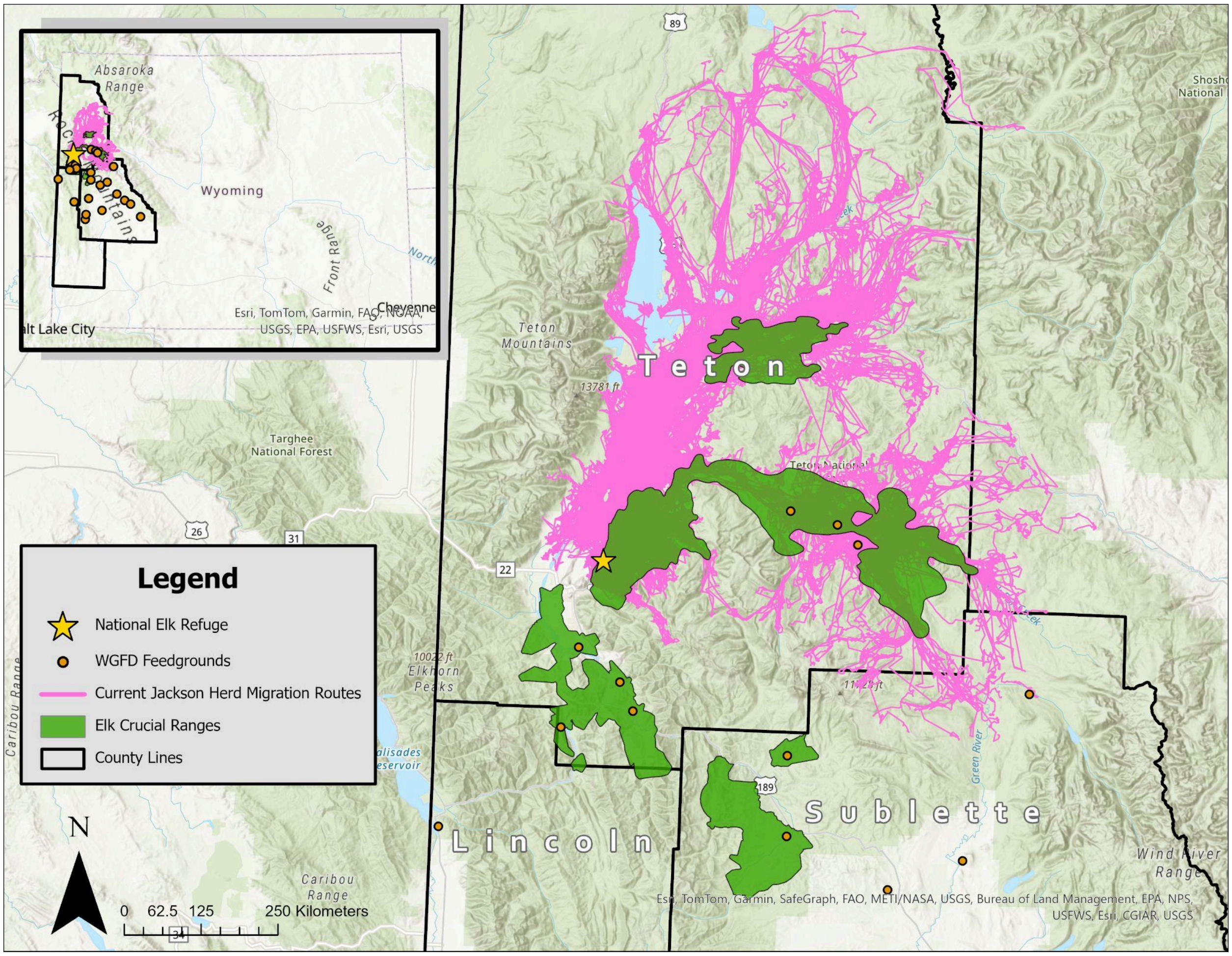

Figure 3. Current migrations routes of the Jackson elk herd. This is depicted in the color pink. This map also shows feedground locations (orange dots and yellow star indicating the NER), elk crucial ranges, and surrounding counties.

Mitigating human-wildlife conflict and improving coexistence has long been a challenge in the GYE. We most often hear about the reintroduction of wolves or the presence of bison. In both of these cases, time and thoughtful management solutions have begun to mitigate the effects of wildlife presence on private lands. Now we are shifting our concerns to a different species: elk. Ultimately, there are many sensitive and controversial factors that surround the potential closure of the NER. **Understanding brucellosis transmission, stakeholder opinions and impacts, elk biology and migration, and the financial impacts that this feedground closure could have will provide insight to potential strategies and solutions in order to mitigate and compensate for human-wildlife interactions. Through the creation and use of an elk feedground public sentiment analysis, a habitat connectivity model, brucellosis transmission risk model, and an analysis of financial repercussions of feedground closure, it is our hope that our overall project results and suggestions will better support an ecosystem that is beneficial to elk, residents, and recreators of the Greater Yellowstone Ecosystem.**

Project Objectives

The main objective of this project is to assess how the simulated closure of the National Elk Refuge feedground on public land will impact private landowner-elk conflict, with a particular focus on Teton County ranchers, the Jackson elk herd, and brucellosis transmission risk during the winter months. To evaluate opportunities to improve elk conservation and mitigate stakeholder costs, this project uses an Elk Feedground Public Sentiment Analysis, Jackson Herd Habitat Connectivity Model, Brucellosis Transmission Risk Model, and Analysis of Financial Repercussions of Feedground Closures to develop results from social, biological, and financial perspectives, respectively. This project focuses on management policies and actions in the state of Wyoming, where the U.S. Fish and Wildlife Service (USFWS) is in the process of updating its elk and bison management plan for the National Elk Refuge (NER), and the Wyoming Game and Fish Department (WGFD) is updating its management plan for the state's elk feedgrounds. This project specifically investigates the Jackson elk herd and the National Elk Refuge due to the size of the elk herd and operation, abundance of data, as well as the active feeding reduction plan initiated by the WGFD and USFWS.[5] The goals of this project were accomplished by first assessing the ecological impacts of simulated NER closure on elk, including potential shifts in migration routes and disease transmission rates. Using those results, we assessed how those new variables will financially impact the ranching community of Teton County, where the Jackson elk herd range is located. From this assessment, we developed suggestions for financial tools for our client, the Property and Environment Research Center (PERC). The purpose of these tools is to alleviate potential financial burdens the ranching community could incur as a result of feedground closure, thus resulting in increased support for wildlife conservation from local communities.

Specific objectives include:

- Estimate how the potential closure of the National Elk Refuge feedground and resulting Jackson herd winter range movement will impact brucellosis prevalence and transmission within the herd, as well as spillover risk from elk to cattle.
    - Investigate the associated risks of feedground closures and brucellosis transmission by understanding the impacts on local stakeholders through an analysis of public comments and survey responses. This investigation will ultimately help to inform potential solutions to address those risks, as well as the forage competition model. It is important to understand public attitudes toward feedground management to navigate a variety of solutions and assess willingness to accept risk to find the solution that would maximize benefits for all groups involved.
    - Determine the potential changes in the Jackson elk herd migration patterns and core habitat due to the closure of public feedgrounds, specifically the National Elk Refuge, through the creation of habitat connectivity models. The model informs elk-to-cattle overlap for the Brucellosis Transmission Risk Model, forage competition calculations for the Financial Analysis, and areas of various stakeholder management concerns identified within the Public Comment Sentiment Analysis.
    - Understand the Jackson herd's elk-to-cattle brucellosis transmission risk within Teton County through a multispecies disease transmission model with a focus on late winter and early spring when brucellosis contamination rate is highest. The results from this model

inform the calculations within the Financial Analysis. The Jackson Herd Habitat Connectivity Model provides a visual estimate of areas where there could be elk and cattle overlap.

- Assess what financial factors are most likely to impact ranching communities in Jackson Hole if the National Elk Refuge feedground were to close. Calculating the costs to ranchers if different elk movements were to take place during the winter months in the area. Finally, evaluate the feasibility of rancher compensation programs to promote coexistence with large herbivores in the Greater Yellowstone Ecosystem (GYE). The primary objective is to assess the feasibility of a brucellosis compensation fund using information from the Jackson Herd Habitat Connectivity Model and Brucellosis Risk Transmission Model.

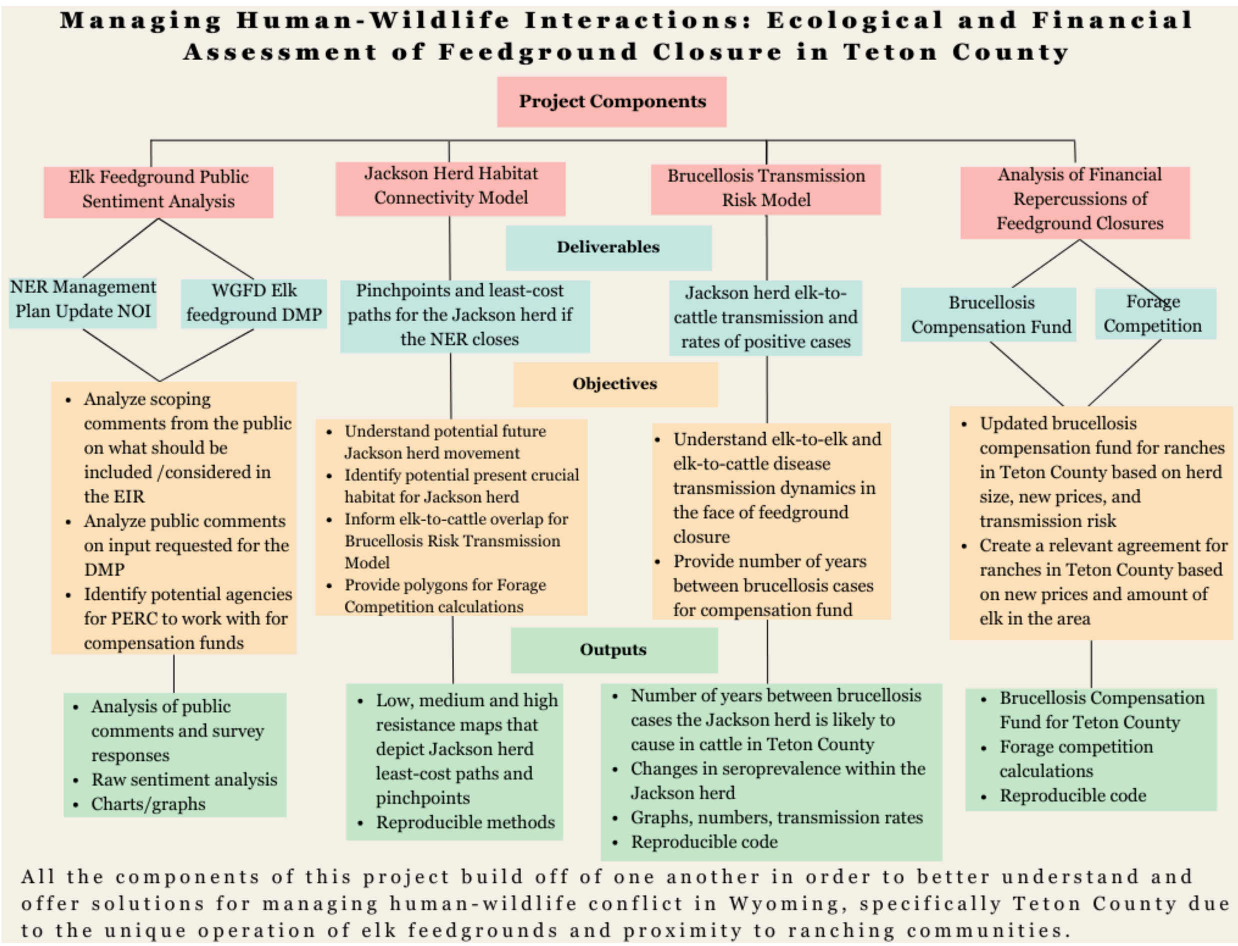

Figure 4. Project concept model. This model depicts each component of the project, along with deliverables, objectives, outputs, and how each component connects to the others.

Land Acknowledgement

Presently, there are nearly 30 tribes associated with the GYE through historical, cultural, or physical connections to the land. We recognize: the Assiniboine and Sioux, the Blackfeet, the Cheyenne River Sioux, the Coeur d'Alene, the Comanche, the Colville Reservation, the Crow, the Crow Creek Sioux, the Eastern Shoshone, the Flandreau Santee Sioux, the Gros Ventre and Assiniboine, the Kiowa, the Little Shell Chippewa, the Lower Brule Sioux, the Nez Perce, the Northern Arapaho, the Northern Cheyenne, the Oglala Sioux, the Rosebud Sioux, the Salish and Kootenai, the Shoshone–Bannock, the Sisseton Wahpeton, Spirit Lake, Standing Rock Sioux, the Turtle Mountain Band of the Chippewa, the Umatilla Reservation, and the Yankton Sioux. With so many tribal nations connected to this area, we acknowledge the value and importance of indigenous knowledge and recognize that each nation's knowledge and culture is uniquely their own. We acknowledge that these tribes continue to be the original stewards of the land and we hope to uplift indigenous knowledge systems in our project by integrating their cultural and ecological knowledge (when appropriate and permitted) and prioritizing cultural and ecological concerns.

We also recognize that we are completing our research through the University of California, Santa Barbara, which occupies Chumash territory. We strongly urge the University of California to respond to Chumash requests for their cultural artifacts and remains to be returned, and engage in active conversations and repatriation with the Chumash people.

Deliverables

- **Elk Feedground Public Sentiment Analysis** explored how the closure of the National Elk Refuge and other state-operated feedgrounds could impact local stakeholders, such as cattle ranchers, local governments and agencies, conservationists, hunting outfitters, sportspersons, and the general public.
    - A sentiment analysis was completed for comments submitted in response to the "Notice of Intent To Prepare an Updated Bison and Elk Management Plan for the National Elk Refuge in Wyoming; Environmental Impact Statement" by the USFWS. This was an opportunity for interested stakeholders to voice ideas and suggestions for what should be evaluated in the EIS and establish their positions on the management of the NER.
    - A separate sentiment analysis was conducted for survey responses and comment letters submitted to the WGFD for the Draft Elk Feedground Management Plan. Stakeholders submitted comments to voice support or critique aspects of the draft management plan.
    - Both of the sentiment analyses revealed the complex and different opinions and ideas surrounding elk feedgrounds in the state of Wyoming. This resulted in a compilation of concerns and suggestions from different stakeholder groups.
- **Jackson Herd Habitat Connectivity Model** used both spatial and temporal variables, such as potential feedground closures and the respective projected elk migration with ranchers' winter and spring land use to model connectivity and suitability within ArcGIS and Circuitscape.
    - Habitat connectivity maps were created through ArcGIS Pro to visualize current and future movement of the Jackson herd across the Jackson Hole area following changes to elk core habitat (e.g., feedground closure); maps identified corridors of least resistance for the elk to travel between core habitats (least-cost paths) and areas where elk movements are funneled or bottlenecked (pinchpoints).
    - These maps inform the elk-to-cattle overlap in the brucellosis transmission risk model and forage competition calculations in the financial analysis, described below.
- **Brucellosis Transmission Risk Model**, based on the Kauffman et al. (2016) Probabilistic Transmission Model, explored potential elk-to-cattle transmission risk scenarios by varying elk-cattle overlap and elk brucellosis seroprevalence to compare NER closure to continued NER operation. Model output was displayed as the expected number of years between detected cattle brucellosis cases within the Jackson elk herd unit.
    - Graphs created display a range of fed elk-to-cattle overlap scenarios from low (NER open) to medium (NER closed) to high (more extreme scenarios), the potential changes to seroprevalence associated with a decrease in elk density, and the associated risk to cattle.
    - These results were used to inform the analysis of financial repercussions to ranchers.
- **Analysis of Financial Repercussions of Feedground Closure** quantified potential economic damages that stakeholders, primarily ranchers, could face due to NER feedground closures.
    - As identified by the public comment analysis, damages examined included what ranchers consider to be the most costly factors impacting their operations when elk are present on their private property over the winter months: property damage, disease spread, predation, and forage competition.

- How a simulated closure of the NER feedground would impact the ranching community was calculated for Teton County. Recommendations were provided for financial tools that can help alleviate those increased costs from elk foraging on private land over the winter.
- The results from our disease model were used to assess how large a brucellosis compensation fund would have to be to support the ranching community in Teton County under the assumption of a total NER feedground closure, with support levels similar to the ones provided by PERC with their brucellosis compensation program run in Paradise Valley, Montana, and their upcoming project in Park County, Wyoming.

Methods

All four components of this project build off of one another to achieve the overall project goal: to assess how the potential closure of the NER will affect the livelihood of the ranching communities and what solutions can mitigate the risks of potential closure. The core of each component, in addition to the foundation of this project, is the evaluation and development of strategies to balance these kinds of human-wildlife interactions. This began with the completion of an Elk Feedground Public Sentiment Analysis to pinpoint what the ranching community and larger public were concerned about in terms of a feedground closure. Next, we created a Jackson Herd Habitat Connectivity Model to understand where the herd will disperse across the landscape if feeding on the NER ceased. This informed the Brucellosis Transmission Risk Model and Analysis of Financial Repercussions of Feedground Closure through modeling elk-to-cattle overlap and forage competition. Third, we coded a Brucellosis Transmission Risk Model to quantify the change of Jackson herd seroprevalence and elk-to-cattle brucellosis risk in yearly intervals. This risk was then used in our Analysis of Financial Repercussions of Feedground Closure, where we calculated the costs of brucellosis in Teton County with a simulated NER closure and the required compensation fund size to mitigate those costs. Our Analysis of Financial Repercussions of Feedground Closure also used the results from the Jackson Herd Habitat Connectivity Model to assess the costs of elk competition with ranchers for hay in the winter.

Elk Feedground Public Sentiment Analysis

As discussed previously, elk feedgrounds are a contentious topic with many different opinions and ideas held by diverse groups. To better understand the perspectives held and solutions offered by different stakeholders concerning feedgrounds, brucellosis, elk and their movements, we analyzed public commentary articulated by different stakeholder groups in response to the WGFD's Draft Elk Feedground Management Plan (DEMP). The first draft of this plan, released by the WGFD in 2022, delineated prospective measures for assessing the eventual closure of feedgrounds through varied management strategies tailored to each distinct feedground. In a concerted effort to enhance the inclusivity and thoroughness of the final management plan, the WGFD initiated a multi-phased effort to solicit public input to incorporate into the conclusive decision-making process.

We also reviewed public comments made on regulations.gov in regard to the "Notice of Intent To Prepare an Updated Bison and Elk Management Plan for the National Elk Refuge in Wyoming; Environmental Impact Statement."[20] This was an opportunity for interested parties to submit comments and suggestions to the USFWS in regard to what the scope of the environmental impact statement should be.

To identify the main sentiments of stakeholders, we organized the public comments into three categories in Appendix 5. These three categories included:

1. Biggest concerns surrounding feedground closures and management of existing feedgrounds.
2. Ideas or solutions ranchers are hoping will be implemented by state agencies (WGFD) for feedgrounds, elk movement, and brucellosis in order to assess alignment and feasibility with

PERC's financial tools.
3. Information wanted by overall stakeholder groups before any decisions are made (this was not directly from ranchers; more general).

To accomplish this, comment letters were read and annotated and survey responses were cleaned and annotated. The analysis involved identifying commonly used words and assigning positive, negative, or neutral connotations to these words using the NRC Word-Emotion Association Lexicon.[21] Once the analysis was completed, we were able to have a quantitative and qualitative analysis of stakeholder attitudes. With this information, we analyzed preferred strategies to diminish conflict with elk and cattle, improve management techniques, understand if our project is addressing the concerns of the community, and develop future projects to aid this subject. Stakeholders represented in the comments and survey responses include: the general public, ranchers, conservation groups, government agencies and coalitions, hunting and outfitting organizations, and sportspersons.

