2021

Developing An Adaptive Resource Management Framework For Sustainable Cashmere Production In Mongolia

Elisabeth Lohre
University of Vermont

Recommended Citation

Lohre, Elisabeth, "Developing An Adaptive Resource Management Framework For Sustainable Cashmere Production In Mongolia" (2021). *Graduate College Dissertations and Theses*. 1483.
https://scholarworks.uvm.edu/graddis/1483

DEVELOPING AN ADAPTIVE RESOURCE MANAGEMENT FRAMEWORK FOR SUSTAINABLE CASHMERE PRODUCTION IN MONGOLIA

A Thesis Presented

by

Elisabeth Kathryn Lohre

to

The Faculty of the Graduate College

of

The University of Vermont

In Partial Fulfillment of the Requirements
for the Degree of Master of Science
Specializing in Natural Resources

October, 2021

Defense Date: August 18, 2021
Thesis Examination Committee:

James Murdoch, Ph.D., Advisor
Pablo Bose, Ph.D., Chairperson
Jon Erickson, Ph.D.
Cynthia J. Forehand, Ph.D., Dean of the Graduate College

ABSTRACT

Cashmere is a multi-billion dollar commodity and recent increases in demand have led to the degradation of grassland and desert steppe ecosystems in East and Central Asia. Cashmere wool is a product of goats and 90% of the world's supply originates from Mongolia and northern China. As global demand for cashmere increases, the consequences to the natural landscapes and people of the region may be severe, especially given the rapid rate of environmental change due to warming climatic conditions in the region.

Textile manufacturers recognize the need for better goat herding practices and support the development of a sustainable cashmere certification program. While simple in concept, sustainable certification requires a clear set of goals and measurable attributes that define the various dimensions of sustainability. Any certification program also needs to account for ongoing landscape changes due to factors like climate change, infrastructure development, and livestock grazing. In Mongolia, several nonprofits, industry representatives, government officials, and herders have formed partnerships in separate areas of the country to develop systems for sustainable cashmere production. However, these projects are mostly operating independently from one another and there is no consensus among these groups about what sustainable cashmere livestock management actually entails.

The goal of this study was to develop a framework for making decisions about the management of goats that maximize sustainable outcomes. The framework accounts for livestock impact on wildlife and habitat composition, two key components of ecological sustainability, and makes use of monitoring data to allow decisions to adapt to changing landscape conditions. The project occurred at Ikh Nart Nature Reserve, a study site in central Mongolia that characterizes many of the goat producing regions of the country. Objectives included: 1) defining rangeland management priorities by seeking input from key stakeholders, 2) developing models that quantify relationship of livestock with wildlife and habitats, and 3) constructing an adaptive management framework that integrates models and ongoing monitoring data to evaluate the ecological outcomes of different alternative livestock density decisions.

Results from this study will provide a framework for informing livestock management decisions at a regional scale that maximize cashmere production and sustainable outcomes. The framework serves as a foundation that can be scaled-up to other parts of the country and possibly support larger-scale sustainable cashmere certification standards.

ACKNOWLEDGMENTS

I know it is cliché, but it is literally impossible to articulate my gratitude for everyone who has helped me get to this point in my academic career and as a person. Anyone who knows me well knows I value people and community pretty much above all else (sometimes to a fault when sequestering myself away to finish my thesis may have been the suggested move). I could not have asked for better people to surround myself with these past few years and I look forward to crossing paths again and again—I have made lifelong connections here.

This research would not have been possible without funding from the Gund Institute Catalyst Award, the Denver Zoological Foundation Tap into Change Scholarship, Earthwatch Institute, the Mongolian Conservation Coalition, the Rubenstein Graduate Student Special Assistance Fund, and the UVM Environment Program.

I have learned so much throughout my time as a Master's student and only a small fraction of it was on my own working in front of the computer. The vast majority was through interacting with incredible mentors, peers, and collaborators in Vermont, Colorado, Mongolia, and beyond.