Jackson Herd Habitat Connectivity Model

The main objective of creating a habitat connectivity model for the Jackson herd is to understand where the elk might disperse across the landscape if feeding on the NER ceases. This informed multiple aspects of our project, such as areas of potential overlap of elk and cattle for the brucellosis risk transmission model and locations of forage competition for the financial analysis. Analyzing where elk may relocate highlights places of management priority, particularly areas where conservation can be improved and stakeholder costs and human-wildlife conflict can be mitigated. To build habitat connectivity models for the Jackson herd, we created resistance rasters, which are a combination of multiple data layers that are important to elk biology with assigned values of resistance, or the cost of traversing each pixel of the landscape. The resistance rasters consisted of roads (including primary, secondary, trails, service drives, and private roads), conservation easements (ranked based on protection level), protected areas (also ranked based on protection level), oil and gas fields and wells, grazing allotments, elevation, and land use (vegetation and waterways as well as human development). The habitat connectivity resistance rasters were composed of layers built from 2011-2024. These raster layers were selected based on expert consultation of what most influences elk movement and biology as well as previous studies that have modeled movement for similar species like mule deer or for elk in different parts of the country.[22] Similarly, resistance values were selected based on how the herd will utilize the land in winter conditions and were further informed by previous literature, expert opinion, or a combination of the two.[22]

Once these layers were uploaded into ArcGIS,[S1] some manipulations of the layers were necessary, specifically for those that were shapefiles or contained broader regional data. Shapefiles were converted to rasters and reprojected to the same projected coordinate system and cell size (Wylam, 90 meters). The layers containing large amounts of data were clipped to the spatial extent of crucial elk areas located in Teton County and the northern extents of Sublette and Lincoln Counties. Each raster layer was then reclassified based on the information it contained and was assigned specific resistance values to mimic winter range habitat use for the Jackson herd. These values were determined based on literature and took into account elk movement, biology, and uncertainty. The resistance values ranged from 1-100, with 1 being the least resistant and 100 being the most resistant. To simulate feedground closure on the NER, the feedground was given a resistance value of 15. While this is still a low value, it was projected by USFWS that even if this feedground closed, about 5000 elk would still remain on the refuge due to how ideal the habitat is.[5]

To capture uncertainty in the raster layers and the likelihood that elk could or could not be present in an area, we classified the values in four different groups: low resistance (value of 25 or less), medium resistance (between 26 to 50), high resistance (51 to 75), and extremely high resistance (76 to 95). Classifying an area as 100 was considered unrealistic as elk could still end up in an area, such as a highway or city, even though it is not ideal habitat. These values were then changed between three different maps: low resistance, medium resistance, and high resistance. Certain raster layers or data within the raster were reclassified based on which map we were calculating. For example, trails were assigned a low resistance value, but to take into account factors such as fencing or high walking traffic, the value was increased across the three maps. As literature has noted, there will always be uncertainty behind resistance values,[23] and it is extremely difficult to capture the true value of resistance for elk, which is why we used low, medium, high, and extremely high values and maps to capture some of that uncertainty and variations within elk movement and habitat connectivity. It is important to note that the NER remained a constant resistance value of 15 across all three maps. Detailed steps for how to run Circuitscape, as well as the specific raster layers and resistance values for the low, medium, and high resistance maps, can be found within Appendix 2 and 3.

After resistance rasters were created, they were used to analyze how elk movement would change due to the simulated cease of feeding on the NER during winter conditions. By using the Linkage Mapper tool[S7] in the Linkage Pathways toolbox, we are able to analyze the least-cost paths that elk will take to move from multiple elk crucial ranges (as determined by WGFD) to new habitats.[24] In addition, the Pinchpoint Mapper tool[S2] identified areas of increased resistance that elk may face due to changes in the landscape.

Understanding elk biology and how the herd moves provides a baseline for elk movement in Teton, Lincoln, and Sublette counties. Ultimately, knowing where elk will move with or without feedgrounds has important implications for measuring the risk and impact of brucellosis, property damage, and food availability in the environment. In addition, it can identify opportunities for migratory corridors as well as provide information on if surrounding feedgrounds can support the influx of elk that may become present on those lands if the NER were to close.

Brucellosis Transmission Risk Model

As highlighted by the habitat connectivity model, the Jackson elk herd's migration patterns would likely shift with the cessation of feeding at the NER, which could bring costs to Teton County ranchers. If that shift leads to increased elk-cattle overlap, some of those costs may result from increased elk-to-cattle brucellosis transmission. To determine what costs from elk-to-cattle brucellosis transmission have the potential to be mitigated, we simulated how frequently ranchers in Teton County may have to quarantine or depopulate their cattle following the closure of the NER feedground.

We used the Kauffman et al. (2016) Probabilistic Transmission Model,[25] a disease risk model adapted specifically to brucellosis transmission from elk to cattle, to estimate the expected number of years until a positive cattle brucellosis case would likely be detected within the Jackson elk herd unit area under different scenarios. The Probabilistic Transmission Model defines the risk to cattle within a given elk herd unit through six main parameters: the expected number of elk overlapping with cattle, the proportion of elk that are female, the proportion of elk that are pregnant, elk brucellosis seroprevalence, the probability of seropositive elk abortion, and the probability of seronegative elk abortion. The equation is displayed as:

Equation 1.

$$\#CattleReactors_h = \sum_{f=0}^{1} \sum_{s=0}^{1} ((OverElk_{hfs})\ x\ (pFem_h)\ x\ (pPreg)\ x\ (seroprev_{hf})\ x\ (pAbort|serostat_s))$$

where *h* represents a given elk herd unit, *f* represents fed versus unfed elk, and *s* represents seropositive versus seronegative elk. The inverse of this equation provides the expected number of years until a detected cattle reactor, or positive cattle brucellosis case. This model assumes that one positive cattle case has the same implication for a ranch as multiple cases, so it does not account for more than one cattle reactor.

Most of the parameter values for the Jackson elk herd unit were taken from literature and consultations with experts (Table 1). We predicted two parameters would change following feedground closure: elk-cattle overlap and elk seroprevalence. To simulate NER closure, we coded functions for the model equation into RStudio[S9] and altered those two parameters to predict how the number of years between cattle brucellosis cases would change with those values.

Table 1. Brucellosis transmission risk model parameters for the Jackson elk herd unit.

Summary of Parameter Choices			
Parameter	**Value**	**Changes with NER Closure?**	**Source**
Elk-to-cattle overlap (*OverElk*)	NER open: 0.5 NER closed: 2.5 (Range of values modeled)	Yes	Eric Cole, personal communication (2024); USDA Census of Agriculture (2022)[26]; USDA APHIS (2023)[27]
Female elk proportion (*pFem*)	0.75	No	Eric Cole, personal communication (2023)
Pregnant elk proportion (*pPreg*)	0.79	No	WGFD (unpublished); Kauffman et al. (2016)[25]
Seroprevalence (*seroprev*)	0.28 (Range of values	Maybe	Merkle et al. (2017)[9]

	modeled)		
Elk abortion probability (*pAbort*|*serostat*)	Seropositive: 0.201 Seronegative: 0.017	No	WGFD (unpublished); Kauffman et al. (2016)[25]

Overlap

Kauffman et al. (2016) defined elk-cattle overlap as the expected number of elk likely to be in contact with cattle, summarized by elk herd unit. We assumed this definition to refer to the average number of elk present per cattle herd within an elk herd unit. Unlike the other parameters, elk-cattle overlap is difficult to estimate without direct observations, especially since factors like annual snowpack and forage availability can change overlap from year to year.[28] To account for a lack of data availability, we modeled a range of fed elk overlap scenarios from 0 (no fed elk overlap) to 6.0 (very high fed elk overlap) and a range of unfed elk overlap scenarios from 0 (no unfed elk overlap) to 2.5 (approximate average overlap in Kauffman et al. (2016). From these overlap values, we highlighted a few scenarios we deemed the most plausible to use in our analysis of financial repercussions.

Plausible overlap scenarios were selected based on the 2022 USDA Census of Agriculture, Jackson elk herd data, and conversations with wildlife managers. Due to the rarity of cattle brucellosis cases in Teton County (only 1 affected cattle herd in the last 20 years),[27] we assumed the current elk-to-cattle overlap within the Jackson elk herd unit is less than one, with a starting overlap of 0.5 elk to cattle for both the fed and unfed portions of the elk herd. With the prediction that 2500 out of 7500 elk will move off the NER if feeding is ceased and largely follow the least-cost paths that cross ranchlands, we reasoned that elk-to-cattle overlap would increase for fed elk, which would spend more time on private lands, but not for unfed elk, which would likely not be affected by feedground closure. Because the NER has a higher fed elk population than most feedgrounds, and because the least-cost paths cross through multiple ranchlands, we assumed an increase in fed elk overlap would likely be higher than the approximate average elk-cattle overlap of 2.5 in Kauffman et al. (2016), which modeled smaller feedgrounds. For this reason, we defined a fed elk-cattle overlap of 3.0 to 4.5 as a plausible overlap increase, while 1.5 to 2.5 was defined as a low overlap increase and 5.0 to 6.0 was defined as a high overlap increase. Unfed elk-cattle overlap was kept at 0.5 for all these scenarios.

Seroprevalence

The fed elk on the NER currently have a brucellosis seroprevalence of around 28%.[9] As of early 2024, there is no recent seroprevalence data for the unfed portion of the Jackson herd, but because of increasingly common pockets of high brucellosis seroprevalence in unfed elk in other parts of the GYE,[29] we assumed the average seroprevalence would be roughly the same for both the fed and unfed Jackson elk.

While elk brucellosis seroprevalence is unlikely to change immediately after feedground closure, as elk density decreases as elk spend less time on the feedground, it is predicted that seroprevalence will eventually decrease as well. According to a study by Proffitt et al. (2015), a herd with a 28% seroprevalence may experience a decrease in seroprevalence to 21%, 12%, 7%, 4%, and 2% following a

10%, 30%, 50%, 70%, and 90% decrease in density respectively.[30] We highlighted the 30% density decrease (12% seroprevalence) as a plausible scenario based on a U.S. Geological Survey (USGS) report that predicted a 25% decrease in elk density around many feedgrounds over the next 20 years.[31] To simulate how this post-feedground closure density change could affect the frequency of cattle reactors, we input these decreasing seroprevalence values into the Probabilistic Transmission Model across five different overlap scenarios. Similar to overlap, we also varied seroprevalence to generate a range of values from 0% (no brucellosis seroprevalence) to 60% (very high brucellosis seroprevalence). These values directly influenced our analysis of the financial repercussions of feedground closure and evaluation of a potential brucellosis compensation fund.

Analysis of Financial Repercussions of Feedground Closure

Prior to working on calculations for this project, we first determined the financial factors that are of high priority to ranchers in Teton County. More specifically, we were interested in factors that are likely to be critical in the event of a NER feedground closure. After completing our literature review and public comment analysis, we found that the four main concerns for Teton County ranchers are brucellosis transmission from elk to cattle, forage competition from elk, increased wolf depredation on livestock due to new migration patterns of their prey, and elk damage to private property. Our methods for our financial analysis focused on brucellosis quarantine cost and forage competition, as those costs are not currently reimbursed by any government program, unlike wolf depredation and property damage.[6, 32] To calculate those costs we used results from both our Jackson Herd Habitat Connectivity and Brucellosis Transmission Risk Model.

Calculations for Change in Brucellosis Costs in Teton County

To start calculating the costs of brucellosis in Teton County if the NER feedground were closed, we needed the expected number of years until a cattle brucellosis case. Results from the Brucellosis Transmission Risk Model were used to compare the changing brucellosis costs to the current status quo costs. Ultimately, we used those calculations to estimate the size of a brucellosis compensation fund that would last for at least three years after the potential closure of the feedground. A minimum duration of three years is the current standard for brucellosis funds managed by PERC.[33] The compensation fund calculations were modeled after the work done by PERC's researchers in Paradise Valley, Montana and Park County, Wyoming. Preliminary estimates and calculations were made using Teton County's agricultural data from the Agricultural Census of 2022 published by the U.S. Department of Agriculture.[26] We ran multiple scenarios, taking into account uncertainty in expected numbers of years until a cattle reactor and various hay price scenarios to reflect the versatility of the hay market. The assumptions made to account for these uncertainties are outlined in Table 2.

Table 2. Brucellosis cost assumptions for the Jackson elk herd unit.

Summary of Assumptions		
Assumption	**Value from Brucellosis Transmission Risk Model**	**Source**
One positive cattle case has the same implication for a ranch as multiple cases.	N/A	Ben Foster, personal communication (2024); USDA Census of Agriculture (2022)[26]
Expected number of years until a cattle reactor.	Scenario #1: ● With NER open: 27.65 years ● With NER closed: 6.60 years Scenario #2 (Lower Overlap): ● With NER open: 27.65 years ● With NER closed: 11.54 years Scenario #3 (Higher Overlap): ● With NER open: 27.65 years ● With NER closed: 4.73 years Other scenarios of overlap also included in our analysis.	Results from our disease model
Quarantine Length	10 months with 5 winter months and 5 non winter months.	Ben Foster, personal communication (2024)
Typical Herd Composition	Cull = 5%, Market = 45%, Herd = 50%	Ben Foster, personal communication (2024)
Cull fee per head	$50.00 USD	Ben Foster, personal communication (2024)
Average Cattle Hay Consumption per day	30 pounds or 0.015 tons	Selk (2022)[34]
Average Price of Hay in USD	$225.00 USD per ton	National Integrated Drought Information System (2022);[35] USDA (2022)[36]

During winter months, only the market individuals were counted as adding to the brucellosis quarantine costs. This was because these cattle would stay at the ranch as part of the herd and would therefore have to be fed hay in the winter regardless of brucellosis status. During summer months, both the market and herd segment of the herds are counted as adding to the quarantine costs in hay as they would otherwise be able to feed from pastures. The 28 year and 7 year scenarios are from the "NER open" and "NER closed" scenarios identified as plausible in the transmission risk model methods. To account for uncertainty, we also analyzed the costs of the results for higher overlap scenarios (5.0-6.0) and lower overlap scenarios (1.5-2.5).

Below are equations used to calculate brucellosis costs. Each assumption can be found in Table 2 above.
Equation 2. Monthly Quarantine Hay Costs for Quarantine per Head of Cattle (*Z*). 30 days is the number of days in a month and 0.015 is average cattle hay consumption per day.

$$Z = (\$\, of\ hay\ in\ tons) \times (30\ days) \times (0.015\ tons)$$

Equation 3. Brucellosis Cost per Case in Cattle Herd (*B*), where *H* was the number of heads of cattle, *W* was the number of winter months, *Z* was from the equation above, and *S* was the number of summer months. 0.05 represents the ratio of cattle that will be culled, 0.45 represents the ratio of additional cattle that need to be quarantined during the winter months, and 0.95 represents the ratio of additional cattle that need to be quarantined during the summer months.

$$B = (H \times 0.05 \times 50) + (H \times 0.45 \times W \times Z) + (H \times 0.95 \times S \times Z)$$

We then coded these equations in RStudio using our dataset, the USDA Agricultural Census of 2022, which provided information about the number and size of ranches in Teton County. While creating our dataset, we excluded ranches that were small (less than twenty heads) as it is difficult to predict the elk-to-cattle overlap for these small operations and as the quarantine costs would not be significant. With our code, we were able to select a random ranch to have a brucellosis case and used our equation to calculate the cost for that ranch and then deflate that cost by the number of years until a cattle reactor in the county. We ran that process a thousand times to get an average cost and compared it to the status quo of 0.5 elk-to-cattle overlap scenario when the feedground is open. To calculate the required size of the fund we also coded in R with restrictions on the costs, as the fund would only cover 75% of the costs and have a maximum payout of 100,000 USD per case. Once we set those limitations, we multiplied the average yearly cost number by five with the expected goal of the fund lasting during that period of time.

Calculations for Forage Competition

For the purpose of this project, we defined forage competition as the hay consumed by elk from haystacks found on private land during the winter months. This is an important factor to consider as protecting the hay found on private land from foraging by large herbivores like elk was a primary reason behind the original creation of feedgrounds.[6] We calculated the increase in forage competition costs for ranches in Teton County under a simulated feedground closure scenario rather than calculate the total cost of forage competition from the Jackson elk herd. To calculate those costs, we used results from the Jackson Herd Habitat Connectivity Model, specifically the pinchpoints from the high resistance simulation, which are outlined in Table 3, to identify three different types of elk winter habitat: prime, average, and subpar. Identifying those habitat types allowed us to predict where the elk are most likely to migrate and how much of their winter range includes private land.

Table 3. Variables used from eventual habitat connectivity results and outline of the assumptions for the forage competition calculations.

Incorporation of Jackson Herd Habitat Connectivity Model Results into Forage Competition Calculation			
Forage Competition Data*	**Assumption**	**Pinchpoint Results from Connectivity Model**	**Land Parcel Results from Connectivity Model**
Number of elk at the refuge during the 2021-2022 season is estimated at 7,381	Prime Habitat: Elk are three times more likely to forage in this habitat compared to average habitat	Prime Habitat outside of NER boundaries = X km^2	Prime habitat on private land = A km^2
Costs of feed pellets during the 2021-2022 season was $572,000.00 USD.	Average Habitat: Considered to be our baseline	Average Habitat outside of NER boundaries = Y km^2	Average habitat on private land =B km^2
Predicted carrying capacity of the NER without supplemental feeding = 5,000 individuals	Subpar Habitat: Elk are not going to forage in this habitat due to factors like elevation, roads, and urban development.	Subpar Habitat outside of NER boundaries = Z km^2	Subpar habitat on private land = C km^2

*Gathered from the NER Feeding Reduction Plan Progress Report[5] and Eric Cole, USFWS (personal communication, 2024)

Below are the calculations made to estimate forage competition. Each variable was outlined in Table 3.

Equation 4. Cost to feed 1 elk over winter. $572,000 USD is the amount spent by the NER on feed pellets during the 2021-2022 winter season. There were an estimated 7,381 elk that rely on the NER.

$$Cost\ to\ feed\ 1\ elk\ over\ winter\ =\ \$572,000/7,381\ =\ \$77.45\ USD$$

Equation 5. The number of elk that are over the natural carrying capacity of the NER. In the 2021-2022 winter season, there were an estimated 7,381 elk fed on the refuge. The NER's natural carrying capacity is around 5,000 elk.

$$Number\ of\ elk\ over\ carrying\ capacity\ =\ 7,381\ -\ 5,000\ =\ 2,381$$

Equation 6. Amount of winter range on private land. This is the percentage of prime, average, and subpar habitat outside the NER boundaries.

$$Private\ Land\ Winter\ Range\ =\ 3A\ +\ B$$

Equation 7. Amount of winter range on private and public land. This utilizes the answer from **Equation 6** and adds the amount of winter range on public lands, including the NER.

$$Private\ +\ Public\ Land\ Winter\ Range\ =\ 3X\ +\ Y$$

Equation 8. This is the ratio of winter range on private land to winter range on public land. This is determined through the use of **Equation 6** and **Equation 7**.

$$Ratio\ =\ Private\ Land\ Winter\ Range\ /\ (Private\ +\ Public\ Land\ Winter\ Range)$$

Equation 9. Change in winter forage competition. This is calculated by multiplying the ratio with the cost to feed 1 elk and the number of elk over the natural carrying capacity of the NER.

$$\Delta\ Winter\ Forage\ Competition\ =\ Ratio\ *\ Feed\ cost\ *\ Number\ over\ carrying\ capacity$$

Results

Elk Feedground Public Comment Sentiment Analysis

NER Public Comments

The analysis of public comments for the NER NOI included 9 formally written comments from organizations and agencies. Of the 9 formal letters submitted, 5 were from conservation organizations, 3 from local governments and agencies, and 1 from a hunting organization. Within the sentiment analysis, all 9 public comments had overwhelmingly positive sentiments, but reading each letter reveals that 2 were opposed to feeding reduction and feedground phaseout, 3 were neutral, and 4 were in support.

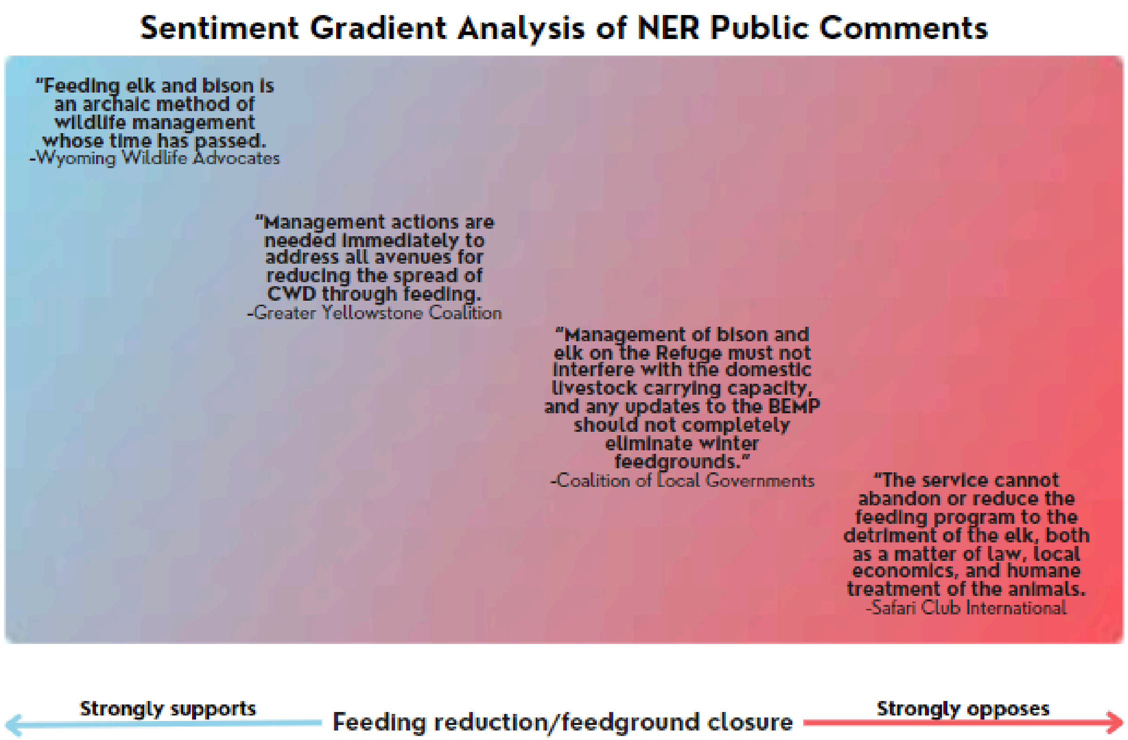

Figure 5. Sentiment gradient of the NER scoping comments. Within a sample of 9 letters, there were a wide range of viewpoints from supporting to outright opposing feeding reduction or feedground phaseout/closure.