From the Denver Zoo and Mongolia Conservation Coalition, I extend sincere thanks to Erica, Gana, Selenge, Remo, Tuvshe, Serchee, Jagaa, Bagii, Bolor, Tsiigee, Aruna, and Ulzii. Erica—I have cherished your mentorship, friendship, and support in particular throughout this graduate school process, from contemplation to completion, and everywhere in between.

Shout out to the incredible RSENR community, specifically Dean Mathews, Carolyn, the Community of Practice, the Gund, and the WFB crew. You all have been a great group of folks to connect with and learn from throughout my time here.

The Sustainable Cashmere Project has been a good team to be part of from day one. For my gracious committee, Jon and Pablo, thanks for being supportive and sharing your insight, patience and empathy with me. Reilly, you were an excellent field companion and enthusiastic kindred spirit.

I cannot thank Jed enough for all he has done for me throughout my time here. He is the most supportive advisor anyone could ask for, balancing keeping me on track with incredible compassion. I am so grateful for his mentorship and for sticking with me, even when I have been in rough spots.

To all of my amazing friends—the 2018 incoming cohort, the ultimate community, Ruckus, Portland Rising, Nati, Hannah, Molly, Rachel, and Scott (one appendix from this experience that is not included in my thesis)—thanks for being with me through the good times and the not-so-good ones.

Last, but not least, all of my love and gratitude to my family. I would not be who I am today without you. I cherished the bonus time at home, even if it was thanks to a global pandemic and am so thankful to be on this journey through life with you all. You continuously support me and encourage me to pursue my dreams. I honestly would not have pulled through without you.

танд их баярлалаа!

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

THESIS OVERVIEW

The thesis below is organized in two chapters. In the first chapter, I begin with a literature review that introduces Mongolia and steppe ecosystems, and provides a synopsis of the issues of cashmere production, and adaptive resource management as a decision-making tool. The second chapter follows and includes a manuscript of my study results—developing the foundation of an adaptive framework to inform sustainable livestock management at the pilot site in the Ikh Nart Nature Reserve. The final section includes conclusions and recommendations. Appendices follow with supplementary tables, figures, and data.

CHAPTER 1: LITERATURE REVIEW

1.1. Mongolia in Context

Mongolia is home to one of the largest remaining intact grassland ecosystems in the world, which is under threat of habitat degradation due to human activities and climate change (Hilker et al. 2014). Steppes or grassland plains are some of the least-studied biomes on earth (Bone et al. 2015). In Mongolia, these semi-arid habitats are characterized by relatively low annual precipitation, extreme climate fluctuations—with cold winters and hot summers, and are dominated by grass and forb species (Bone et al. 2015). Better understanding not only the Mongolian steppe ecosystems themselves, but also human influences on these ecosystems will be imperative for developing effective strategies to manage this land and combat degradation.

Mongolia has historically been a pastoralist society, with nomadic herding and agriculture being the primary livelihoods in Mongolia for hundreds of years (Sternberg 2008). As of 2018, almost 30% of Mongolia's population were herders and agriculture (including livestock production) was the second largest contributor to Mongolia's GDP behind mining, comprising nearly 11% of Mongolia's total GDP (MSIS 2020). A country of only 3.3 million people in 2019, Mongolia has approximately 66.5 million livestock at present, a >250% increase from the 25.9 million livestock reported in 1990 (MSIS 2020; Figure 1). In the early 1990s, the collapse of the Soviet Union paved the way for the privatization of livestock in Mongolia. This, coupled with growing demand for cashmere wool, fueled the exponential rise in the number of livestock in Mongolia over the past 30 years (Nixson and Walters 2006, NSO Mongolia 2018; Figure 1).