WGFD Public Comments

178 comment letters were submitted to WGFD when the request for comments from stakeholders were released in Summer of 2023. 158 of them were submitted by members of the Sierra Club, so for the purposes of the sentiment analysis, we considered this as 1 letter since it was the same letter submitted. Like in the NER comments, conservation groups were still overrepresented in this comment period, with 10 different organizations or agencies represented. There was only 1 official hunting organization (Backcountry Hunters and Anglers), but some respondents mentioned they personally hunt elk. Ranchers

were represented by 3 letters, all of which oppose feedground closure. The rest of the letters were submitted by members of the public that were not writing for any particular stakeholder group, organization, or government agency.

Seventy percent of the conservation organizations were in support of feedgrounds phasing out. Some conservation organizations took a more neutral stance and did not outright support or oppose feedground phaseout, and instead offered suggestions and expressed a willingness to be involved as WGFD explores their options. Ranchers did not like the tone toward the ranching and agriculture community in the plan, with one saying "I'm especially disappointed with the plan's overall treatment and tone towards livestock production…We've been your partners on many important wildlife and habitat accomplishments, but the public wouldn't be able to tell this from this plan." Overall, ranchers felt that this plan was an attack on ranching, and they do not think this plan is a good idea. Some individuals that were in favor of feedground phaseout were pessimistic about the feasibility and reality of feedground phaseout. Government agencies in general remained neutral on the topic of feedground phaseout, but expressed a desire to be included.

Major Concerns Surrounding Feedground Closures and Management of Existing Feedgrounds

Predominantly, the commentary regarding the apprehensions surrounding the prospective management and potential closure of feedground centered on the anticipated repercussions of elk dispersal across the landscape, raising considerable concern among the ranching community. The overarching concern expressed was the potential for heightened risk of property damage if feedgrounds were diminished or ceased to exist. This risk could also entail the escalating likelihood of impacts on ranchers' crops, land, fencing and equipment. Another key potential concern was the potential of brucellosis cattle cases arising from the closer proximity of elk. Being closer in proximity to one another not only amplifies the risk of brucellosis transmission, but also introduces the plausible scenario of heightened predation pressures on cattle herds as seen in Table 4.

For conservation organizations, many were concerned with the spread of CWD. This is a main driver behind the desire for these organizations to advocate for reduced feeding and feedground phaseout. Biologists and conservationists also worry about the natural carrying capacity of the NER and its surrounding habitats.

Hunters were primarily concerned about the potential of reduced hunting opportunities and access. They worry that, with elk on private lands, they will not be able to access the elk as they traditionally have.

Analysis of a survey that WGFD conducted was inclusive of a diverse range of stakeholders, rather than solely reflecting the perspective of ranchers. The survey's principal finding revealed that a substantial (60%) proportion of participants deemed the economic impact on agriculture stemming from changes in feedground management as a matter of top concern. Concurrently, 53% identified wildlife-related damage on private lands, while 44% underscored brucellosis transmission as high-priority issues demanding attention by the state.

Table 4. Concerns mentioned by stakeholder groups in survey responses and group conversations hosted by WGFD. The survey responses are in regards to the WGFD Draft Plan that was published. In addition, WGFD convened stakeholder groups for conversations[37] to discuss concerns, suggestions, solutions, and management.

Primary Concerns Mentioned by Stakeholder Groups	
Stakeholder Group	**Primary Concerns**
Landowners	• Depredation from predators due to increase elk presence • Property damage from increased elk presence (fencing) • Grazing permit losses • Brucellosis and damage compensation • How to disperse elk to minimize the risk of CWD
Government	• Primary diseases of concern: Brucellosis and CWD • Paradigm shift of elk on private lands • Ability to respond to population issues and diseases
NGOs	• Long-range effects of CWD • Management actions should be rooted in science-based decisions • Habitat availability and suitability • Long-term and near-term solutions to address disease and population dynamics
General Public	• Long-range effects of CWD • Impacts on tourism and sustainability if feedgrounds close • WGFD will not take action rapidly or aggressively enough in order to tackle disease concerns • Management actions should be rooted in science-based decisions • Timing of feedground phase-out is too slow • Politics of feedground closure
Hunting/Outfitting	• Reduction of feedgrounds could result in reduced hunting opportunity and accessibility • CWD outbreaks on feedgrounds • WGFD plan looks like a plan to close feedgrounds • How to incorporate the opinions/ideas of individuals who live outside the area but recreate in Wyoming
Sportspersons	• Suitability and availability of natural native winter range • Feedground operator/feeder training and capabilities (proper training) • How much does it cost to operate feedgrounds, where does the money come from? • CWD research • Impact of severe winters on elk herds if feeding ceases • Urban expansion and encroachment on elk habitat • Flexibility in addressing disease and population management

Ideas/Solutions Suggested by Stakeholders

Many of the solutions that ranchers suggested for WGFD to implement in their Final Elk Feedground Management Plan steered the agency away from fully closing feedgrounds. Instead, these suggestions advocated for strategic modifications aimed at mitigating disease prevalence and decreasing the high density of elk on individual feedgrounds. This included establishing a network of smaller feedgrounds, strategically positioned to disperse elk across the landscape. This approach envisions a more extensive feeding area, thereby minimizing the concentration of elk in any single location. Additionally, ranchers proposed adjusting the elevation of feedgrounds to encompass a broader area, a consideration that gains significance in light of how elk habitats may evolve under the influence of climate change. Another recommendation included enhancing habitat and food quality within feedgrounds to curtail the duration of the feeding season, thereby contributing to the overall reduction in elk density. In response to the potential encroachment of federal control over land as elk disperse across the landscape, ranchers proposed a solution that involves allowing government agencies to lease private land for elk grazing.

There were also ideas and suggestions that were repeatedly mentioned across stakeholder groups. For example: ranchers and NGOs suggested the use of fencing to reduce elk and cattle from mingling. Sportsmen and hunting/outfitting groups suggested that the elk be fed on clean snow or that they be fed over larger areas. Similar to ranchers, hunting/outfitting groups mentioned the use of a network of smaller feedgrounds. Conservation organizations, government agencies, and landowners expressed interest and offered a suggestion of implementing elk occupancy agreements. Conservation organizations, government agencies, and the general public suggest that WGFD take a proactive approach to managing disease and elk populations.

Table 5. Notable ideas and solutions suggested by stakeholders through written comments on the WGFD Draft elk Management Feedground Plan. Responses written in bold are ideas/solutions that align with our project objectives and PERC's brucellosis compensation and elk occupancy agreement work.

Ideas/Solutions Suggested by Stakeholders in WGFD Draft Elk Management Feedground Plan	
Sentiment	**Suggestions offered by stakeholders**
Positive (supports feedground phase out)	Close feedgrounds that are currently near suitable winter range and where vehicle collisions could be mitigated with wildlife fencing
	Reallocate WGFD feeding funds to fence operations that still feed during the winter to reduce co-mingling
	Only feed elk on clean snow to reduce disease transmission and begin to move elk toward transition ranges
	The effects of climate change cannot be ignored and muse be addressed in the plan and future FMAPS
	Use fencing to funnel elk into desirable locations away from high traffic areas
	Large carnivore populations will help with CWD management and should be encouraged

Neutral (does not support nor oppose feedground phase out)	**WGFD and partners should actively pursue voluntary occupancy agreements that expand winter range**
	WGFD and stakeholders should work with state and federal land agencies to expand and improve winter range
	Increase access to private lands to expand the use of hunting as a management tool
	Working with organizations with significant capital to facilitate easement acquisitions and large scale habitat enhancement projects
	Proactively manage feedgrounds, ideally in a step-down plan approach that will allow for maintenance of current or near-current hunting opportunity
	Public funds should not be used to pay landowners for elk tolerance
	There needs to be mechanisms to revisit the appropriate population target if one or more feedgrounds close
	Consider the potential for voluntary, privately-funded conservation programs to reduce potential conflicts between elk and agricultural landowners
	WGFD must consider all available options, both private and public
	Management actions are needed immediately to address all avenues of reducing CWD spread through feeding
Oppose (opposes feedground phase out)	Keep feedgrounds open, but feed elk over a larger area to reduce density
	The plan includes an economic impact analysis for other stakeholder groups, but not for the agriculture industry. A comprehensive economic impact analysis should be completed and included for the agriculture industry.
	The goal should be to reduce conflicts and challenges on individual feedgrounds through a collaborative process, when challenges arise
	Consider alternative locations for feeding, not consideration of closure.
	Oppose the goal of having WGFD work with NGOs to "maximize opportunities" to increase elk occupancy on native winter ranges.
	WGFD should work closely with the Wyoming Department of Agriculture in any decisions where elk will negatively impact private landowners and federal lands grazing permits

Information Requested By Stakeholder Groups Before Final Decisions Are Made

The questions posed by ranchers demonstrated a clear concern for the economic impacts of a potential feedground closure or feeding reduction. Questions such as, “What are the economic impacts of feedgrounds in terms of their existence, closure, agricultural damage, etc?"; "How are landowners being compensated/will be compensated for elk use during the winter if feedgrounds close?" and "How will elk habitat change over time?" reflect a convergence of interests between the ranching community and the objectives pursued by these projects. Conservationists and biologists are concerned about the natural carrying capacity of the NER and its surrounding habitat, and what this would mean for wildlife managers. In addition, there are still a lot of questions on how diseases like CWD will be managed. Conservation organizations that support feedground phaseout have questions on disease and wildlife management because they feel that the plan is not detailed enough in preparing for these scenarios. Government agencies have questions regarding being involved in the decision making process and hope to be included. Hunting groups have a lot of questions about access in the event of a feedground closure. They do not support public funds compensating private lands for elk presence, but are amenable to funds from NGOs and nonprofits compensating private lands. Ultimately, hunters are concerned that they will lose access to elk and want answers for how they will still be able to hunt in a future where feedgrounds are no longer present.

Jackson Herd Habitat Connectivity Model

Through the Circuitscape analysis, we were able to identify least-cost paths and pinchpoints that the Jackson herd would likely travel on to reach identified winter range crucial areas. This was an important step towards understanding where elk move throughout the Jackson Hole landscape as well as the areas in which there could be elk-to-cattle overlap and forage competition, two priorities highlighted in the public comment analysis. In Figure 6, it was evident that least-cost paths and areas of highly suitable pinchpoint locations are located close to, as well as within the NER, but a majority are located outside of it. While this was our medium resistance analysis, we had similar findings when also running low and high resistance maps as seen in Appendix 5 and 6.

Figure 7, also showed that prime corridors for elk movement are located in low elevation ranchlands and grazing allotments as well as other private lands. While these would likely be suitable habitat, the low development and ranchlands can present pathway barriers for elk as well as increased opportunities for elk and cattle interaction. By overlaying the parcel data with the least-cost paths and pinchpoints, we can identify who owns land in crucial migratory pathways. Not all listed owners had descriptions of what the land was used for. For this reason, we only identified those that were explicitly labeled as ranching operations. A lot of the ranchlands along the Snake River, which is west of the National Elk Refuge, have conservation easements with the Jackson Hole Land Trust in order to conserve integral land for migratory corridors.[38]

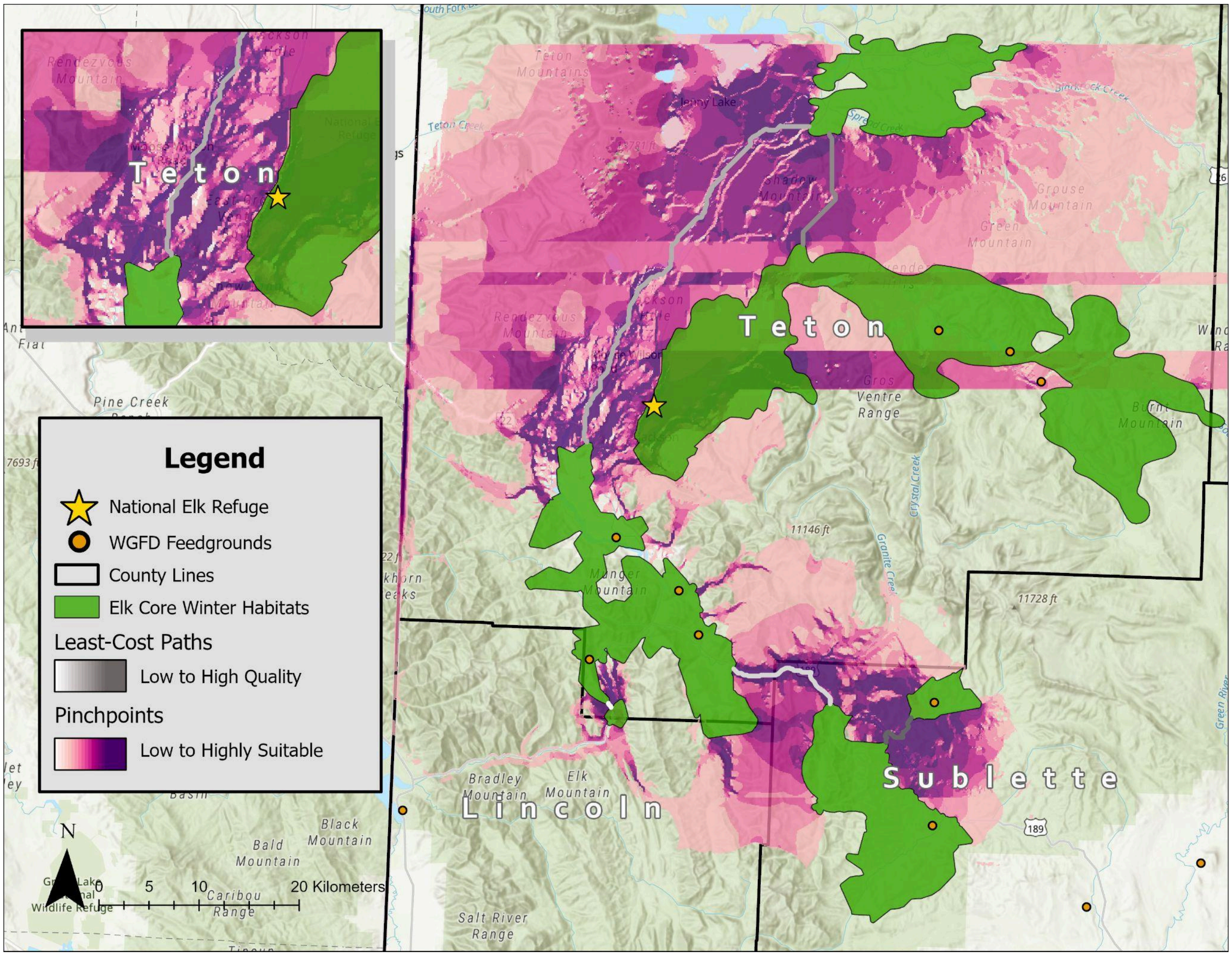

Figure 6. The Jackson herd's medium resistance habitats and pathways. This map depicts medium resistance least-cost paths and pinchpoints of the Jackson herd during winter range months if the NER were to cease feeding. Light pink depicts areas that are the least suitable corridors based on the presence of data with high resistance. As the pinchpoints get darker in color (closer to purple), the habitats increase in suitability due to a decrease in resistance and barriers. The pinchpoints are based on the least-cost paths (white to gray gradient) and therefore there is higher suitability, or darker colors, surrounding the least-cost paths. Least-cost paths (LCPs) are ranked based on the ability of the herd to use that path. White depicts a path of low quality where it is unlikely for elk to use the path. The LCPs transition to a darker gray indicating the increasing suitability of the path.

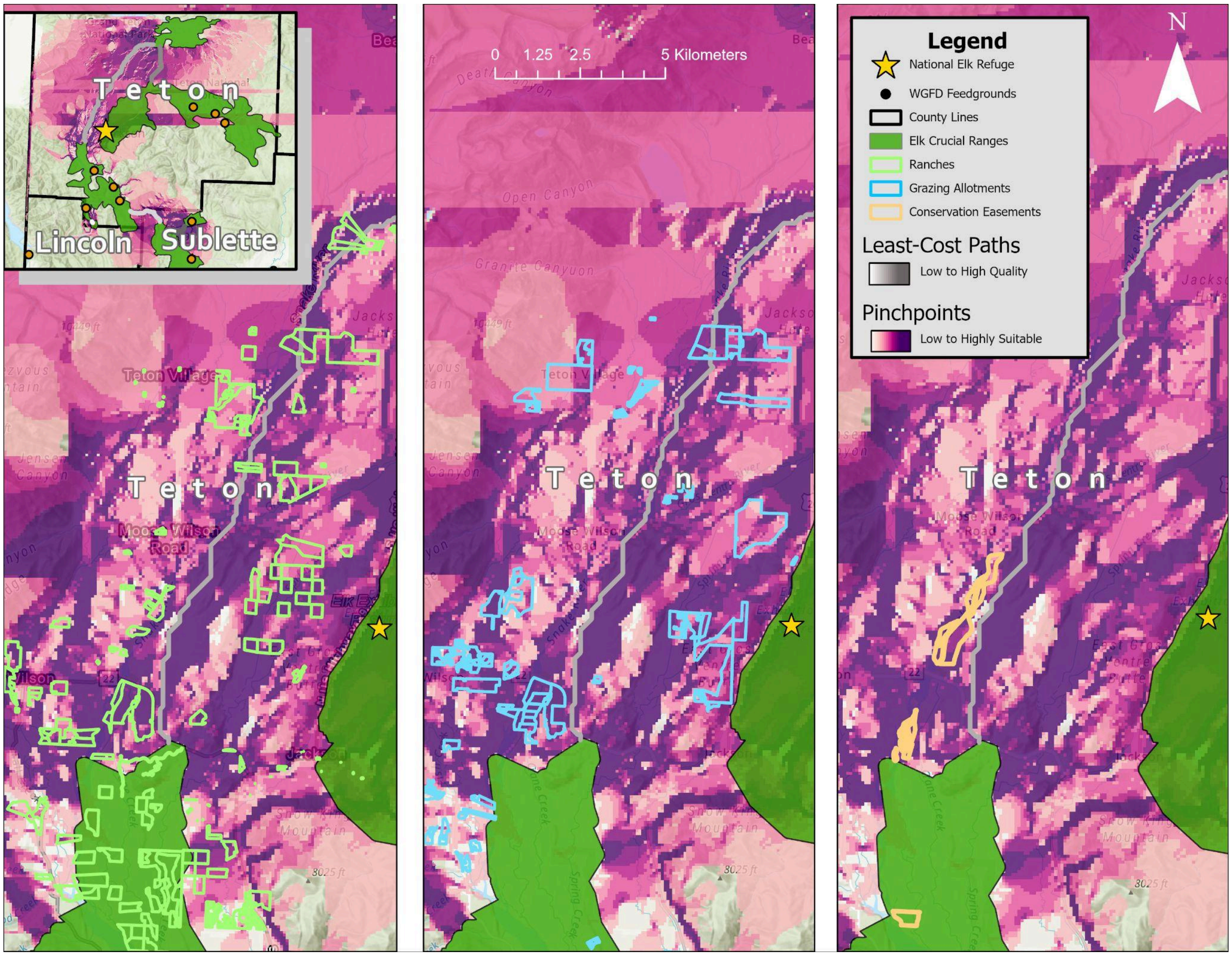

Figure 7. The Jackson herd's medium resistance least-cost paths and pinchpoints overlaid with land ownership data. Many of the medium resistance least-cost paths and pinchpoints run through private ranchlands as well as public lands. When there is overlap with private ranchlands and grazing leases, the probability of brucellosis transmission and forage competition increases due to the spatial overlap between elk and cattle.

Brucellosis Transmission Risk Model

Overlap

Simulating a range of elk-to-cattle overlap scenarios shows that, as overlap increases, the expected number of years between cattle reactors decreases exponentially. The assumption that the overlap is around 0.5 elk per cattle herd while the NER is in operation leads to an output of 27.65 years between detected cattle reactors within the Jackson elk herd unit. Increasing the fed elk-to-cattle overlap to 3.0-4.5 elk per cattle herd to simulate feedground closure decreases the number of years to an average of 6.60 years between cattle reactors (SD = 0.85; range = 5.53-7.90 years). On the more extreme ends of the modeled scenarios, a high overlap of 5.0-6.0 elk-to-cattle reduces the time between cattle reactors to an average of 4.73 years (SD = 0.38; range = 4.25-5.27 years), while a low overlap of 1.5-2.5 elk-to-cattle increases that time to an average of 11.54 years (SD = 2.61; range = 8.51-15.80 years). The full range of overlap scenarios we modeled are visualized in Figure 8 and Figure 9.

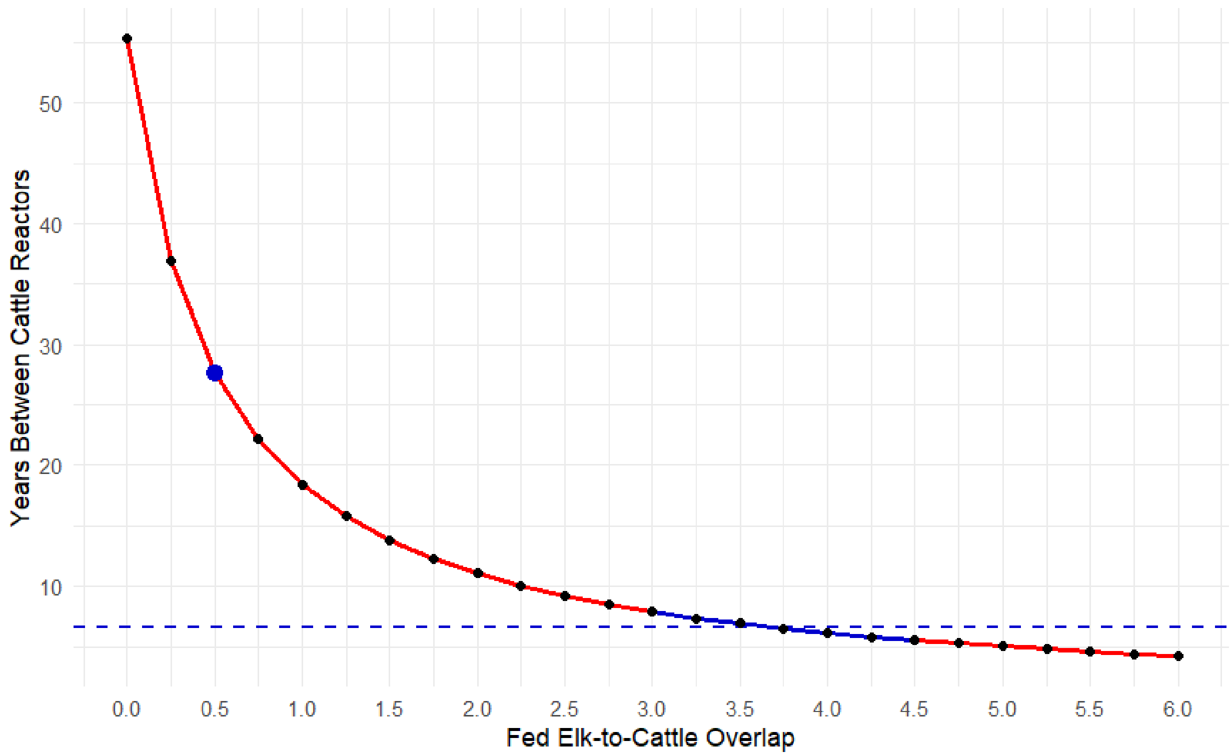

Figure 8. Fed elk-to-cattle overlap scenarios. Shown are the number of years until at least one cattle reactor within the Jackson elk herd unit, based on a range of fed elk-to-cattle overlap scenarios between 0.0 and 6.0 elk per cattle. The leftmost blue point, based on current predicted Jackson elk-to-cattle overlap, indicates a likely frequency of cattle brucellosis cases if the NER were to remain in operation. The solid blue line indicates a likely range of scenarios if the NER were to close. The dashed blue line is the average cattle case frequency of that range (6.60 years between cases).

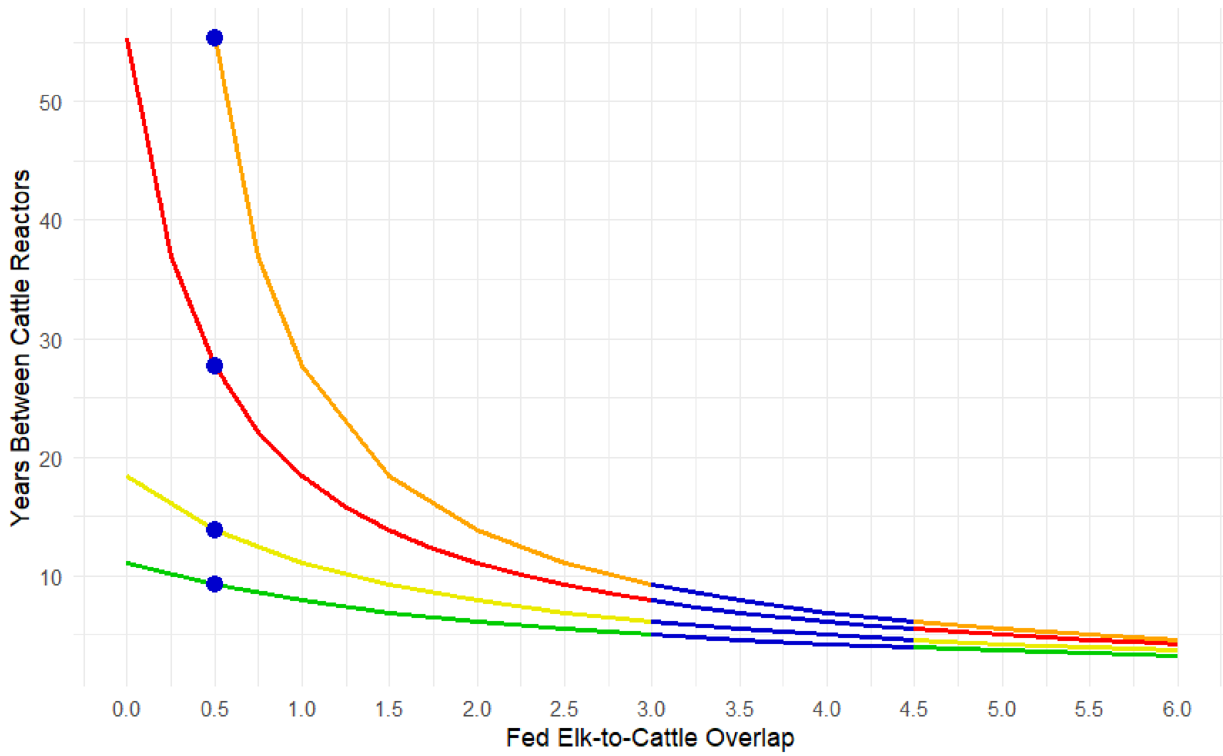

Figure 9. Fed elk-to-cattle overlap changes under different unfed elk overlap scenarios. Shown are the number of years until at least one cattle reactor within the Jackson elk herd unit, under four different unfed elk overlap scenarios, based on a range of fed elk overlap scenarios between 0.0 and 6.0 elk per cattle. The four unfed elk overlap scenarios here are 0.0 (orange), 0.5 (red), 1.5 (yellow), and 2.5 (green). The leftmost blue point indicates the NER in operation. The blue line segments indicate feeding at the NER has ceased.

Seroprevalence

Like with overlap, as seroprevalence increases, the expected number of years between cattle reactors decreases exponentially, and vice versa. Assuming a post-NER closure overlap scenario of 0.5 unfed elk-to-cattle and 3.75 fed elk-to-cattle (median plausible scenario), simulating the elk seroprevalence decreases associated with the Proffitt et al. (2017) models of 10%, 30%, 50%, 70%, and 90% elk herd density decreases resulted in outputs of 8.67, 15.18, 26.02, 45.54, 91.08 years between detected cattle reactors respectively. With regards to extremes, a very high elk seroprevalence of 60% reduces the time between cattle reactors to 3.04 years, while a seroprevalence of 0.01% increases that time beyond 100 years, eventually nearing infinity as seroprevalence approaches 0% (Figure 10).

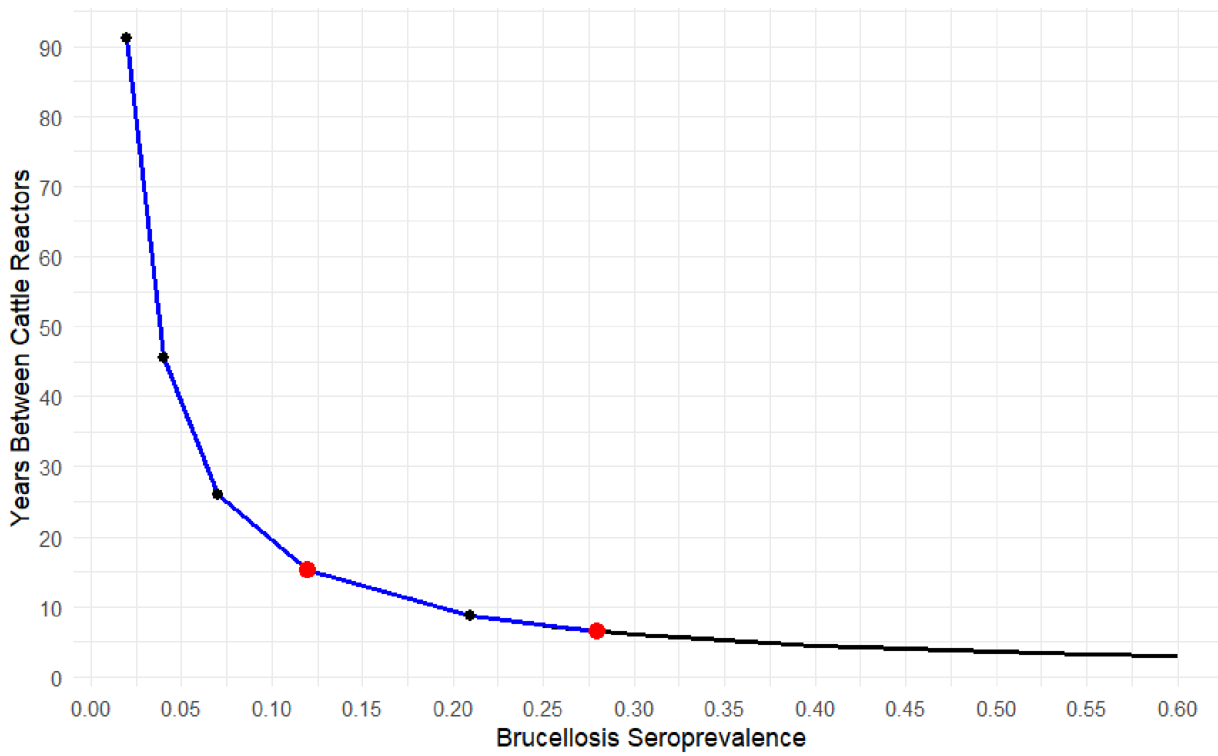

Figure 10. Elk brucellosis seroprevalence scenarios. Shown are the number of years until at least one cattle reactor within the Jackson elk herd unit, based on a range of elk brucellosis seroprevalence scenarios between 0% and 60%, assuming a 0.5 unfed elk/cattle and 3.75 fed elk/cattle overlap. The blue line represents the change in seroprevalence associated with the elk herd density decreases modeled by Proffitt et al. (2017). The rightmost red point indicates current Jackson elk herd seroprevalence (28%). The leftmost red point indicates a decrease in elk seroprevalence after a 30% herd density decrease. The black line indicates additional high seroprevalence scenarios.

Varying the fed elk-cattle overlap with the Proffitt et al. (2017) seroprevalence scenarios produced a range of outputs from 5.53 to 27.65 years (mean = 12.63 years; SD = 8.97) between cattle reactors for a 28% elk seroprevalence (current) and from 12.90 to 64.52 years (mean = 29.46 years; SD = 20.93) for a 12% elk seroprevalence (30% density decrease). These outputs, in addition to the other seroprevalence scenarios, are displayed in Figure 11.

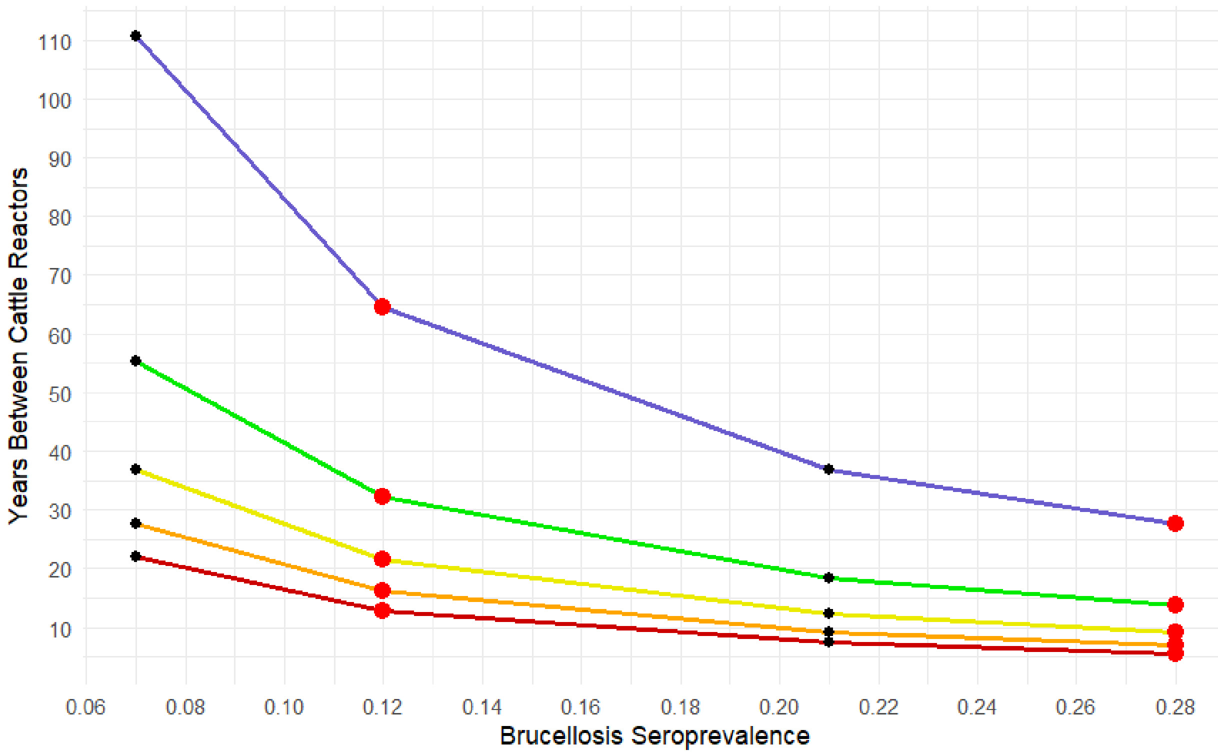

Figure 11. Seroprevalence changes under five overlap scenarios. Shown are the number of years until at least one cattle reactor within the Jackson elk herd unit, based on a range of elk brucellosis seroprevalence scenarios associated with the elk herd density decreases modeled by Proffitt et al. (2017). Seroprevalence changes were simulated with five fed elk/cattle overlap scenarios: 0.5 (purple), 1.5 (green), 2.5 (blue), 3.5 (orange), and 4.5 (red). The rightmost red points indicate current Jackson elk herd seroprevalence (28%). The leftmost red points indicate a decrease in elk seroprevalence after a 30% herd density decrease.

Analysis of Financial Repercussions of Feedground Closure

Results for Change in Brucellosis Costs in Teton County

We used the results from the Brucellosis Transmission Risk Model to predict a range of average yearly cost of brucellosis to the ranchers of Teton County, depending on various elk-to-cattle overlap scenarios. For the plausible overlap scenarios with simulated feedground closure (3.0-4.5), the average cost ranges from $28,000.00 USD to $40,000.00 USD (Figure 12-A). Still using the same method and scenarios, if we look at the change in costs from the baseline open feedground scenario to the simulated closure scenario, we see an average yearly increase ranging from $20,000.00 USD to $32,000.00 USD (Figure 12-B). All these costs end up being low even with the most extreme scenario, with an overlap of 6.0 elk-to-cattle, which leads to an increased cost of $44,000.00 USD per year for a total cost of $52,000.00 USD per year. Despite this, a case can have a great impact on individual ranches, creating a massive financial burden. Therefore the implementation of a brucellosis compensation fund would be recommended. Thus, we calculated the recommended brucellosis compensation fund size needed to support ranchers by minimizing the financial impacts of a brucellosis case. Our fund, like other PERC funds, was designed to have a maximum payout of $100,000.00 USD per case and only reimburse ranchers for a maximum of 75% of their brucellosis related expenses. This allows the fund to not be drained after only one case, and it gives ranchers an incentive to take measures to prevent brucellosis. We looked at a wide range of overlap scenarios, and the results for the most likely scenarios range from $104,000.00 USD to $151,000.00 USD (Figure 12-C).

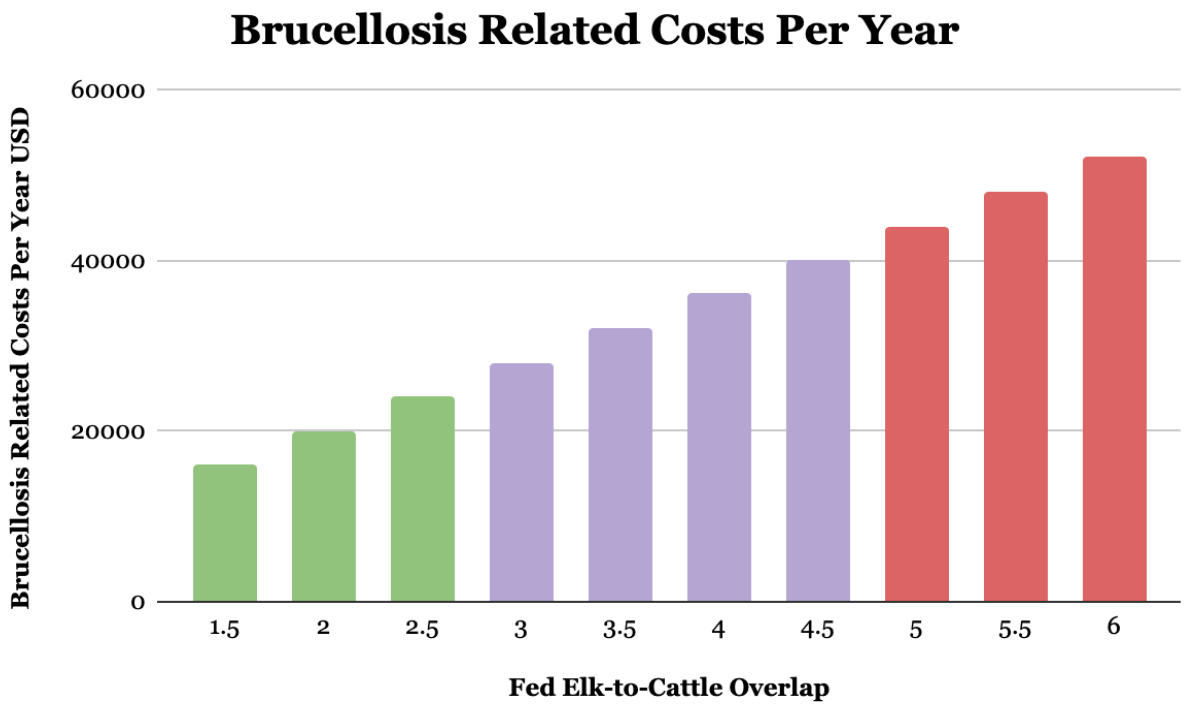

Figure 12-A. Brucellosis costs under simulated feedground closures. Shown are the total costs in USD of brucellosis in Teton County due to elk's potential new winter migration paths. The x-axis visualizes how different fed elk-to-cattle overlap impacts those costs. The purple bars represent the most likely scenarios, the green bars represent the scenarios on the low end of the spectrum, and the red bars represent the scenarios on the high end of the spectrum. Through our literature review and discussion with experts, we identified 3.0 to 4.5 elk-to-cattle overlap as the most likely scenarios if the feedground were to close, but a range of possibilities are shown here to account for uncertainty.

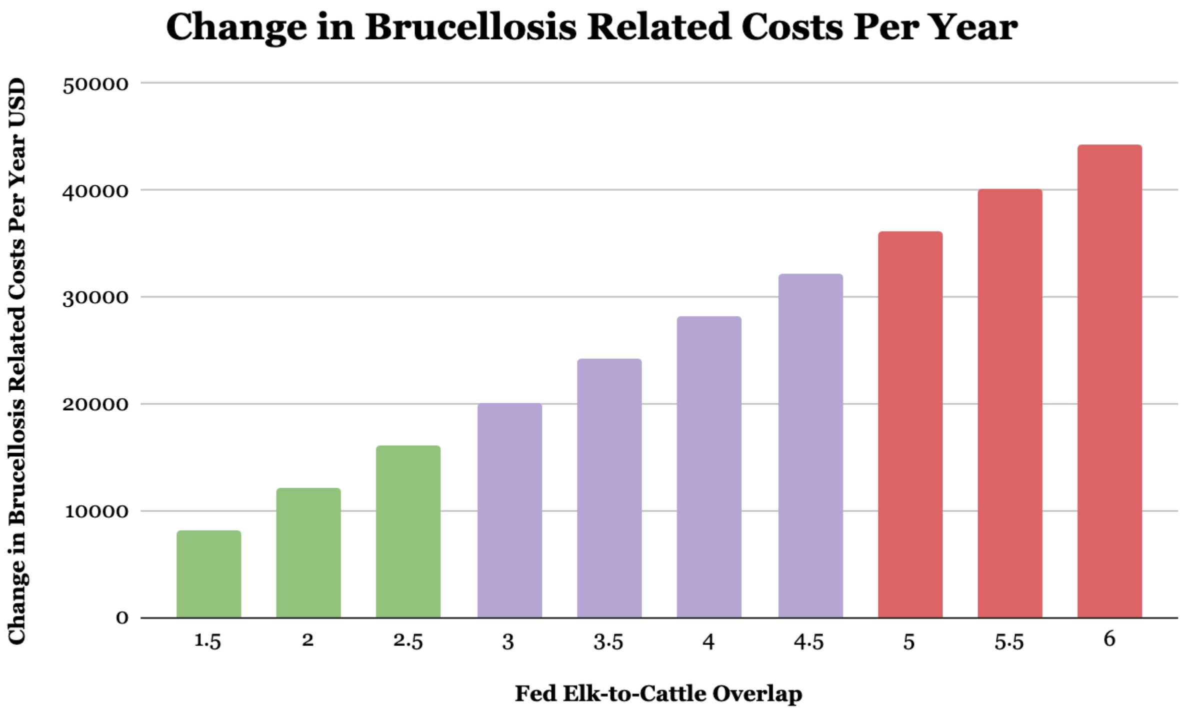

Figure 12-B. Change in brucellosis costs under simulated feedground closures. This figure shows the change in brucellosis costs between a feedground closure and a status quo scenario. Results indicate that ranchers are right in their assumption that brucellosis costs would increase; however the increase in cost is still manageable for a county with the economic production of Teton County. The purple bars represent the most likely scenarios, the green bars represent the scenarios on the low end of the elk-cattle overlap spectrum, and the red bars represent the scenarios on the high end of the elk-cattle overlap spectrum.