Mounting livestock pressures on this arid land have led to serious issues with overgrazing (Bazha et al. 2012, Liu et al. 2013, Hilker et al. 2014). Overgrazing has led to detrimental impacts on local ecosystems, causing shifts in landscape composition away from forbs and grasses to shrubs, and in cases of extreme overgrazing, loss of vegetation and root biomass leads to loss of topsoil and water-retention—a process known as desertification (Bazha et al. 2012, Liu et al. 2013, Hilker et al. 2014). These shifts in habitat are amplified by the accelerated rate of climate change Mongolia has experienced—enduring over 2.2°C warming since 1940, relative to the global average of 1.0°C warming (Dagvadorj et al. 2014, Masson-Delmotte et al. 2018). Mongolia is also prone to extreme winter weather events, known locally as dzuds, which can kill off large numbers of livestock (Sternberg 2010). The combined effects of overgrazing, mining, and climate change have contributed to the classification of 70% of Mongolia's habitat as degraded (Hilker et al. 2014).

1.2. Cashmere Industry

Cashmere wool is a natural fiber used in the production of luxury garments and provides the largest profit for Mongolian herders of any livestock product (Addison and Brown 2014). Cashmere, hand-combed from the downy undercoats of domestic goats, is known for its soft texture and warmth (Kerven et al. 2009). The harsh climates of the Mongolian steppe provide ideal conditions for goats to grow this thick, insulating wool and 90% of the world's supply comes from northern China and Mongolia (Berger et al. 2013). The growing popularity of cashmere, including the expansion of the material beyond luxury status (e.g., the multinational H&M company is one fast fashion brand that has incorporated cashmere into their product catalog), has contributed to a rise in cashmere production from 1.5 thousand metric tons in 1990 to 10.2 thousand metric tons in 2017 (NSO Mongolia 2018; Figure 2).

Mongolian wool is typically of lower quality than Chinese wool and competition in the cashmere market is substantial (Danforth 2017, UNDP Mongolia 2019b). The quality of cashmere fiber depends on its thickness, length, crimp, and color—with thin diameter, long, highly crimped, white wool being the highest quality. Chinese breeders generally have the more favorable white goats, while Mongolian goat breeds have non-white hair (UNDP Mongolia 2019b). In order to maximize overall number of cashmere-producing goats, Mongolian herders no longer cull their herds of older and male goats, which have coarser hair, leading to a decrease in average cashmere wool quality (Danforth 2017). Increasing grassland ecosystem degradation and severe weather contribute to poor goat health, which also negatively affects wool quality (Oyuntulkhuur and Batkhishig 2019).

Decreasing cashmere quality has economic impacts for already vulnerable herders. The price differential for sales of high versus low quality cashmere can be >30% (World Bank 2003). Higher prices in the long-term could incentivize herders to raise fewer, high-quality goats, but low household incomes have pushed herders to prioritize producing as much cashmere as quickly as possible (World Bank 2003, Danforth 2017). Herders often use loans to help counteract the uncertainty and unpredictability of raising livestock, helping to manage short-term risk, but amplifying their long-term economic vulnerability (Murphy 2018). Herders are then further incentivized to shift to cashmere production to help repay loans, a process known as the “cashmere debt cycle” (Murphy 2018). Increasing herd size to produce greater amounts of lower quality cashmere can offset the lower earnings of that cashmere in the short term, but potentially results in negative environmental impacts. As the effects of overgrazing and climate change have become more severe, herders are often caught in a cycle of continuing herding practices with negative trade-offs to the environment to repay debts and earn a living.

1.3. Push for Sustainability Standards

Concern over herder livelihoods and decreases in cashmere and rangeland quality has mobilized organizations, herders, and textile manufacturers to work towards developing a sustainable cashmere standard in Mongolia (Danforth 2017, Sustainable Fibre Alliance 2017, Wildlife Conservation Society Mongolia 2019, UNDP Mongolia 2019b). Not only are herders financially vulnerable, but much of the raw cashmere wool from Mongolia ends up being exported to China for processing and manufacturing (Oyuntulkhuur and Batkhishig 2019). This results in a large loss of potential capital from the Mongolian economy. The Mongolian textile industry has a significant interest in improving processing capacity within country to ensure value-added to the Mongolian economy. One unique angle that the Mongolian government, textile manufacturers, and garment companies hope may give them an edge in the market over Chinese cashmere is capitalizing on the rugged and natural brand of Mongolia (Oyuntulkhuur and Batkhishig 2019). If production in Mongolia can be verifiably sustainable, this could increase demand for Mongolian cashmere and increase the price of the wool.

Sustainability efforts focus on creating a certification program in which higher cashmere prices will be paid to herders that adopt sustainable practices that reduce impacts on the environment while also improving animal welfare and health (Danforth 2017, Sustainable Fibre Alliance 2017, Wildlife Conservation Society Mongolia 2019).

There are currently six different institutions operating projects in Mongolia with sustainable cashmere as a stated project output: Asian Development Bank (ADB), Agronomists and Veterinarians Without Borders (AVSF), Swiss Development Corporation (SDC), Sustainable Fibre Alliance (SFA), United Nations Development Program (UNDP), Wildlife Conservation Society (WCS) (Table 1). Each organization operates their own regional programs throughout the country, with many of their project areas overlapping, and takes a different approach depending on their expertise and goals (UNDP Mongolia 2019a; Table 2). Brand representatives tend to be focused on traceability and ensuring cashmere can be verified as being sustainably raised. WCS is focused on minimizing impact to the environment and animals. ACSF and Green Gold focus more on livestock health and capacity building. The UNDP Mongolia has undergone serious efforts in recent years to consolidate these sustainable cashmere efforts and encourage collaboration between groups. The Sustainable Fibre Alliance is another organization working to create a unifying umbrella within which groups can operate. Some issues with these efforts thus far are that there is a lack of consensus on what sustainable cashmere management entails and how to measure it (UNDP Mongolia 2019b). Several of the groups have significant monitoring programs in place, but most focus on vegetation and rangeland health, without considering other important intersecting ecological components, such as wildlife. For the most part, approaches by the aforementioned groups have looked at ecological and social/economic factors separately. True sustainable management needs to include ecological, social, and economic components (Lozano 2008). Management efforts also need to be able to adapt to new information (e.g., from ongoing monitoring) and changing conditions over time—

something that is not incorporated explicitly into many cashmere programs (Conroy and Peterson 2013).

1.4. Adaptive Resource Management

Managing for sustainable cashmere production means making decisions about goat herding that account for the different dimensions of sustainability and lead to long-term sustainable outcomes. Decisions also need to be made regularly that account for changes in landscape conditions due to climate change and other forms of environmental variation. The Adaptive Resource Management (ARM) approach provides a means of structuring a decision making framework for the problem (Conroy and Peterson 2013, Walters 1986). The ARM approach involves articulating the alternative decisions and objectives of the problem, and using models to estimate the best decision to make at the scale of interest. Objectives of sustainable cashmere production include ecological, economic, and social factors that define sustainability. People want to maximize the benefit to herder's livelihoods based on market price and demand for cashmere wool, while also sustaining cultural ties to the land and nomadic herding. Implementing an ARM framework allows for the elicitation of stakeholder values in each of these dimensions of sustainable production. Models then capture the consequences of each alternative on each objective and result in a utility score. Scores are then used to compare alternatives and a recommendation can be made based on the highest-ranking alternative.

The ARM framework can reduce uncertainty in decisions, account for multiple interdisciplinary objectives, illuminate decision thresholds, and adjust to changing conditions by incorporating new information to "update" the recommended decision (Conroy and Peterson 2013, Martin et al. 2009, Walters 1986). The ARM approach incorporates an adaptive element using a single-loop learning process (Conroy and Peterson 2013; Figure 4). This involves implementing an action (i.e., a particular decision about goat density), observing the outcome through monitoring, then using monitoring data to update the models in the framework and evaluate whether another decision may be better. Over time, decisions that lead to the best sustainable outcomes adapt to changing conditions in the landscape. The ARM framework has been applied to a variety of natural resource problems ranging from setting harvest regulations of waterfowl to the management of water resources (Conroy et al. 2002, Nichols et al. 2007, Freeman et al. 2013).