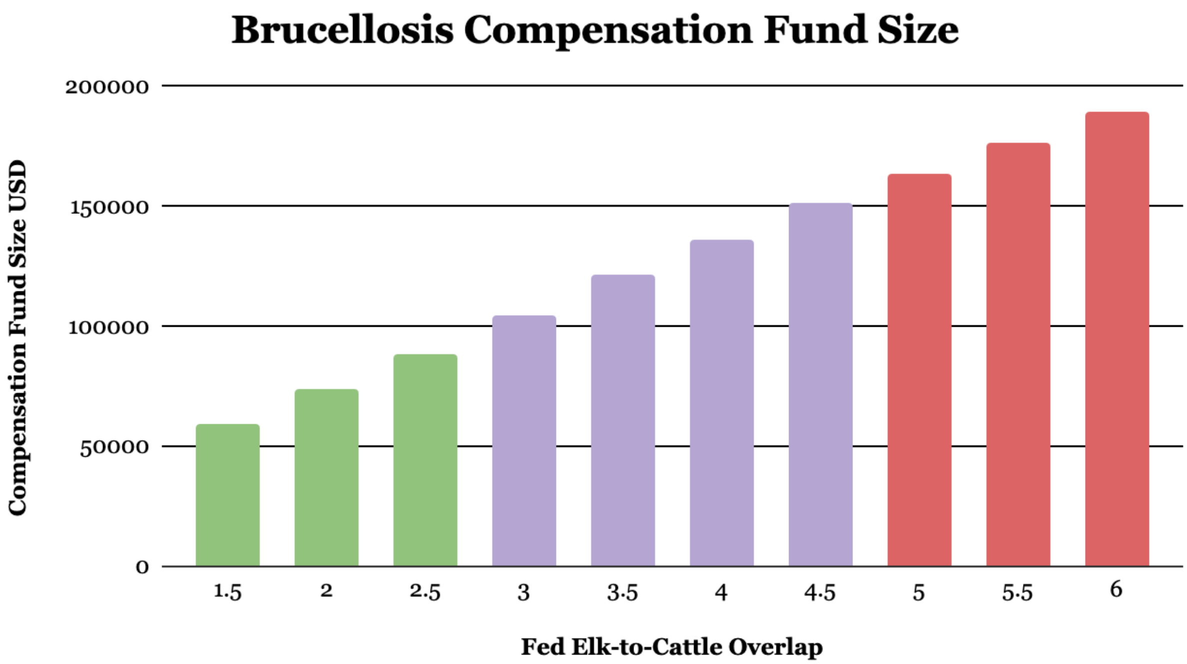

Figure 12-C. Brucellosis compensation fund size under simulated feedground closures. Shown here is the required brucellosis compensation fund size in USD under different levels of fed elk-to-cattle overlap scenarios. The most likely scenarios range from $104,000.00 USD to $151,000.00 USD. The fund was calculated to last for five years, with a maximum payout of $100,000.00 USD per case, and with a reimbursement rate of 75%. The purple bars represent the most likely scenarios, the green bars represent the scenarios on the low end of the elk-cattle overlap spectrum, and the red bars represent the scenarios on the high end of the elk-cattle overlap spectrum.

Results for Forage Competition

The second part of the financial analysis uses the results from the Jackson Herd Habitat Connectivity Model to calculate an estimate for the forage competition related to the additional hay consumption by elk that would occur if the NER feedground would close. A necessary component to achieve this was to predict where the Jackson elk that are over carrying capacity in the simulated closure scenario would migrate to. Figure 13 shows where elk are most likely to forage over the winter months with habitat suitability that ranges from prime to subpar under a high resistance scenario. It stands out that most of the prime winter habitat is located in southern Teton county in areas that are low in elevation, in between buttes, and alongside creeks such as Spring Creek. Those areas are also where most of private ranching lands are concentrated, as seen in Appendix 7. Our calculation for forage competition came out relatively large with a total average yearly cost of $98,785.90 USD spread across all of Teton County. While this increase in financial damages is significantly more than the increased costs related to brucellosis, Figure 14 shows that those costs are marginal compared to how much the National Elk Refuge system spends on elk feed pellets, which totals around $572,000.00 USD each winter.

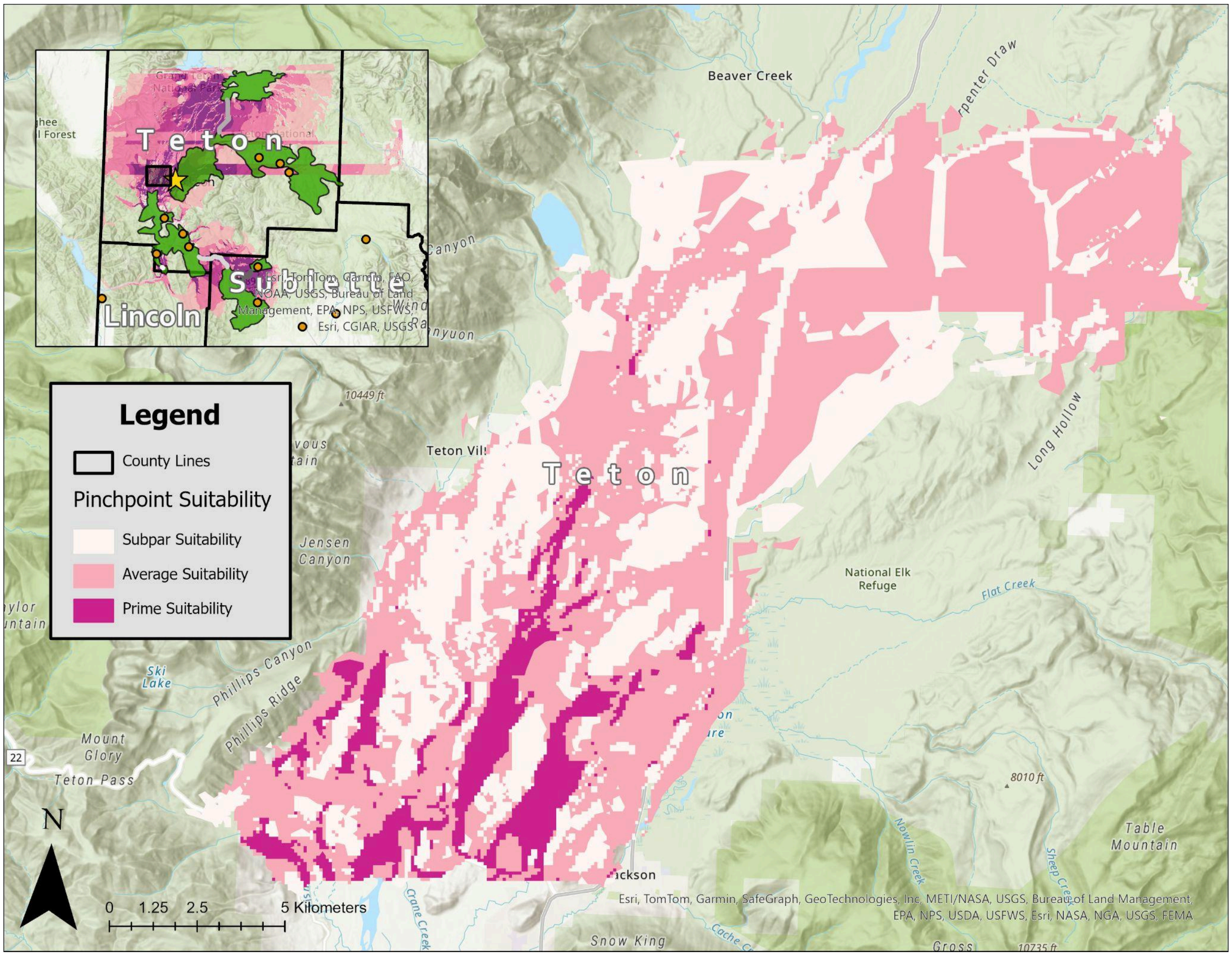

Figure 13. Winter habitat suitability within Teton County based on forage competition classifications. According to the high resistance pinchpoints from our Jackson Elk Herd Habitat Connectivity Model, the most suitable winter elk habitat is located in the southern part of the valley where most of the private lands in Teton County are located, as defined by the dark pink. This could lead to increased costs to the ranching community. Subpar habitat is primarily found where there are buttes and development. The reference map shows the area of concentration within the high resistance pinchpoints as mapped in Appendix 5.

Table 6. Use of habitat connectivity results within the forage competition calculations. This is the filled in version of Table 3 in the methods, now incorporating the habitat connectivity results.

Incorporation of Jackson Herd Habitat Connectivity Model Results into Forage Competition Calculations			
Forage Competition Data	**Assumption**	**Pinchpoint Results from Connectivity Model**	**Land Parcel Results from Connectivity Model**
Number of elk at the refuge during the 2021-2022 season is estimated at 7,381	Prime Habitat: Elk are three times more likely to forage in this habitat compared to average habitat	Prime Habitat outside of NER boundaries = 21.68 km^2	Percentage of Primate Habitat on private land = 87.9% Total Prime habitat on private land = 19.05km^2
Costs of feed pellets during the 2021-2022 season was $572,000.00 USD.	Average Habitat: Considered to be our baseline	Average Habitat outside of NER boundaries = 147.90 km^2	Percentage of Average Habitat on private land = 39.6% Total Average habitat on private land = 58.63km^2
Predicted carrying capacity of the NER without supplemental feeding = 5,000 individuals	Subpar Habitat: Elk are not going to forage in this habitat due to factors like elevation, roads, and urban development.	Subpar Habitat outside of NER boundaries = 96.33 km^2	Percentage of Subpar Habitat on private land = 47.7% Total Subpar habitat on private land = 45.97 km^2

Below are the filled in forage competition equations from the method section:

Equation 4. $Cost\ to\ feed\ 1\ elk\ over\ winter\ =\ \$572,000/7,500\ =\ \$76.267$ USD
Equation 5. $Number\ of\ elk\ over\ carrying\ capacity\ =\ 7,381\ -\ 5,000\ =\ 2,381$
Equation 6. $Private\ Land\ Winter\ Range\ =\ (\ 3\ *\ 19.05)\ +\ 58.63\ =\ 115.78$
Equation 7. $Private\ +\ Public\ Land\ Winter\ Range\ =\ (3\ *\ 21.68)\ +\ 147.90\ =\ 212.94$
Equation 8. $Ratio\ =\ 115.78/212.94\ =\ 0.544$
Equation 9.
$\Delta\ Winter\ in\ Forage\ Competition\ Cost\ =\ 0.544\ *\ \$\ 77.45\ USD\ *\ 2,381\ =\ \$\ 100,318.17$ USD

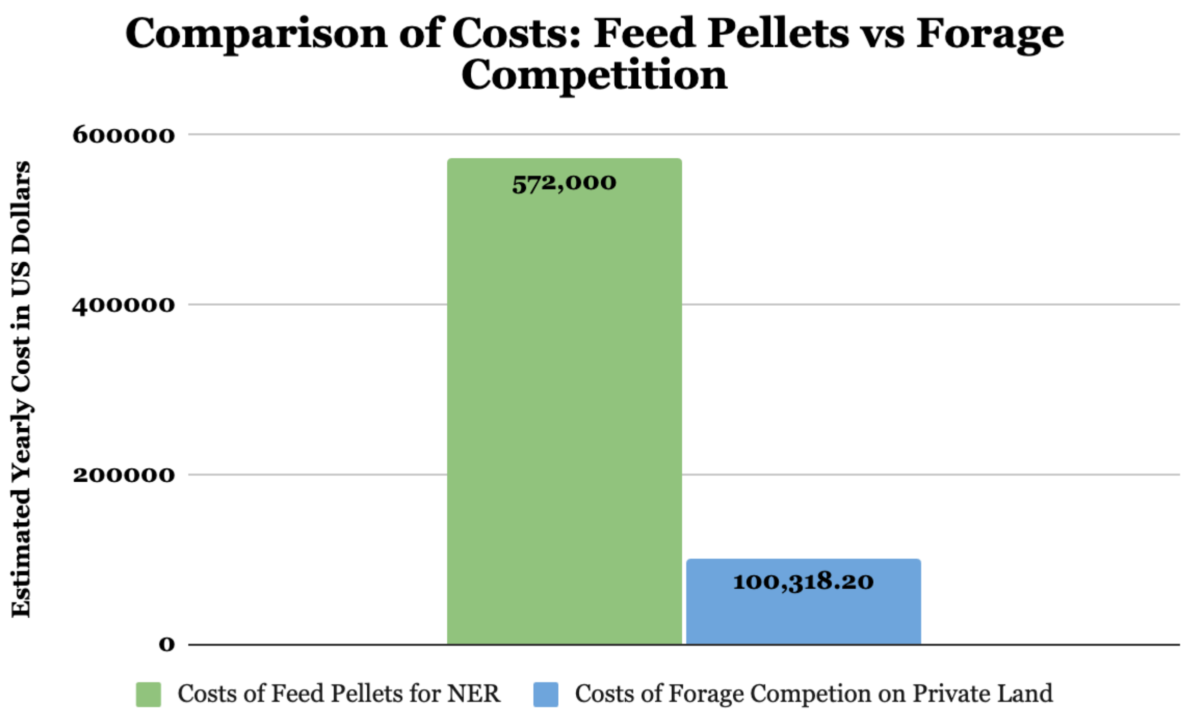

Figure 14. Comparison of the yearly budget of the NER for elk feed pellets against the expected yearly cost of forage competition on private land in Teton County. The cost of feed pellets alone are almost six times greater than the costs of additional elk foraging on hay. The money saved on feed pellets would not go back to the ranching community of Teton County and would instead go back to the National Wildlife Refuge System (Eric Cole, personal communication, 2024).

Discussion

Elk Feedground Public Comment Sentiment Analysis

Implementation of Suggestions and Comments in Updated Draft Plan

An updated draft plan of the WGFD's Elk Feedground Management Plan was released on February 12, 2024. Comprehensive updates and edits were made to the draft plan based on comments, suggestions, ideas, and conversations with stakeholders after the first draft was published in Spring of 2022, however, the WGFD has been tackling this complex issue since 2020. The updated draft plan is ultimately a reflection of years of work between stakeholders. As such, we felt it would be beneficial to evaluate some of the changes incorporated into the updated draft plan based off of the comment letters and survey responses from the public and stakeholders.

A notable inclusion in the updated draft plan is the addition of financial information about the agricultural industry, which was suggested by stakeholders since it was originally left out in the original draft plan. This section was noticeably missing from the original plan while other industries/stakeholders had their own economic values section. "Given the financial and logistical consequences of brucellosis exposure in a cattle herd, management changes to feedgrounds have the potential to impact the economic sustainability of individual cattle producers and the local agricultural lands and economy."[6] Landowners and livestock producers repeatedly noted that they did not feel represented well in the original draft plan, and the inclusion of cattle ranching's financial value in the state of Wyoming properly highlights the financial impact that ranchers could face if the effects of a potential feedground closure are not mitigated.

In addition, the updated draft report also highlights disease concerns beyond CWD and brucellosis. While these two diseases have most of the attention, diseases like necrobacillosis, psoroptic mange, and bovine tuberculosis, are also present on the feedgrounds and have harmful effects on individual elk and herd health. These diseases were mentioned by conservation groups, scientists, and sportspersons as other causes of concern for elk health on and off of feedgrounds. The inclusion of these diseases along with some ideas of how to reduce disease spread of all the diseases (CWD, brucellosis, necrobacillosis, psoroptic mange, and bovine tuberculosis) acknowledges that more work in management needs to be done to improve herd health. One suggestion that is included is to reduce herd densities and feed elk on clean snow to reduce the risk of disease spread.

The updated plan also highlights the importance of voluntary elk occupancy agreements in creating accessible habitats with the objective of increasing "opportunities for elk to winter away from feedgrounds and conserve elk habitat permeability on the landscape." The plan acknowledges that there are voluntary elk occupancy agreements in place, but that more work can be done to explore this conservation tool. One of the challenges with voluntary elk occupancy is getting buy-in from landowners in an area. However, the WGFD hopes to work closely with NGOs and landowners to find solutions that would benefit the landowner, the NGO, WGFD, the general public, and the elk.

The purpose of this section is not to provide a comprehensive analysis of the new updated draft management plan, but rather to highlight some of the new and important changes that were made. More information about the WGFD's updated draft elk management plan can be found here.

Main Takeaways

When we first began this project, we were warned of the complexities and polarities that were ingrained in feedground operations in Wyoming. However, analysis of the comments and working groups with the WGFD say otherwise. There is no doubt that there are many competing interests involved, but there are parties that are interested in working with one another to find effective solutions. All the groups and individuals involved value a strong and healthy elk population in Wyoming, specifically Western Wyoming, but the root of their differences comes from how a healthy and strong elk population is obtainable. Some groups believe that this goal can be accomplished through the elimination of feedgrounds while others believe that feedground operations are the key to strong and healthy elk populations. As such, we believe that there is a lot of room for exploration of innovative solutions and research to identify practices that support healthy and viable elk populations in the state. There is openness from respondents to explore alternatives to the status quo such as: creating smaller feedgrounds, feeding elk over larger areas, phasing out feeding to wean elk, allowing the state to lease agricultural lands for feeding, improving natural habitats and corridors, using fencing to separate elk and cattle and encourage migration and movement, and allowing the state to purchase easements for suitable habitats.

We repeatedly saw suggestions of voluntary elk occupancy agreements which are directly aligned with our project goals and objectives, as well as PERC's. This indicates an openness to the use of private funds to compensate private landowners like ranchers for elk presence or the creation of fences to keep elk from mingling with cattle when on private lands. In addition, the new updated draft plan further explores forage competition and where there is suitable forage for elk in Wyoming. Ultimately, there are concerns from both WGFD and stakeholders that there is insufficient natural forage and habitat for elk in their winter range which indicates opportunities for habitat restoration or purchase/lease of private and public lands for elk to have sufficient grazing opportunities to prevent starvation. As mentioned above, multiple individuals from different stakeholder groups mentioned the use of voluntary elk occupancy agreements to reduce livestock-wildlife conflict. This is directly related to PERC's elk occupancy pilot project in Paradise Valley in Montana and Park County.

Jackson Herd Habitat Connectivity Model

Understanding the future movement and migration corridors of the Jackson herd has important implications for not only this project, but for future management decisions. With the crucial areas defined by the WGFD and Circuitscape modeling, we were able to find the paths of least-cost resistance and pinchpoints for the Jackson herd. A majority of these paths and pinchpoints ran through private ranchlands, which is a present concern from ranchers in the area due to the risk of brucellosis, property damage, and potential increased wolf predation, as seen in the Public Comment Sentiment Analysis. Identifying these least-cost paths (LCPs) and pinchpoints could be informative for ranchers looking to protect their cattle herd and wildlife managers interested in managing healthy lands for the Jackson herd. This has the potential to inform present and future land management in the Jackson Hole area.

Due to the uncertainties surrounding elk biology and movement, three maps were made, low (medium and high resistance) that assigned different resistance values to each data layer. This not only accounted for uncertainties that may have been present within the data layers themselves, but also simulated the removal of resources and the increase in climatic conditions during the winter months. The simulation included increasing elevation resistance values between the three maps in order to account for heavy snowpack. We also made the decision to focus on crucial areas in lower elevation as it would be unlikely that the Jackson herd would be using high elevation habitat during Wyoming's harsh winters.

The changes in LCPs between the low, medium, and high resistance maps were minimal, but there were substantial changes to the pinchpoints. This was due to certain data layers, such as grazing allotments, land use, and roads, increasing in resistance values. This provided crucial insight into how barriers such as development, highways, and wildlife management techniques (fencing) could alter and inhibit potential habitat for the Jackson herd. It also showed how elk and cattle overlap could potentially change if fencing would be applied to areas where cattle are grazing. This would affect both the Brucellosis Transmission Risk Model and forage competition calculations in the Financial Analysis as overlap could either increase or decrease. It could also provide insight into habitats and migration corridors where conservation and government agencies could focus their habitat conservation efforts, such as areas where the Jackson herd might cross major highways and be hit by cars. This was shown in both the LCPs and pinchpoints of the three maps, Figure 6 and Appendix 4 and 5.

After increasing the resistance values for the NER, the key finding was the pinchpoints, which indicated that the herd would shift away from the feedground more towards private lands, conservation easements and grazing allotments, as seen in Figure 7. This has major implications for the rate of brucellosis transmission, property damage, and forage competition that ranchers could face with the potential closing of the NER. It was noticed that the herd was shifting away from the NER itself and moving to other crucial areas within the northern extents of Sublette and Lincoln counties, where other feedgrounds are located, as seen in Figure 6. This could be a finding that other feedground managers should be aware of as these other feedgrounds may go over carrying capacity with the presence of a new herd and may not be able to sustain the increase in elk. It could also mean that with a higher density of elk in these areas, rates of brucellosis transmission (as well as other diseases) between the elk could increase.