1.5. Ikh Nart Pilot Study

The goal of this thesis project was to develop an adaptive management framework for the management of cashmere goats that incorporates multiple dimensions of sustainability (ecological, economic, and social) to support ongoing sustainable cashmere management efforts. Due to the time constraints of a Master's program and complexity of accounting for multiple elements of sustainability, I focused on developing the foundation of a cashmere framework, examining the relationships between goat density, habitat composition, and wildlife as a proxy for state of environment. The project occurred at the Ikh Nart Nature Reserve, a well-studied site in central Mongolia that characterizes many goat-producing regions of the country. Ikh Nart is home to a long-term research program for wildlife and landscape studies, and local community engagement efforts (Reading et al. 2016).

Objectives of the study included: 1) defining rangeland management priorities by seeking input from key stakeholders, 2) developing models that quantify relationship of livestock with ecological priority areas, and 3) constructing an adaptive management framework that integrates models and ongoing monitoring data to evaluate the ecological outcomes of different alternative livestock density decisions. This study provides a foundation for science-based livestock management at Ikh Nart that uses ongoing information to ensure that the landscape meets certain user-defined minimum conditions year after year. The results provide two important elements for improving sustainable cashmere efforts region-wide: 1) using models that capture the relationship between livestock and environment to quantify and predict impacts, and 2) using ongoing monitoring data to incorporate an adaptive component that allows livestock decisions to be updated as landscape conditions change. These elements and the use of a structured decision making framework provide a means of building science and transparency in to livestock management throughout the country.

CHAPTER 2: DEVELOPING AN ADAPTIVE RESOURCE MANAGEMENT FRAMEWORK FOR SUSTAINABLE CASHMERE PRODUCTION IN IKH NART NATURE RESERVE

2.1. Abstract

Livestock populations in Mongolia have increased exponentially in the last three decades, leading to overgrazing and rangeland degradation. Cashmere, a multi-billion dollar global commodity, comes from the undercoat of domestic goats and provides the largest profit for herders of any livestock product—fueling a nearly six-fold increase in goat numbers in Mongolia from 5.1 million in 1990 to 29.3 million in 2019. Several non-government organizations, industry representatives, government officials, and herders have formed partnerships to develop systems for sustainable cashmere production in the country. However, these projects are mostly operating independently from one another and there is no consensus among groups about what sustainable cashmere livestock management actually entails.

The goal of this study was to develop a framework for making decisions about the management of livestock for cashmere that maximizes sustainable outcomes. The project occurred at the Ikh Nart Nature Reserve, a study site in central Mongolia that characterizes many goat-producing regions of the country. Objectives included: 1) defining rangeland management priorities by seeking input from key stakeholders, 2) developing models that quantify ecological priority areas, and 3) constructing an adaptive management framework that integrates models and ongoing monitoring data to evaluate the outcomes of different alternative livestock density decisions. Stakeholders identified several management priorities including healthy wildlife populations, high quality forage for livestock, and access to water. Elements of these priorities were modeled with a

combination of field data and remotely sensed imagery, and used to predict the outcomes of alternative livestock density decisions in a multi-criteria decision analysis framework. A set of monitoring data were also used to demonstrate how the decisions can be updated over time. Results provide a structured approach to defining the elements of sustainability and using models to evaluate the trade-offs of different livestock densities over time. The approach is transparent, data-driven, and adaptive, and can be modified to include other elements. As sustainability is a priority for the cashmere industry, this approach provides a foundation for setting a standard for cashmere production across Mongolia that balances the needs of people and the environment.

2.2. Introduction

Consumer decisions have far-reaching environmental and social consequences due to the nature of globalized supply chains of commercial goods (Myers and Kent 2003). The clothing industry in particular has received scrutiny for generating negative social and environmental impacts throughout the production and life-cycle of garments (Kozlowski et al. 2012). For example, natural fibers used in the manufacturing of textiles are produced from finite natural resources, and poor production practices often lead to long lasting environmental degradation of the source regions, especially in developing countries (Chen and Burns 2006).

Cashmere is one example of a natural fiber used in the production of luxury garments. Cashmere wool, combed from the insulating undercoat of goats from cold winter climates, is known for its soft texture and warmth (Kerven et al. 2009). Cashmere has risen dramatically in popularity over the past decade to become a multi-billion dollar global commodity (Danforth 2017). Nearly 90% of the global supply of cashmere comes from Mongolia and northern China, where the recent increase in cashmere demand and production has resulted in high levels of environmental damage (Berger et al. 2013).