It is important to note that within each of these maps, there is a band that runs across each map above the NER. This is most likely due to how ArcGIS weights and combines the resistance layers together when making one main low, medium, and high resistance raster. While the team has attempted to change multiple of the model's parameters to remove or minimize this band, we have not been able to pinpoint exactly what is causing its creation. Luckily, it minimally affects our results as we are primarily focused on the Jackson Hole area next to the NER and the Snake River area, which is not disturbed by the bands. As such, we are still confident in the maps and conclusions made during this section of the project.

In summary, the results from the Jackson Herd Habitat Connectivity Model revealed that with the cessation of feeding on the NER, the herd will most likely move to low elevation ranchlands or other feedgrounds where feeding would be provided to them in the winter months. This would thus heighten the risk of brucellosis transmission from elk to elk and elk to cattle as well cause an increase in forage competition and property damage. Understanding how elk move between their core habitats provides important management considerations for both conservation and government agencies, such as increased travel on roadways (more frequent roadkill incidents) and higher herd density on other feedgrounds. Coupling the LCP and pinchpoint results with the results from the Public Comment Sentiment Analysis, Brucellosis Transmission Risk Model, and Analysis of Financial Repercussions of Feedground Closures will provide methods and strategies to mitigate these impacts both for the ranching community and Jackson herd.

Brucellosis Transmission Risk Model

Cattle brucellosis cases in Teton County are currently very infrequent, likely around at least one case every 28 years. If feeding ceases at the NER and more fed elk move across ranchlands, then the frequency of cattle brucellosis cases will likely increase, with a potential of at least one case every 7 years. While the number of years and cases may vary, these results suggest ranchers would experience an increase in brucellosis-related costs, as shown in the analysis of financial repercussions. Density-related elk seroprevalence decreases could eventually decrease the frequency of cattle brucellosis cases again over time, potentially to at least one case every 15 years, though it is uncertain when a decrease in seroprevalence could occur.

Overall, risk to cattle is predicted to increase in the first few years after feeding ceases, meaning ranchers may have to quarantine and depopulate their cattle more often. However, these results also provide a sense of how those costs can be mitigated. While the brucellosis transmission model highlights how much an increase in elk-cattle overlap increases transmission risk, the reverse is also true: reducing overlap would likely reduce transmission risk. Kauffman et al. (2016) noted that their model tended to overestimate cattle case frequency, as management strategies, such as fencing and adjusting cattle seasonal grazing location to avoid contact with elk, were often more effective at reducing elk-to-cattle transmission than the model accounted for. In the long term, it may be worth looking into management strategies that have been implemented in counties that already experience a high number of cattle brucellosis cases. The Hoback and Upper Green River elk herd units are predicted to contribute to at least one cattle brucellosis case every 12 years, while the Piney herd unit is predicted to contribute to at least one cattle case every 4 years.[25] The U.S. Forest Service and USGS are currently reevaluating the management of the feedgrounds within those herd units precisely because of issues with disease among elk,[31] so there may be future potential to apply some of those updated management strategies to the NER if the USFWS decides to continue with feedground phaseout. In the short term, until elk-cattle overlap is reduced or brucellosis seroprevalence decreases with elk density, a brucellosis compensation fund may be the most feasible approach to mitigating costs, as laid out in the financial analysis.

It is important to note that the feedgrounds and the disease dynamics of the GYE are in many ways unprecedented. The NER and other GYE feedgrounds have been in place for over a hundred years, so while there are a lot of data about current conditions, future elk-cattle overlap and seroprevalence are difficult to accurately predict. While we modeled a range of scenarios to account for this uncertainty, it is always possible that if the NER were to cease feeding for the first time in a century, then a different transmission risk scenario could occur than the ones we reasoned to be the most plausible. The Probabilistic Transmission Model is also a broad snapshot: it does not account for seasonal or yearly fluctuations in brucellosis transmission, and because it summarizes by elk herd unit, it does not indicate which individual ranches might be at higher risk than others. However, this latter limitation was partially accounted for by the habitat connectivity model.

Despite these uncertainties, a snapshot of transmission risk is still incredibly useful for creating a starting point for the implementation of a brucellosis compensation fund in Teton County. If the NER eventually proceeds with feedground phaseout and elk-cattle overlap increases, then we have a range of brucellosis transmission risk scenarios that can be accounted for. These results also serve as a starting point for more in-depth modeling of disease risk. Since our modeling did not account for yearly fluctuations in brucellosis transmission, a future model may wish to incorporate climate change projections, particularly since warming temperatures have the potential to reduce brucellosis persistence in the environment and cause additional shifts in elk migration.[39, 40] In the meantime, PERC has the ability to use these broader Jackson herd unit transmission risk results to evaluate the feasibility of a brucellosis compensation fund for Teton County.

Analysis of Financial Repercussions of Feedground Closure

Our public comment analysis identified four main areas of concerns for ranchers due to the potential new management of the NER. The Teton ranching community was worried about brucellosis transmission, forage competition, wolf depredation, and elk property damage if the NER feedground operations were to stop. Brucellosis transmission from now unfed elk to livestock was arguably most concerning. While the original reasons behind the creation of feedground did not include reducing disease transmission, it is now a key contentious point in the debate regarding their management.

The costs related to brucellosis-mandated quarantine depend on a multitude of factors such as herd size, time of infection, and infrastructure availability. However, none is bigger than hay price. The hay markets can be subjected to fluctuations. Looking at USDA reports from 2022, during a drought year the hay prices stagnate around $225.00 USD per ton in Wyoming, which is almost twice less than the national average. Thus it is possible for the Wyoming hay prices to move up in the future, especially if more intense droughts happen due to climate change. Despite this, we are still confident that we can make some definitive conclusions using the $225.00 USD assumption.

Another variable that impacted our calculations greatly is the elk-to-cattle overlap. Since we were less confident about our predicted overlap number for the feedground closure scenario, we ran multiple scenarios changing that variable. Looking only at the scenarios we deemed likely, our highest estimated brucellosis cost per year without the feedground was $40,103.44 USD. This cost appears minimal at first glance. However, there are two important factors to consider when analyzing our financial results. First, while the increase in cost is slim in comparison to the greater economic landscape of Jackson Hole, it is still not insignificant as the brucellosis related costs can increase by $32,132.83 USD per year from the baseline costs while the NER feedground is open. Secondly, those numbers represent an average expected cost per year. If in a given year one of the bigger ranches in Teton County is hit with a case of brucellosis, then the costs can quickly add up to over $150,000.00 USD. Since the costs for a single case are high, despite a low likelihood of occurrence, we recommend that PERC implements a compensation plan similar to the pilot program currently in place in Paradise Valley. We believe that a fund size of

$136,144.28 USD should be sufficient to support the ranching community, as it is the expected value we found using the most likely scenario of a new elk-to-cattle overlap of four. It is feasible to implement a fund in Teton County for PERC since it is within the range of the Paradise Valley fund and the expected range of the Park County one. This would help alleviate tensions in the Jackson Hole community by spreading the costs of living with wildlife more evenly.

While disease transmission was not a reason to create elk feedgrounds in the early 20th century, limiting elk consumption of private haystacks over the winter month was. For the sake of our financial analysis, we refer to this phenomenon as forage competition. Using the Jackson Elk Herd Habitat Connectivity Model, we were able to calculate the increase in forage competition on private land under a simulated feedground closure which came to $98,785.90 USD per year for all of Teton County. Those costs are more important per year compared to brucellosis costs, due to the fact they are guaranteed to occur every year while a brucellosis outbreak might only occur once every 7 years. It is important to recognize, however, that those costs are more evenly spread throughout the ranching community as almost all 19 ranches[26] will be impacted to a certain extent. Additionally, these costs are easier to take into account when budgeting since they are less likely to dramatically change from one year to the next, which likely means a smaller emotional burden and better financial stability for ranchers. This is a contrast from brucellosis costs that can stay at zero for over a decade and then suddenly jump up to $150,000.00 USD when the entire herd has to be quarantined.

Even if those costs are more diffuse throughout the ranching community, we still recommend that PERC attempts to find partners to create financial tools to mitigate the impact of forage competition. PERC should strongly consider implementing a financial mitigation tool, similar to the pilot elk rent program that just started in Paradise Valley.[41] Ranches that are located within the prime habitat suitability range of our habitat connectivity model (Figure 13 and Appendix 7) will be impacted more than others, and a financial migration tool would be highly beneficial for those ranches. One way to acquire funds for the recommended elk rent program could be to work with conservation organizations to lobby for the NER to use funds that would otherwise have gone to feed pellets for elk, which amount to over half a million dollars each year.

We believe that the results from our forage competition model demonstrate how valuable private ranching lands are to wildlife as they find a lot of valuable resources there. Lands that are extremely suitable for elk are also desirable for other species as well. This was already demonstrated when looking at the movement of grizzly bears in the areas which often relied on ranch land.[42] If megafauna, like elk and bears, actively use this land when humans are not interacting with their feeding habits, then those areas are worth protecting since large parts of the local economy is based on wildlife tourism. The financial impacts of wildlife living on private property have to be mitigated to protect wildlife. Otherwise, ranching is not sustainable and ranchers may take measures to prevent wildlife from using their property or leave, leading the land to be developed. Our financial results show that quarantine costs due to brucellosis would average less than $40,000.00 USD per year for all of Teton County and that forage competition would be just over $100,000.00 USD each year. This means that the impacts are reasonable and thus financial mitigation programs such as brucellosis compensation funds and elk rent programs could be introduced to Teton County. If the NER feedground were to close due to concerns about CWD, protecting the ranching community from those impacts can and should be done for both the benefit of ranchers and wildlife.

The other two areas of concerns that our public comment analysis identified were increased wolf depredation and property. There is limited anecdotal evidence that wolves follow elk to feedgrounds in the winter and in certain scenarios can displace them entirely to another winter feedground location.[43] Additionally if the NER feedground were to close, the number of elk that migrate through private land is expected to increase as the natural carrying capacity of the refuge is around 5000 elk and there are currently an average of 7500 elk on the refuge each winter.[5] Taking this information into account, certain stakeholders are worried that wolves will follow elk onto private lands where they are more likely to come in contact with livestocks leading to an increase in depredation. Due to limited data available and time constraints with this project, we were unable to help assess a potential change in livestock depredation from apex predators with NER feedground closure. However, we are confident that any change would not financially impact ranchers because Teton County is located in the Trophy Game Management Area of the state of Wyoming.[43] This area, managed by the WGFD, is the only area in the state where a compensation program for wolf depredation is already in place. According to data from 2021, the WGFD compensated 18 livestock producers $208,124 USD in that area.[32] Therefore, we did not attempt to calculate the changing costs related to wolf depredation. Lastly, migrating elk can cause damage to private property, primarily fences. Increased migration onto private lands can exacerbate that pressure; however, we did not take a deep-dive into the potential change in property damage because the WGFD is mandated to cover verified elk damage. Furthermore, the state is responsible for elk-proof fencing in strategic areas to minimize elk's distribution onto private property.[6] For these reasons, we also did not attempt to calculate the changing costs related to elk property damage.

Conclusion

Overall, this project was a huge accomplishment for our team and provided valuable information to our group project, PERC, and the GYE's ranching communities. The key findings of this project accomplished our main objective of investigating possible solutions and management techniques to create harmonious human-wildlife interactions for the ranching community, numerous interested stakeholders, and the Jackson elk herd.

Beginning with our Elk Feedground Public Comment Sentiment Analysis, it was concluded that while there is a large diversity of opinions and solutions when evaluating feedground management in Wyoming, many stakeholders suggested or indicated openness to voluntary elk occupancies as a tool to mitigate human-wildlife conflict. Through this analysis, we believe that there is ample opportunity for PERC to build relationships and collaborate with landowners, state agencies, and other stakeholders to find effective solutions to mitigate the risks of potential feedground closure and improve human-wildlife coexistence.

The Elk Feedground Public Comment Sentiment Analysis demonstrated that in order to create effective management strategies to mitigate conflict if a feedground were to close, we first needed to understand where elk could disperse on the landscape. Through our Jackson Herd Habitat Connectivity Model, we confirmed our assumptions that if feeding on the NER were to cease, then the elk herd would move onto low elevation private ranchlands and to other feedgrounds. This could have important implications to potentially increasing elk-to-cattle overlap, brucellosis transmission, and forage competition.

Understanding where this overlap could change provided insight into where brucellosis transmission could occur between elk and cattle. This became important in creating our Brucellosis Transmission Risk Model. Overall, risk to cattle was predicted to increase in the first few years after feeding ceases, meaning ranchers may have to quarantine and depopulate their cattle more often. However, these results also provide a sense of how those costs can be mitigated. A snapshot of transmission risk is incredibly useful for creating a starting point for the implementation of a brucellosis compensation fund in Teton County.

The calculation of an amount for this brucellosis compensation fund was completed through our Analysis of Financial Repercussions of Feedground Closure. Based on the results found in the Jackson Herd Habitat Connectivity Model and Brucellosis Transmission Risk Model, we were able to quantify the changing costs related to brucellosis and forage competition in the event of an NER feedground closure. It was concluded that the brucellosis costs are small on a yearly basis, but can cause a significant financial burden per case. Implementation of a brucellosis compensation fund is feasible and we recommend its application to Teton County in order to reduce tensions between stakeholders and lead to better conservation efforts within the community. The stakeholder sentiments analyzed in the Elk Feedground Public Comment Sentiment Analysis provide PERC with potential partners, such as government agencies and conservation organizations, to work with to create programs to mitigate any human-wildlife conflict. Our habitat connectivity model showed us that the Jackson elk herd would need to rely on private land as part of its new winter range if the feedground were to close or be phased out. We were able to calculate the increased costs of elk forage competition and estimate that it will lead to a yearly increase of just over

100,000 USD. These costs, while being more predictable and more evenly distributed, are still not insignificant to small ranching operations, which leads us to recommend the implementation of a second financial tool, an elk rent program. If both of these feasible programs are implemented, tensions between wildlife and ranchers will hopefully be lightened and these private lands that are undeniably valuable for biodiversity will be better protected.

This project took about a year to complete, and within that year, we were met with policy updates and changes that we had not anticipated at the beginning of the project. Namely, the updated Elk Feedground Management Plan from WGFD was published a few weeks before our deadline and after our Elk Feedground Public Comment Analysis had already been completed. As such, we had little time to thoroughly analyze the differences between the draft plan and final plan, but we still found valuable information in the comparison of the two plans. In addition, the Wyoming Game and Fish Commission voted on March 12, 2024 to approve the final plan.[44] This was met with disappointment from many conservation groups that felt this move would only uphold the status-quo of artificial feeding with no end in sight and increase the risk of CWD in the region.[45] On the other hand, private landowners expressed gratitude for their concerns being heard and that they look forward to further collaboration with WGFD.[46] WGFD's Elk Feedground Management plan has been in the works for years now, with plenty of updates and changes made in the past year alone. The NER's updated management plan is also expected to publish the draft of the Updated Bison and Elk Management Plan this year. With the amount of potential expected changes that this area may be subject to, we believe that our project has the potential to drive lasting collaborative conservation in Wyoming and the GYE.

While there were many components to this project, which tackles a complex system of (sometimes conflicting) social, ecological, and financial factors, the overall goal of managing human-wildlife interactions threads throughout. In this system, that management potential consistently comes back to the importance of private land. Elk rely on private land, particularly in their winter range, and this reliance will only increase if elk shift away from the NER and other feedgrounds with the reduction of feeding. Elk are valued by many stakeholders, including ranchers, but it can be difficult to reconcile the value elk have to the costs of providing the land to support them. It is unknown when, or even if, any feedgrounds may cease operation, but if they do, then this project has helped lay the groundwork to assess and mitigate the costs ranchers may face from brucellosis risk, forage competition, and other stressors. A brucellosis compensation fund would both support ranchers and give them the financial capacity to support elk habitat on their land in turn. There is strong potential for elk to coexist with private landowners without conflict and for private landowners to host elk without significant financial burden.

This project was extremely complex, and we are all so proud of our results and believe that they could have lasting impacts, not only within Wyoming, but across the GYE. These quantitative and qualitative results could be used to fully understand the risks and concerns associated with feedground closures for multiple stakeholder groups. With this information, we hope that PERC, state agencies, and other stakeholder groups are able to find ways to develop comprehensive and applicable solutions for those affected in Teton County and throughout Wyoming.

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Appendix

Appendix 1. Habitat Connectivity data description and metadata

Data Name and Type	Source	Description	Intended Use	Website Download
Climate Data				
Climate PRISM Raster *Geodatabase Raster*	NRCS GeoSpatialDataGateway Data from 1981-2010	30-yr precipitation and temperature data.	Resistance raster creation and habitat suitability comparison	https://datagateway.nrcs.usda.gov/GDGOrder.aspx?order=QuickState
Snow Stats *Geodatabase Raster*	USGS Published on June 7, 2021. Data from 2015-2020	30 m fractional snow covered area for the National Elk Refuge.	Resistance raster creation and habitat suitability comparison	https://www.sciencebase.gov/catalog/item/60be858ed34e86b938912245
WorldClim 2: new 1km spatial resolution climate surfaces for global land areas *GeoTIFF*	Fick, S.E. and R.J. Hijmans Published in 2017	Monthly climate data for temperature, precipitation, solar radiation, wind speed, water vapor pressure, and total precipitation from 1970-2000.	Habitat suitability map creation	https://worldclim.org/

Data Name and Type	Source	Description	Intended Use	Website Download
Land Cover Data				
Anthropogenic Disturbance *Geodatabase*	Wyoming Game and Fish Department - Nongame Department, The Nature Conservancy	Impacts of human development like oil and gas pipelines, agricultural land, power lines, roads, and residential	Resistance raster creation	https://geodata.geospatialhub.org/metadata/AnthropogenicDisturbance30m.xml

	Published in 2010	development. Data is from methodology in Copeland et al. 2017.		
USGS National Boundary Dataset (NBD) in Wyoming *Shapefile*	USGS ScienceBase-Catalog Published in 2023	Boundaries for the state of Wyoming and its counties. Also includes territory boundaries.	Fundamental characteristics for the creation of elk habitat suitability maps.	https://www.sciencebase.gov/catalog/item/59fa9f67e4b0531197affb79
TIGER/Line Shapefile, 2016, state, Wyoming, Current County Subdivision State-based *Shapefile*	US Census Bureau Published in 2021	Boundaries for the state of Wyoming and its counties based on 2016 census data.	Fundamental characteristics for the creation of elk habitat suitability maps.	https://catalog.data.gov/dataset/tiger-line-shapefile-2016-state-wyoming-current-county-subdivision-state-based
TIGER/Line Shapefile, Current, State, Wyoming, Place *Shapefile*	US Census Bureau Published in 2021	Parcels of incorporated areas in Wyoming from 2016 census data.	Fundamental characteristics for the creation of elk habitat suitability maps.	https://catalog.data.gov/dataset/tiger-line-shapefile-current-state-wyoming-place
TIGER/Line Shapefile, 2022, State, Wyoming, Primary and Secondary Roads *Shapefile*	US Census Bureau Published in 2021	Roads and highways in Wyoming from 2016 data.	Resistance raster creation	https://catalog.data.gov/dataset/tiger-line-shapefile-2022-state-wyoming-primary-and-secondary-roads
USGS National Transportation Dataset (NTD) for Wyoming *Shapefile*	USGS ScienceBase-Catalog Published in 2023	Wyoming's roads, railways, and airports.	Resistance raster creation	https://www.sciencebase.gov/catalog/item/5a61c942e4b06e28e9c3bddc

GAP/LANDFIRE National Terrestrial Ecosystems 2011 data *GeoTIFF*	USGS Gap Analysis Project Published in 2019.	Wyoming land cover data based on forest type, vegetation, development, water, and human use based on 2011 landsat data.	Resistance raster creation	https://www.usgs.gov/programs/gap-analysis-project/science/land-cover-data-download
National Land Cover Dataset (NLCD) *GeoTIFF*	USGS, Multi-Resolution Land Characteristic Consortium Multiple datasets published in different years.	Wyoming land use and land cover data from 2019.	Resistance raster creation	https://www.mrlc.gov/data?f%5B0%5D=year%3A2022
Conterminous United States Land Cover Projections - 1992 to 2100 *GeoTIFF*	USGS Published in 2018	Land use and land cover projections for the conterminous United States from 1992-2100 based on the USGS's FORE-SCE model	Habitat suitability map creation and future projections	https://www.sciencebase.gov/catalog/item/5b96c2f9e4b0702d0e826f6d

Data Name and Type	Source	Description	Intended Use	Website Download
Elevation Data				
Digital Elevation Model for Wyoming at 90m *Shapefile*	Wyoming GIS Center Published in 1997	Elevation data for the state of Wyoming.	Resistance raster creation	https://uwyo.maps.arcgis.com/sharing/rest/content/items/93f5bf3f057a44c2a8c299c29d0410da/info/metadata/metadata.xml?format=default&output=html