The climate, traditional livestock herding culture, and large extent of open rangeland make Mongolia an ideal region for cashmere production (World Bank 2003). Growing demand for cashmere coupled with the privatization of livestock in Mongolia in the early 1990s, and a high price for cashmere relative to other goods led to an increase in the goat population from 4.4 million in 1988 to 29.3 million in 2019 (Liu et al. 2013, Danforth 2017, MSIS 2020). The impacts on wildlife have been substantial. For example, a study of wildlife at sites in Mongolia, India and the Tibetan Plateau (three cashmere producing regions) found that native ungulate species constitute less than 5% of the biomass of domestic livestock (Berger et al. 2013). Livestock have nearly replaced native wild ungulates, and resulted in declines of most large mammal species (Berger et al. 2013).

Climate change further magnifies the effects of overgrazing. Mongolia has undergone a more rapid shift in temperature than the global average partly due to its continental geography, with a greater than 2 °C increase in annual temperature since 1940 (Dagvadorj et al. 2014). From 1998 to 2008, Mongolia experienced significant declines in vegetation biomass across its steppe regions. Climate trends accounted for 60% of the decline in biomass, with fires and the substantial increase in goat numbers accounting for most of the remaining declines (Liu et al. 2013). In 2013, nearly 80% of the total landscape in Mongolia was affected by degradation, with 10% qualifying as extremely degraded (Dagvadorj et al. 2014, Hilker et al. 2014). This degradation has implications not only for wildlife, but also for domestic livestock and the herders that rely on these rangelands for their livelihood.

The unsustainable increase in goats on the landscape in Mongolia has direct negative impacts on the quality of the wool produced. Cashmere wool quality and price are driven by cashmere fineness (diameter of the fiber), color, length, crimp (degrees of curliness), and yield (percentage of down relative to total weight of raw cashmere) (World Bank 2003, Kerven et al. 2009). Goats now constitute 41% of the total livestock in Mongolia and cashmere production rose from 1.5 thousand metric tons in 1990 to 10.2 thousand metric tons in 2017 (NSO Mongolia 2018; Figure 2). As herders have expanded their herds, they have also shifted herd demographics, forgoing culling of young male goats (who have coarser hair) and allowing goats to live longer, which decreases the overall health of individuals and reduces the yield of marketable raw cashmere per goat (World Bank 2003, Danforth 2017). These practices increase raw cashmere production, but at the expense of quality. Lower quality raw cashmere also increases processing expense and results in substantially more harvesting waste during processing of the raw wool, as a greater percentage of cashmere fails to meet industry standards (Danforth 2017).

Decreasing cashmere quality has economic impacts for already vulnerable herders. The price differential for sales of high versus low quality cashmere can be >30% (World Bank 2003). Higher prices in the long-term could incentivize herders to raise fewer, high-quality goats, but low household incomes have pushed herders to prioritize producing as much cashmere as quickly as possible (World Bank 2003, Danforth 2017). Herders often use loans to help counteract the uncertainty and unpredictability of raising livestock, helping to manage short-term risk, but amplifying their long-term economic vulnerability (Murphy 2018). Herders are then further incentivized to shift to cashmere production to help repay loans, a process known as the “cashmere debt cycle” (Murphy 2018). Increasing herd size to produce greater amounts of lower quality cashmere can offset the lower earnings of that cashmere in the short term, but potentially results in negative environmental impacts. As the effects of overgrazing and climate change have become more severe, herders are often caught in a cycle of continuing herding practices with negative trade-offs to the environment to repay debts and earn a living.

Concern over herder livelihoods and decreases in cashmere and rangeland quality have mobilized organizations, herders, and textile manufacturers to work towards a sustainable cashmere standard in Mongolia (Danforth 2017, Sustainable Fibre Alliance 2017, Wildlife Conservation Society Mongolia 2019). Sustainability efforts focus on creating a certification program in which higher cashmere prices will be paid to herders that adopt sustainable practices that reduce impacts on the environment while also improving animal welfare and health (Danforth 2017, Sustainable Fibre Alliance 2017, Wildlife Conservation Society Mongolia 2019). Development of certification standards have largely been unsuccessful due to the challenges of defining and measuring sustainability.