Data Name and Type	**Source**	**Description**	**Intended Use**	**Website Download**
		Elk Data		
Elk Feedgrounds - 2003 for Wyoming at 1:100,000 *Shapefile*	WGFD Published in 200.	Point locations of Wyoming elk feedgrounds.	Elk core habitat identification and general map features	https://wgfd.wyo.gov/Wildlife-in-Wyoming/Geospatial-Data/Big-Game-GIS-Data
Elk Migration Barriers - 2005 for Wyoming at 1:100,000 *Shapefile*	WGFD Published in 2005	Statewide migration barriers for elk, including severity of threat to migration routes.	Resistance raster creation	https://wgfd.wyo.gov/Wildlife-in-Wyoming/Geospatial-Data/Big-Game-GIS-Data
Elk Seasonal Range Boundaries - 2018 for Wyoming at 1:100,000 *Shapefile*	WGFD Published in 2018	Wyoming elk seasonal range boundaries, depicting lands that are important in each season for certain biological processes within a herd unit. Includes crucial range boundaries.	Elk core habitat identification	https://wgfd.wyo.gov/Wildlife-in-Wyoming/Geospatial-Data/Big-Game-GIS-Data
Elk Parturition Areas - 2018 for Wyoming at 1:100,000 *Shapefile*	WGFD Published in 2018	Wyoming elk parturition areas: areas with seasonally high concentrations of birthing animals.	Elk core habitat identification	https://wgfd.wyo.gov/Wildlife-in-Wyoming/Geospatial-Data/Big-Game-GIS-Data
Elk Hunt Area Boundaries - 2022 for Wyoming at 1:100,000 *Shapefile*	WGFD Published in 2022	Wyoming elk hunt area and herd unit boundaries.	Elk core habitat identification and general map boundaries	https://wgfd.wyo.gov/Wildlife-in-Wyoming/Geospatial-Data/Big-Game-GIS-Data
Remotely sensed elk locations on the National Elk Refuge, Wyoming,	Northern Rocky Mountain Science Center, USGS (Graves, T. and others)	Remotely sensed elk locations in the NER from 2017-2019.	Habitat suitability map creation and elk core habitat identification	https://www.sciencebase.gov/catalog/item/61533df9d34e0df5fb9c5c6c

2017-2019 *Tabular digital data*	Published in 2021			
Migration Routes of Elk in the Jackson Herd in Wyoming *Shapefile*	USGS (Courtemanch, A., Cole, E., and Dewey, S.) Published in 2020	Jackson elk migration routes, developed from the GPS locations of 247 elk collected every 2-8 hours from 2006-2018.	Resistance raster creation and habitat suitability comparison	https://www.sciencebase.gov/catalog/item/5f8db61982ce32418791d56d
GBIF Occurrence Download *Tabular digital data*	GBIF.org Published between 1995-2023 Downloaded 2023.	Human observations of elk throughout Wyoming.	Habitat suitability map creation and elk core habitat identification	https://doi.org/10.15468/dl.9nmgsw

Data Name and Type	**Source**	**Description**	**Intended Use**	**Website Download**
Cattle Data				
Bureau of Land Management (BLM) National Grazing Allotments *Shapefile* *Vector*	US Department of the Interior Last updated September 15, 2023.	Land designated and managed for livestock grazing. Allotments include private and public land.	Identify potential overlap between areas where elk migrate and cattle graze.	https://gbp-blm-egis.hub.arcgis.com/datasets/BLM-EGIS::blm-natl-grazing-allotment-polygons/explore?location=44.295813%2C-108.934229%2C7.92
BLM Surface Management Agency Boundaries *Shapefile* *Vector*	US Department of the Interior Published in 2022	Depicts surface management across Wyoming; delineates the boundaries of each federal agency's management area	Will aid in understanding which agencies control the land that elk may migrate to.	https://gis.blm.gov/arcgis/rest/services/lands/BLM_Natl_SMA_Cached_with_PriUnk/MapServer

Global Cattle Distribution *GeoTIFF*	Harvard Dataverse Published in 2015	The global distribution of cattle in total number of cattle per pixel.	Be able to map where cattle are located in Wyoming. This will inform the potential overlap of cattle and elk.	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/LHBICE
State Land Grazing Leases *Shapefile*	Wyoming Office of State Lands and Investments Published in February 2023	State land assets and leases, such as state land public access info, restrictions and closures on state land, and state surface and subsurface ownership.	More data on public grazing leases and where elk may overlap with cattle.	https://gis2.statelands.wyo.gov/portal/apps/webappviewer/index.html?id=b8051ebac03744f7835331ae8afc01e5
United States Forest Service (USFS) Grazing Allotments for Wyoming *Shapefile*	USFS, National Integrated Land System (NILS) Published November 15, 2019	Grazing range allotments provided by USFS in Wyoming state forests for cattle.	Data on USFS grazing leases, where elk may overlap with cattle.	https://hub.arcgis.com/datasets/48d3b953b7e941d4a575beacef62bcb5_0/explore

Appendix 2. Instructions for creating a habitat connectivity model.

Habitat Connectivity Instructions				
Resistance Raster Composition				
Data Name	**File Name**	**Year**	**Website**	**Notes (if applicable)**
National Elk Refuge	FWSInterestSimplified.shp	2018	Koordinates Website - Information from National Park Service	
Roads	tl_2023_56001 to tl_2023_56045.shp	2023	Census Bureau	"This includes all primary, secondary, local neighborhood, and rural roads, city streets,

				vehicular trails (4wd), ramps, service drives, alleys, parking lot roads, private roads for service vehicles (logging, oil fields, ranches, etc.), bike paths or trails, bridle/horse paths, walkways/pedestrian trails, and stairways.” See abbreviation_info_for_r… for information on what MTFCC stands for and other data information
Conservation Easements	NCED_Polygons_07282023/.shp	2023	NCED (where to download data) Here can find detailed information about each polygon/conservation easement	“ranking system to characterize protection level (1 = managed for biodiversity and natural disturbances are permitted, 2 = managed for biodiversity, but natural disturbances are suppressed, 3 = managed for multiple use and extraction is permitted, 4 = protected but no known mandate for biodiversity protection)” This is categorized under ‘gapcat’ in the layer's Attribute Table
Protected Areas	PADUS2_1WDPASchemaMetadataV1_1.shp	2021	USGS - Download data here Map of data	“ranking system to characterize protection level (1 = managed for biodiversity and natural disturbances are permitted, 2 = managed for biodiversity, but natural disturbances are suppressed, 3 = managed for multiple use and extraction is permitted, 4 = protected but no known mandate for biodiversity protection)” This is categorized under ‘GAP_Sts’ in the Attribute Table

Oil and Gas	WSGS_OilGas_Fields_2023_AllAttributes.shp	2023	Wyoming State Geological Survey	This layer gives locations to both gas and oil wells and fields.
Grazing Allotments	BLM_Natl_Grazing_Allotment_Polygons.shp	2024	Bureau of Land Management Map	
Elevation	usgs_merged_30m.tif	2011	USGS	Resolution = 30m
Land Use	nlcd_wy_utm13.tif	2021	MRLC	See what each number stands for here NLCDclasses.pdf
Jackson Zoning	toj_zoning.shp	2020	Teton County	
Other Necessary Data				
Data Name	**File Name**	**Year**	**Website**	**Notes (if applicable)**
Elk Crucial Ranges	ElkCrucialRange.shp	2018	WGFD	
Jackson Herd Migrations	Elk_WY_Jackson_Routes_Ver1_2019.shp	2019	USGS	
Feedground Locations	FWSInterest_Simplified.shp	2011	WGFD	
Wyoming Counties	GU_CountyOrEquivalent.shp	2024	USGS	
Wyoming Land Ownership Parcels	Wyoming_Parcels.shp	2022		

Low Resistance Steps

1. **Add all data listed above into the map**
2. **Manipulate layers if needed:**
    a. Counties
        i. Since the Jackson herd will mostly likely move into nearby counties, we will clip to Teton, Sublette, Lincoln and Fremont (not evaluating Fremont but having the extra area will aid in running circuitscape) counties
        ii. Add in the data file 'GU_CountyOrEquivalent'
            1. Right click on the layer and choose 'Select Features'

2. Hold down the shift button and choose the four counties, then in the data tab on the top of the screen click 'Layer from Selection'
3. The four counties should now be in their own layer titled 'GU_CountyOrEquivalent selection'
4. Rename to 'teton_sublette_lincoln'

b. Crucial Ranges
   i. Add in the data file 'ElkCrucialRange'
      1. This file contains what WGFD defines as crucial ranges for the elk, including feedgrounds
   ii. This file will also need to be clipped to the counties extent
   iii. Following similar steps when selecting the county, only select the crucial areas within the county shapefile (make sure these are only the crucial areas within the Teton, Sublette and Lincoln counties). Then 'Layer from Selection'
   iv. The crucial ranges are currently individual polygons, but need to dissolve the boundaries between connecting polygons in order to provide some clarification when running circuitscape in the next steps.
      1. Use the tool 'Dissolve Boundaries'
         a. 'Input features' = 'ElkCrucialRange selection'
         b. 'Output Feature Class' = 'ElkCrucialRangeselection_DissolveBoundaries'
         c. Under 'Field' choose 'UNIT' and 'Statistic' choose 'Count'
         d. Run - now there should be now boundaries between the connected crucial ranges
   v. Now need to add another attribute column in order to allow circuitscape to run properly (this will be helpful for later)
      1. Go to the attribute table
      2. Next to 'Field:' select 'Add'
         a. Type in the 'Field Name' as 'COREID'
         b. Under 'Number Format' select 'Numeric'
         c. Click save and you should be redirected back to the attribute table
         d. Now we need to fill in those values
            i. Highlight the new column and click 'Calculate'
            ii. You will now choose it by 'OBJECTID' as this will create the pathways to each crucial area
            iii. Click 'Save'

c. Roads:
   i. Merge roads into one shapefile
      1. Search for 'Merge' tool
      2. Add all road shapefiles into the 'Input Datasets'
      3. Rename the 'Output Dataset' to wyoming_all_roads
      4. Make sure 'MTFCC' is included in the 'Output Fields'
      5. Run
   ii. Clip to the counties

1. Using the ‘Clip Layer’ tool
    a. Input layer: wyoming_all_roads
    b. Clip layer: ‘teton_sublette_lincoln’
    c. Rename layer: teton_sublette_lincoln_roads

iii. Buffer roads
1. This is to create a 100 meter buffer on either side of the roads. Most likely, elk will keep some distance away from people, cars, traffic, etc. This buffer is to take that into account.
2. Search for ‘Buffer’ tool
3. Enter teton_sublette_lincoln_roads into the ‘Input Features’
4. Rename the ‘Output Feature Class’ to teton_sublette_lincoln_roads_100m_buffer
5. ‘Distance’ enter 100 and under right dropdown select ‘meters’
6. Leave all other fields in their preset setting
7. Run

d. Conservation Easement
   i. Since this layer is for the entire country, need to select the conservation easements located in our three counties.
      1. Use ‘Clip Layer’ tool
         a. Input Layer: NCED_Polygons_07282023
         b. Clip Layer: ‘teton_sublette_lincoln’
         c. Output layer: county_conservation_easements

e. Protected Areas
   i. This layer contains information for the entire world, so it needs to be cut down to our three counties
   ii. Use ‘Clip Layer’ tool
      1. Input Layer: PADUS2_1WDPASchemaMetadataV1_1
      2. Clip Layer: ‘teton_sublette_lincoln’
      3. Output layer: county_protected_areas

f. Oil and Gas
   i. Clip to the counties
      1. Use ‘Clip Layer’ tool
         a. Input Layer: WSGS_OilGas_Fields_2023_AllAttributes
         b. Clip Layer: teton_sublette_lincoln
         c. Output layer: county_oil_gas

g. Grazing Allotments
   i. This is layer contains national grazing allotments, so needs to be cut down to the counties
   ii. Use ‘Clip Layer’ tool
      1. Input Layer: BLM_Natl_Grazing_Allotment_Polygons
      2. Clip Layer: teton_sublette_lincoln
      3. Output layer: county_grazing_allotment

h. Elevation Clip
   i. Clip to three counties

ii. Use ‘Clip Layer’ tool
   1. Input Layer: usgs_merged_30m
   2. Clip Layer: teton_sublette_lincoln
   3. Output layer: county_elevation

i. Land Use
   i. Clip to three counties
   ii. Use ‘Clip Layer’ tool
      1. Input Layer: nlcd_wy_utm13
      2. Clip Layer: teton_sublette_lincoln
      3. Output layer: county_land_use

3. Convert shapefiles into raster layers and reproject to correct cell size/projected coordinate area

a. NER
   i. Search for ‘Polygon to Raster’
   ii. Enter FWSInterestSimplified.shp layer into ‘Input features’
   iii. Rename ‘Output Feature’ to NER_raster
   iv. Change ‘Cell Size’ to 500
   v. Run
   vi. Once changed to a raster, check the cell size and projected coordinate area
      1. This can be done by right clicking on the raster layer, clicking ‘Properties’, going to ‘Source’ and
      2. For Projected Coordinate Area, go to ‘Spatial Reference’
         a. In WGS 1984
      3. For cell size, go to ‘Raster Information’
         a. 500x500 meters
      4. Change the coordinate system and cell size so that it matches that of the crucial areas
         a. Use tool ‘Project Raster’
         b. Input raster: ‘ ner_raster’
         c. Output Raster Dataset: ‘ner_raster_reprojected’
         d. Output Coordinate System: ‘crucial areas’
            i. Wylam should appear after choosing this data layer
         e. Change cell size to 90 x 90
         f. Run

b. Roads
   i. Search for ‘Polygon to Raster’
   ii. Enter teton_sublette_lincoln_roads_100m_buffer layer into ‘Input features’
   iii. For ‘Field’ dropdown select ‘MTFCC’ as this is what presents the code for the type of road present within the Attribute Table
   iv. Change ‘Cell Assignment Type’ to ‘Maximum Area’
   v. Cell Size: 0.001
   vi. Rename ‘Output Feature’ to roads_raster
   vii. Leave all other fields in preset setting

    viii. Run
    ix. Check the cell size and projected coordinate area
        1. This can be done by right clicking on the raster layer, clicking 'Properties', going to 'Source' and
        2. For Geographic Coordinate System, go to 'Spatial Reference'
            a. In Geographic Coordinate System: NAD 1983
        3. For cell size, go to 'Raster Information'
            a. 0.001 x 0.001
        4. Change the coordinate system and cell size so that it matches that of the crucial areas
            a. Use tool 'Project Raster'
            b. Input raster: ' roads_raster'
            c. Output Raster Dataset: 'roads_raster_reprojected'
            d. Output Coordinate System: 'crucial areas'
                i. Wylam should appear after choosing this data layer
            e. Change cell size to 90 x 90
            f. Run
c. Conservation Easements
    i. Use 'Polygon to Raster' tool
    ii. Enter county_conservation_easements layer into 'Input features'
    iii. For 'Field' dropdown select 'gapcat' as this is what is used to classify the protection level of the conservation easements
    iv. Rename 'Output Feature' to conservation_easements_raster
    v. Change 'Cell Size' to 500
    vi. Leave all other fields in preset setting
    vii. Run
    viii. Check the cell size and projected coordinate area
        1. This can be done by right clicking on the raster layer, clicking 'Properties', going to 'Source' and
        2. For Projected Coordinate Area, go to 'Spatial Reference'
            a. USA Contiguous Albers Equal Area Conic USG
        3. For cell size, go to 'Raster Information'
            a. 500 x 500
        4. Change the coordinate system and cell size so that it matches that of the crucial areas
            a. Use tool 'Project Raster'
            b. Input raster: 'conservation_easements_raster'
            c. Output Raster Dataset: 'conservation_easements_raster_reprojected'
            d. Output Coordinate System: 'crucial areas'
                i. Wylam should appear after choosing this data layer
            e. Change cell size to 90 x 90
            f. Run
d. Protected Areas

i. Use ‘Polygon to Raster’ tool
ii. Enter county_protected_areas selection layer into ‘Input features’
iii. For ‘Field’ dropdown select ‘GAP_Sts’ as this is what is used to classify the protection level of the protected areas
iv. Change ‘Cell Size’ to 2000 in order to capture the small features within the layer
v. Rename ‘Output Feature’ to protected_areas_raster
vi. Check the cell size and projected coordinate area
    1. This can be done by right clicking on the raster layer, clicking ‘Properties’, going to ‘Source’ and
    2. For Projected Coordinate Area, go to ‘Spatial Reference’
        a. WGS 1984 Web Mercator (auxiliary sphere)
    3. For cell size, go to ‘Raster Information’
        a. 2000 x 2000
    4. Change the coordinate system and cell size so that it matches that of the crucial areas
        a. Use tool ‘Project Raster’
        b. Input raster: ‘protected_areas_raster’
        c. Output Raster Dataset: ‘protected_areas_raster_reprojected’
        d. Output Coordinate System: ‘crucial areas’
            i. Wylam should appear after choosing this data layer
        e. Change cell size to 90 x 90
        f. Run

e. Oil and Gas
    i. Use ‘Polygon to Raster’ tool
    ii. Enter county_oil_gas layer into ‘Input features’
    iii. For ‘Field’ dropdown select ‘FIELD_TYPE’ as this will distinguish between oil and gas through the abbreviation ‘O’ or ‘G’
    iv. Rename ‘Output Feature’ to oil_gas_raster
    v. Change ‘Cell Size’ to 500
    vi. Leave all other fields in preset setting
    vii. Run
    viii. Check the cell size and projected coordinate area
        1. This can be done by right clicking on the raster layer, clicking ‘Properties’, going to ‘Source’ and
        2. For Projected Coordinate Area, go to ‘Spatial Reference’
            a. WGS 1984 Web Mercator (auxiliary sphere)
        3. For cell size, go to ‘Raster Information’
            a. 500 x 500
        4. Change the coordinate system and cell size so that it matches that of the crucial areas
            a. Use tool ‘Project Raster’
            b. Input raster: ‘oil_gas_raster’
            c. Output Raster Dataset: ‘oil_gas_raster_reprojected’
            d. Output Coordinate System: ‘crucial areas’

                i. Wylam should appear after choosing this data layer
            e. Change cell size to 90 x 90
            f. Run

f. Grazing Allotments
    i. Use ‘Polygon to Raster’ tool
    ii. Enter county_grazing_allotments layer into ‘Input features’
    iii. For ‘Field’ dropdown select ‘ADMIN_ST’ as this layer will not need to be reclassified based off of a specific description in the attribute table
    iv. Rename ‘Output Feature’ to grazing_allotment_raster
    v. Change ‘Cell Size’ to 500
    vi. Leave all other fields in preset setting
    vii. Run
    viii. Check the cell size and projected coordinate area
        1. This can be done by right clicking on the raster layer, clicking ‘Properties’, going to ‘Source’ and
        2. For Geographic Coordinate System, go to ‘Spatial Reference’
            a. In Geographic Coordinate System: NAD 1983
        3. For cell size, go to ‘Raster Information’
            a. 0.007999 x 0.007999
        4. Change the coordinate system and cell size so that it matches that of the crucial areas
            a. Use tool ‘Project Raster’
            b. Input raster: ‘grazing_allotment_raster’
            c. Output Raster Dataset: ‘grazing_allotment_raster_reprojected’
            d. Output Coordinate System: ‘crucial areas’
                i. Wylam should appear after choosing this data layer
            e. Change cell size to 90 x 90
            f. Run

g. Jackson
    i. Use ‘Polygon to Raster’ tool
        1. Enter toj_zoning layer into ‘Input features’
        2. For ‘Field’ dropdown select ‘zoning’
        3. Rename ‘Output Feature’ to jackson_raster
        4. Change ‘Cell Size’ to 90
        5. Leave all other fields in preset setting
        6. Run
    ii. Check the cell size and projected coordinate area
        1. This can be done by right clicking on the raster layer, clicking ‘Properties’, going to ‘Source’ and
        2. For Projected Coordinate System, go to ‘Spatial Reference’
            a. In Projected Coordinate System: NAD 1983
        3. For cell size, go to ‘Raster Information’
            a. 90 x 90 (but it is feet and need it in meters)

4. Change the coordinate system and cell size so that it matches that of the crucial areas
    a. Use tool ‘Project Raster’
    b. Input raster: ‘jackson_raster’
    c. Output Raster Dataset: ‘jackson_raster_reprojected’
    d. Output Coordinate System: ‘crucial areas’
        i. Wylam should appear after choosing this data layer
    e. Change cell size to 90 x 90
    f. Run

h. Elevation
    i. This is already a raster
    ii. Check the cell size and projected coordinate area
        1. This can be done by right clicking on the raster layer, clicking ‘Properties’, going to ‘Source’ and
        2. For Projected Coordinate Area, go to ‘Spatial Reference’
            a. NAD_1983_Lambert_Conformal_Conic
        3. For cell size, go to ‘Raster Information’
            a. 152.253… x 152.253…
        4. Change the coordinate system and cell size so that it matches that of the crucial areas
            a. Use tool ‘Project Raster’
            b. Input raster: ‘county_elevation’
            c. Output Raster Dataset: ‘elevation_raster_reprojected’
            d. Output Coordinate System: ‘crucial areas’
                i. Wylam should appear after choosing this data layer
            e. Change cell size to 90 x 90
            f. Run

i. Land Cover
    i. This is already a raster
    ii. Check the cell size and projected coordinate area
        1. This can be done by right clicking on the raster layer, clicking ‘Properties’, going to ‘Source’ and
        2. For Projected Coordinate Area, go to ‘Spatial Reference’
            a. NAD 1983 UTM Zone 13N
        3. For cell size, go to ‘Raster Information’
            a. 30 x 30
        4. Change the coordinate system and cell size so that it matches that of the crucial areas
            a. Use tool ‘Project Raster’
            b. Input raster: ‘county_land_use’
            c. Output Raster Dataset: ‘land_cover_raster_reprojected’
            d. Output Coordinate System: ‘crucial areas’
                i. Wylam should appear after choosing this data layer
            e. Change cell size to 90 x 90

f. Run

j. All layers should now be rasters, clipped to the crucial ranges, in wylam projected coordinate system and have a cell size of 90 x 90

4. Reclassify all raster layers to a scale of 1-100 for low resistance map

a. In Geoprocessing Toolbar search 'Reclassify (Spatial Analyst Tool)'
    i. This is the tool that will be used throughout this portion of the project

b. NER
    i. In the 'Input raster' choose 'ner_raste_reprojected'
    ii. Under 'Reclass field' choose 'VALUE' as this is the attribute that will be used to assign different resistance values to
    iii. A table should appear with the VALUE values under the 'Value' column and values will appear under the 'New' column
        1. 735 = 15
    iv. In 'Output raster' rename the layer to ner_reclassified_low
    v. Run

c. Roads:
    i. In the 'Input raster' choose 'roads_raster_reprojected'
    ii. Under 'Reclass field' choose 'MTFCC' as this is the attribute that will be used to assign different resistance values to
    iii. A table should appear with the MTFCC values under the 'Value' column and values will appear under the 'New' column
        1. S1200 - secondary roads (US highway, state highway, county highway systems) - value = 85
        2. S1400 - local neighborhood road, rural road, city street = 30
        3. S1500 - vehicular trail (4WD) = 5
        4. S1740 - private road for service vehicles (logging, oil fields, ranches) = 55
        5. S1750 - Internal US Census Bureau use = 85
        6. S1100 - primary roads (interstate highways) = 85
        7. S1730 - Alley = 85
        8. S1630 - ramp (controlled access from road to highway) = 85
        9. S1640 - service drive (usually along primary roads) = 55
        10. S1710 - walkway/pedestrian trail = 5
        11. S1820 - bike path/trail = 5
        12. S1780 - parking lot road = 85
    iv. In 'Output raster' rename the layer to roads_reclassified_low
    v. Run

d. Conservation Easements
    i. In the 'Input raster' choose 'conservation_easement_raster_reprojected'
    ii. Under 'Reclass field' choose 'gapcat' as this is the attribute that will be used to assign different resistance values to
    iii. A table should appear with the gapcat values under the 'Value' column and values will appear under the 'New' column

        1. 1 - managed for biodiversity and natural disturbances are permitted = 25
        2. 2 - managed for biodiversity, but natural disturbances are suppressed = 50
        3. 3 - managed for multiple use and extraction is permitted = 75
        4. 4 - protected but no known mandate for biodiversity protection = 25
    iv. In 'Output raster' rename the layer to conservation_easements_reclassified_low
    v. Run
e. Protected Areas
    i. In the 'Input raster' choose 'protected_areas_raster_reprojected'
    ii. Under 'Reclass field' choose 'GAP_Sts' as this is the attribute that will be used to assign different resistance values to
    iii. A table should appear with the GAP_Sts values under the 'Value' column and values will appear under the 'New' column
        1. 1 - managed for biodiversity and natural disturbances are permitted = 25
        2. 2 - managed for biodiversity, but natural disturbances are suppressed = 50
        3. 3 - managed for multiple use and extraction is permitted = 75
        4. 4 - protected but no known mandate for biodiversity protection = 25
    iv. In 'Output raster' rename the layer to protected_areas_reclassified_low
    v. Run
f. Grazing Allotments
    i. In the 'Input raster' choose 'grazing_allotment_raster_reprojected'
    ii. Under 'Reclass field' choose 'Value' as there is only one type of reclassification value for this layer
    iii. A table should appear with the one value under the 'Value' column and under the 'New' column
        1. 1 = 25
    iv. In 'Output raster' rename the layer to grazing_allotments_reclassified_low
    v. Run
g. Oil and Gas
    i. In the 'Input raster' choose 'oil_gas_raster_reprojected'
    ii. Under 'Reclass field' choose 'FIELD_TYPE' as this is the attribute that will be used to assign different resistance values to
    iii. A table should appear with the FIELD_TYPE values under the 'Value' column and values will appear under the 'New' column
        1. O = 95
        2. G = 95
    iv. In 'Output raster' rename the layer to oil_gas_reclassified_low
    v. Run
h. Elevation
    i. In the 'Input raster' choose 'elevation_raster_reprojected'
    ii. Under 'Reclass field', 'VALUE' should immediately be populated

iii. A table should appear but there will be no values within it, so click ‘Classify’ and a table should pop-up in the middle of the screen. We only want two classes since elevation should only affect elk when it is greater than 2500 meters.
   1. Change ‘Classes’ to 3
      a. Then in the table itself change to these three upper bound elevation numbers (meters)
         i. ‘< 2000’
         ii. ‘<2200’
         iii. Then leave the upper value as is (should be 4112
   2. Hit ‘Okay’
   3. The reclassification table should not have these updated values within it. Reclassify:
      a. 1716 to 2000 = 1
      b. 2000 to 2200 = 15
      c. 2200 to 4112 = 75

iv. In ‘Output raster’ rename the layer to elevation_reclassified_low

v. Run

i. Land Use
   i. In the ‘Input raster’ choose ‘land_use_raster_reprojected’
   ii. Under ‘Reclass field’ choose ‘NLCD_Land’ as this is the attribute that will be used to assign different resistance values to
   iii. A table should appear with the NLCD_Land type under the ‘Value’ column and values will appear under the ‘New’ column
      1. Open water = 50
      2. Perennial snow/ice = 25
      3. Developed, open space = 25
      4. Developed, low intensity = 30
      5. Developed, medium intensity = 55
      6. Developed, high intensity = 85
      7. Barren land = 5
      8. Deciduous forest = 5
      9. Evergreen forest = 5
      10. Mixed forest = 5
      11. Shrub/scrub = 5
      12. Herbaceous = 5
      13. Hay/pasture = 25
      14. Cultivated crops = 25
      15. Woody wetlands = 5
      16. Emergent herbaceous wetlands = 5
   iv. In ‘Output raster’ rename the layer to land_use_reclassified_low
   v. Run

j. Jackson
   i. In the ‘Input raster’ choose ‘jackson_raster_reprojected’

ii. Under 'Reclass field' choose 'zoning' as this is the attribute that will be used to assign different resistance values to
iii. A table should appear with the zoning type under the 'Value' column and values will appear under the 'New' column
    1. All zones will be assigned a value of 95
iv. In 'Output raster' rename the layer to jackson_reclassified_low
v. Run

5. Merge all low resistance reclassified rasters into one layer

a. Use the tool 'Mosaic to New Raster'
    i. https://pro.arcgis.com/en/pro-app/latest/tool-reference/data-management/mosaic-to-new-raster.htm
b. Under 'Input Raster' enter all layers with ending _reclassified_low
    i. Should be 9 layers total
c. For 'Output Location' make sure that it is in the project files folder and that the .gdb is within that file name
d. 'Raster Dataset Name with Extension' write 'combined_rasters_low'
e. Under the 'Spatial Reference for Raster' choose the crucial areas
f. Change 'Pixel Type' to '8 bit unsigned'
g. 'Cellsize' = 90
h. 'Number of Bands' write 1
i. Where it says 'Mosaic Operator'. Choose 'Blend'
j. Run

6. Run Circuitscape for low resistance

a. Now to run Circuitscape
    i. Search for the tool 'Build Network and Map Linkages' under the Linkage Mapper toolbox
        1. This will create the least cost paths between the crucial ranges
        2. In 'Project Directory' enter where your project is saved to
            a. I recommend making a folder under your main project directory titled 'lowresoutput' (no underscores/spaces because Circuitscape gets mad)
        3. 'Core Area Feature Class' = 'ElkCrucialRangeselection_DissolveBoundaries'
        4. 'Core Area Field Name' = 'COREID'
        5. 'Resistance Raster' = combined_rasters_low
        6. Change 'Truncate Cost-Weighted Distance Threshold' to 20,000
        7. Leave all other fields the way it is
        8. Run!
    ii. Now to get pinchpoints – search for the tool 'Pinchpoint Mapper'
        1. In 'Project Directory' enter where your project is saved to
            a. Use the same project location as you did for linkage mapper
        2. 'Core Area Feature Class' = 'ElkCrucialRangeselection_DissolveBoundaries'

3. 'Core Area Field Name' = 'COREID' 4. 'Resistance Raster' = combined_rasters_low 5. 'CWD cutoff distance' = 1000000 6. Leave all other fields the way it is 7. Run!
Now re-run for medium and high resistance maps, following the resistance values below (Appendix 3).

Appendix 3. Reclassified raster values.

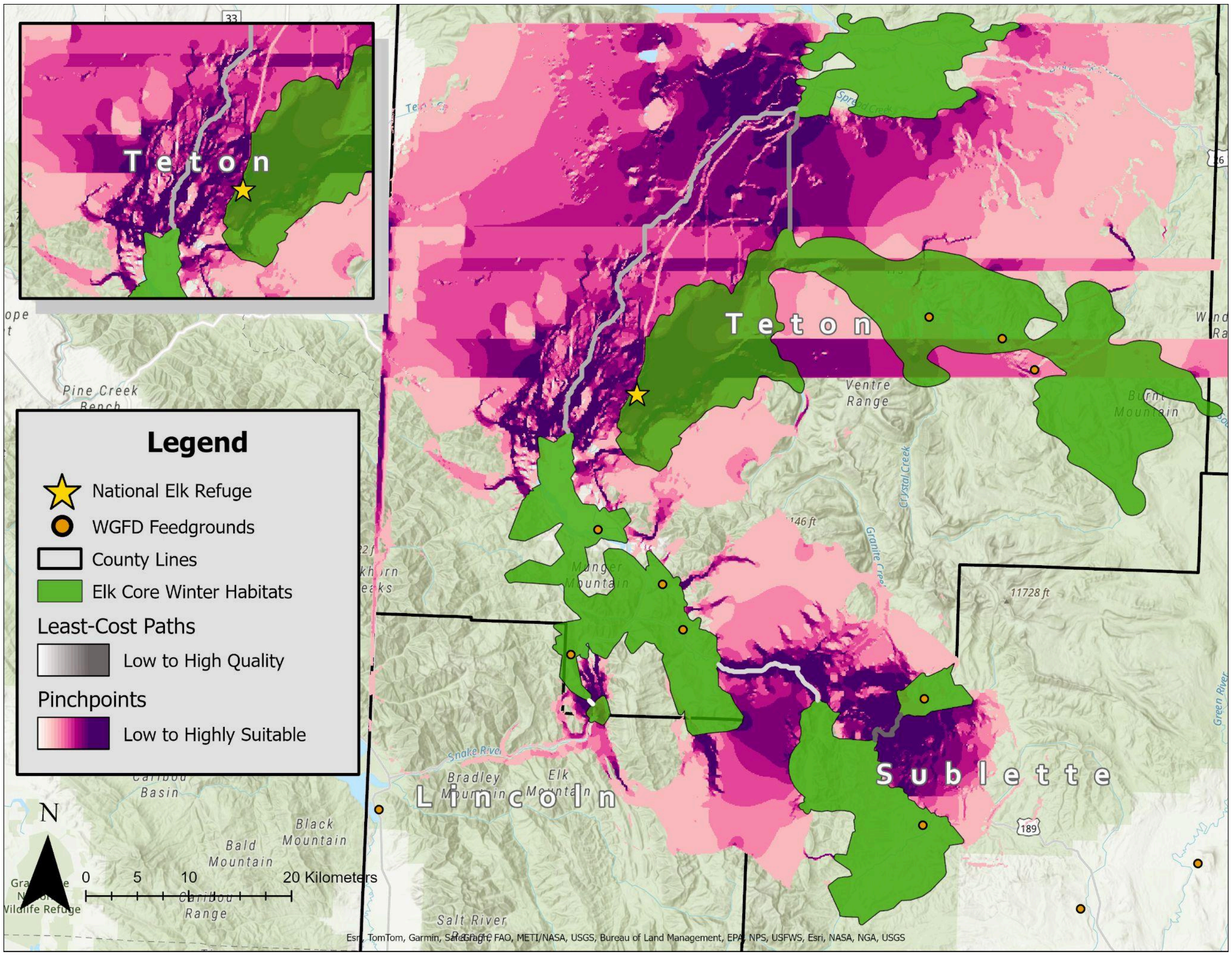
Resistance Values				
Raster Layer	**Layer Information**	**Low Resistance Map Raster Values**	**Medium Resistance Map Raster Values**	**High Resistance Map Raster Value**
National Elk Refuge	NER feedground	15	15	15
National Land Cover Data	Barren land	5	5	5
	Deciduous forest	5	5	5
	Mixed forest	5	5	5
	Shrub	5	5	5
	Herbaceous, woody wetland	5	5	5
	Emergent herbaceous woodland	5	5	5
	Perennial snow/ice	25	50	75
	Hay/pasture	25	50	75
	Cultivated crops	25	50	75
	Open water	50	50	50
	Developed, open space	25	50	75

	Developed, low intensity	30	40	50
	Developed, medium intensity	55	65	75
	Developed, high intensity	85	90	95
USGS Elevation 30m	1716 to 2000 meters	1	1	1
	2000 to 2200 meters	15	15	15
	2200 to 4112 meters	75	85	95
Roads	S1500 - vehicular trails (4WD)	5	15	25
	S1710 - walkway/pedestrian trail	5	15	25
	S1820 - bike path/trail	5	15	25
	S1400 - local neighborhood road, rural road, city street	30	40	50
	S1640 - service drive (usually along primary roads)	55	65	75
	S1740 - private road for service vehicles (logging, oil fields, ranches)	55	65	75
	S1100 - primary roads (interstate	85	90	95

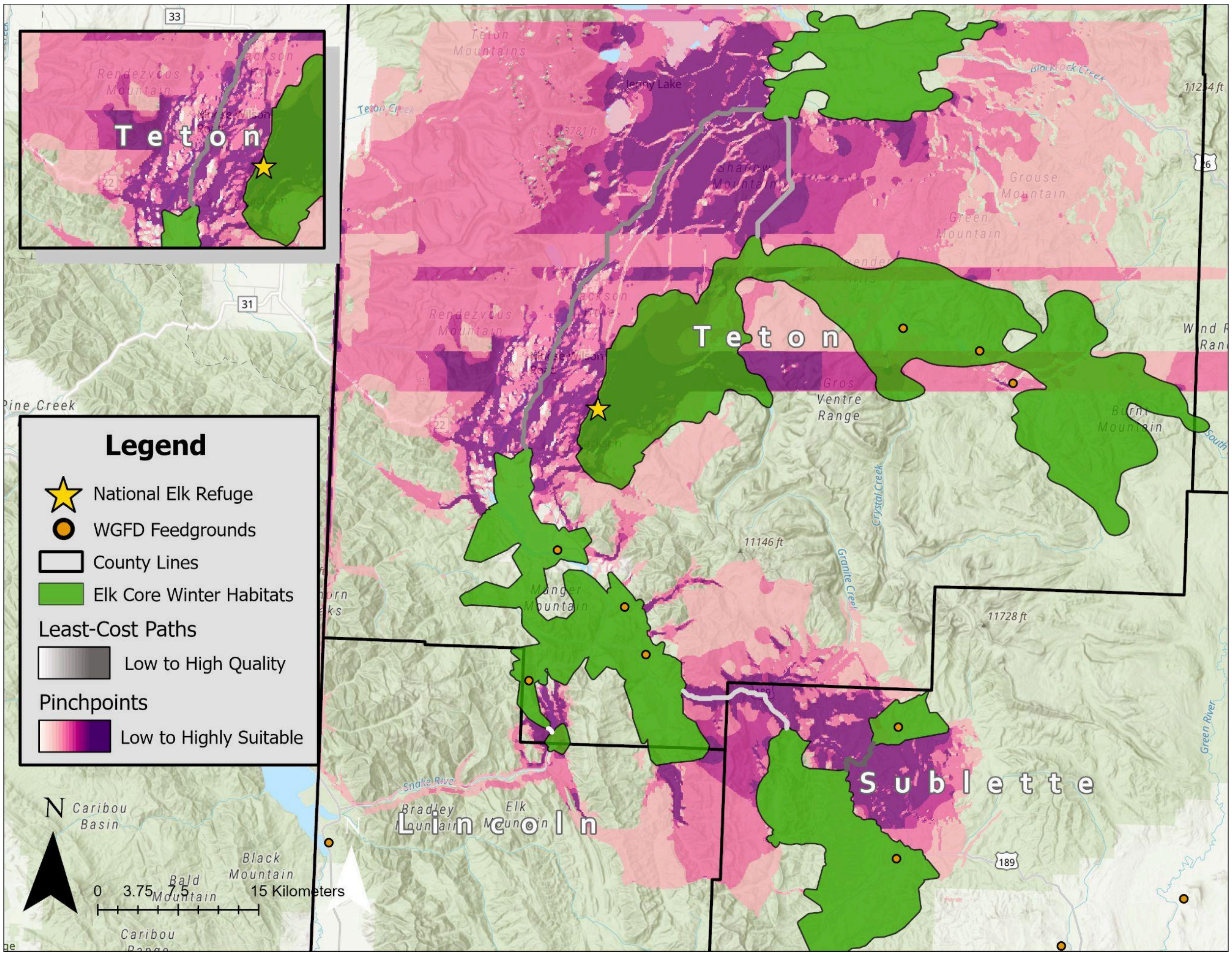
	highways)			
	S1200 - secondary roads (US highway, state highway, country highway systems)	85	90	95
	S1630 - ramp (controlled access from road highways)	85	90	95
	S1730 - alleys	85	90	95
	S1750 internal US Census Bureau use	85	90	95
	S1780 - parking lot road	85	90	95
Conservation Easements	1 - managed for biodiversity and natural disturbances are permitted	25	25	25
	2 - managed for biodiversity, but natural disturbances are suppressed	50	50	50
	3 - managed for multiple use and extraction permitted	75	75	75
	4 - protected but no known mandate	25	50	75
Protected Areas	1 - managed for biodiversity and natural	25	25	25

	disturbances are permitted			
	2 - managed for biodiversity, but natural disturbances are suppressed	50	50	50
	3 - managed for multiple use and extraction permitted	75	75	75
	4 - protected but no known mandate	25	50	75
Grazing Allotments	Grazing allotment area	25	50	75
Oil and Gas Fields	Oil and gas fields	95	95	95
Jackson Zoning	Zoning	95	95	95

Appendix 4. Low Resistance Least-Cost Paths and Pinchpoint Suitability.



Appendix 5. High Resistance Least-Cost Paths and Pinchpoint Suitability.



Appendix 6. Public comments and survey responses pulled from the Wyoming Game and Fish Departments Draft Elk Feedground Management Plan.

Ranchers/Landowners Public Comments from the WGFD Draft Elk Feedground Management Plan	
Biggest concerns surrounding feedground closures / management of existing feedgrounds	● If elk are closer to cattle, they could potentially bring more predators leading to an increase in cattle predation ● More elk on the land means more property damage ● Increase in brucellosis transmission ● Loss of permitted grazing ● Land authority of government agencies could increase with more elk being on the land ● Traffic safety ● Can native winter ranges even support elk if feedgrounds are not available for them? ○ Will this push them to eat the hay put out for cattle on private lands? ● Out of the 129 people who took their survey, 57 people or 44% ranked brucellosis as high priority/concern ● Out of 129 people, 69 or 53% ranked wildlife damage on private land as high priority/concern ● Out of 129 people, 79 or 60% ranked economic impact that the change of management of feedgrounds could cause on agriculture as high priority/concern
Ideas/solutions ranchers are hoping will be implemented by state agencies (WGFD) for feedgrounds, elk movement, and brucellosis	● In order to prevent an increase in federal lands that are set aside for elk, ranchers want them to either buy or rent out private land (so do grazing leases for elk) ● Provide funding for ranches to develop, maintain and support the changes that are being implemented ● Want each feedground to be evaluated for potential closure/future management decisions independently since each feedground has different needs and situations. Property damage caused by elk is also different in each location ● Plans need to be flexible and be able to change, especially if there is a harsh winter where forage is low and feedgrounds may need to be reopened/increase feed availability ● Can feed over larger areas in order to spread elk out ● Putting more of a focus on habitat enhancement within the feedgrounds could shorten the feeding season. This could be done by providing the elk higher quality forage, such as using alfalfa rather than native grasses ● Having "Winter Elk Management Areas" instead of

	feedgrounds ● Changing the elevation of feedgrounds ● Do more research on feedgrounds, CWD and brucellosis before making any rash decisions ● Open more feedgrounds in order to spread elk out ● Complete more disease modeling to understand if feedgrounds close, how disease dynamics will change ● Leave feedgrounds open but put an emphasis on understanding disease dynamics
Information wanted by overall stakeholder groups before any decisions are made: (this was not directly from ranchers, more general)	● How will elk habitat change over time? ● What are the economic impacts of feedgrounds in terms of their existence, closure, agricultural damage, etc? ● What are the strategies that other Western states have done/doing for winter elk habitat and management? ● What does the political pressures look like on this issue? ● What are the impacts of feedgrounds on other species such as mule deer, predators, and bison? ● How are landowners being compensated/ will be compensated for elk use during the winter if feedgrounds close? ● How can/how are elk encouraged to use native winter range vs. feedgrounds vs. ranchers hay?

Appendix 7. Private and Public Land Location for Forage Competition Calculations.