Managing for sustainable cashmere production is complex and dynamic, and includes not only decisions about the relative density of goats on the landscape, but also their impacts on key elements of sustainability. Management decisions also need to be made regularly that account for changes in landscape conditions due to climate change and other forms of environmental variation over time. The Adaptive Resource

Management (ARM) approach provides a means of structuring a decision-making framework for a given problem (Conroy and Peterson 2013). The ARM approach involves articulating the alternative decisions and objectives of the problem, and using models to estimate the best decision to make. In the case of cashmere production, the problem relates to estimating an optimal number of goats in a landscape, and alternatives represent a set of different goat densities. Objectives essentially provide a means of defining the elements of sustainability and can include ecological, economic, and social factors. Models then capture the consequences of each alternative on each objective and result in a utility score that allows alternatives to be ranked related to each other. These scores provide a quantitative assessment of the trade-offs of each goat density alternative and key information for livestock decision makers.

The ARM framework can also reduce uncertainty in decisions and adjust decisions to changing conditions by incorporating new information to “update” the recommended decision (Conroy and Peterson 2013). The ARM approach incorporates an adaptive element using a single-loop learning process (Conroy and Peterson 2013; Figure 4). This involves implementing an action (i.e., a particular decision about goat density), observing the outcome through monitoring, then using monitoring data to update the models in the framework and evaluate whether another decision may be better. Over time, decisions that lead to the best sustainable outcomes adapt to changing conditions in the landscape. The ARM framework has been applied to a variety of natural resource problems ranging from setting harvest regulations of waterfowl to the management of water resources (Conroy et al. 2002, Nichols et al. 2007, Freeman et al. 2013).

The goal of this study was to develop a framework for making decisions about management of cashmere goats that maximizes sustainable outcomes. The study occurred in central Mongolia at the Ikh Nart Nature Reserve, which characterizes many goat producing regions of Mongolia and has an active park management program. Objectives included: 1) defining rangeland management priorities by seeking input from key stakeholders, 2) developing models that quantify ecological priority areas, and 3) constructing an adaptive management framework that integrates models and ongoing monitoring data to evaluate the outcomes of different alternative livestock density decisions. Results provide a new quantitative approach to managing livestock for cashmere that can be easily modified to include additional elements of sustainability and fit the social, economic, and ecological contexts of other regions.

2.3. Methods

2.3.1. Study Area

The study occurred in the Ikh Nart Nature Reserve and its surrounding regions in Dornogobi and Dundgobi Aimags, Mongolia (45.6°N, 108.7°E; Figure 3). The reserve covers 666 km^2 and occurs in the Gobi-steppe ecosystem, at the transition between the Gobi Desert to the south and the grassland steppes to the north and east (Reading et al. 2011). Habitat types in Ikh Nart include semi-desert areas composed mostly of rocky outcrops with sparse vegetation and steppe areas composed of semi-arid vegetation including short grasses, shrubs, and forbs (Jackson et al. 2006). The climate is characterized by cold winters and short, hot summers with temperatures ranging from -40 °C to +40 °C (Reading et al. 2011). The region is arid with < 200 mm of annual precipitation, most of which falls as rain in summer.

Ikh Nart is a multi-use landscape, home to approximately 110 herding families that raise livestock for subsistence (Davie et al. 2014). These families are semi-nomadic pastoralists, herding primarily goats, sheep and horses, and most income is from the sale of cashmere in the spring months (Davie et al. 2014). Individual families move anywhere from 5 to > 50 km between summer and winter ger (yurt) sites and generally follow a transhumant lifestyle (Davie et al. 2014, Reading et al. 2016). While Mongolian law allows pastoralists to graze livestock in nature reserves, Ikh Nart limits grazing within a core area of the reserve and parts of two adjacent local protected areas (Figure 3; Wingard 2001, Reading et al. 2016). The reserve harbors a globally important population of argali sheep (*Ovis ammon*), which is considered a flagship species for the region (Murdoch et al. 2017). At least 33 species of mammal, 150 species of bird, and 7 species of reptiles also occur in the reserve (Murdoch et al. 2006, Reading et al. 2011).

2.3.2. Objective 1: Elicitation of Stakeholder Priorities

Stakeholders are people or organizations who have personal interest, and often influence, in the outcomes of management decisions (Freeman 2010). Involving the appropriate people is critical to creating effective management decisions with lasting impact and public support (Reed et al. 2009, van Eeden et al. 2017). To ensure the most relevant stakeholders are involved in the decision-making process, I conducted a stakeholder analysis (Conroy and Peterson 2013). This process examined different potential stakeholders and their ability to influence management decisions as well as how the management decisions will affect each stakeholder (Table 3). It is most critical to involve stakeholders with the highest ability to influence the decision that will also be most impacted by the outcomes of the decision (Conroy and Peterson 2013). The results indicated that key stakeholders include representatives from herder collective units, Ikh Nart research staff, the Ikh Nart Scientific Authority, and local Soum government officials in the decision-making process.

In August 2019, we organized a workshop with key stakeholders at Ikh Nart. Opinions on important dimensions of sustainability were elicited through group discussion and surveys of workshop participants. Respondents were asked to list the top values they felt should be incorporated in an adaptive management framework. The top nine values were determined from combining all groups' lists and individual participants were then asked to rank their first, second, and third priority values. These individual rankings were used to develop weights and final rankings of each value (Table 4). The workshop also provided an opportunity to better understand the cultural, political, and social context of the region and issues of power and privilege that may influence results and eventual adoption of a sustainable cashmere program in the future. All elicitation protocols were reviewed by the Institutional Review Board of the University of Vermont (IRB # 00000242).

2.3.3. Objective 2: Development of Models

2.3.3.1. Occupancy Modeling

Although stakeholders provided multiple priorities, we focused the development of the framework around the 'wildlife' priority. This priority was high ranking and serves as an effective proxy or indicator for the broader state of environment in the study area (Garroutte and Wingard 2019). An annual wildlife monitoring program also exists in the Ikh Nart reserve, which generates ongoing data on the abundance and distribution of several taxa (important for updating; see below). We used five focal species as indicators of ecological sustainability. These species included argali sheep (*Ovis ammon*) – a flagship species for the reserve and important species for tourism; corsac fox (*Vulpes corsac*) and red fox (*Vulpes vulpes*) – the most common carnivore species in the reserve; toad-headed agama (*Phrynocephalus versicolor*) – the most common vertebrate in the reserve; and Mongolian marmot (*Marmota sibirica*) – a highly endangered species. Occupancy probability provides a measure of landscape quality for a species and was used as a measure of sustainability. Models that predict occupancy probability as a function of landscape variables (biotic, abiotic, and human-related) had already been developed in previous studies for argali, corsac fox, red fox, and agama (Table 5, Table 6; Murdoch et al. 2013, Lkhagvasuren et al. 2016, Murdoch et al. 2016, Murdoch et al. 2017). We also developed a marmot model based on colony locations from a systematic survey of the reserve, followed by a model selection approach using logistic regression (Appendix I e., Appendix III e.; Burnham and Anderson 2002, Becchina 2020).

2.3.3.2. Livestock and Climate Impacts on Habitat Composition

We examined impacts livestock have indirectly on wildlife through their effects on habitat composition in northern Ikh Nart and the surrounding area. This was necessary as habitat composition serves as the primary input for the wildlife occupancy models. We used logistic regression with model selection techniques to model the influence of livestock number and climate variables on the amount of 5 habitats as defined by Jackson et al. 2006 based on a supervised classification of Landsat imagery. The habitats included *Caragana*-dominated shrubland (referred to as high density shrub), *Amygdalus*-dominated shrubland (referred to as low density shrub), open plain, tall vegetation, and rocky outcrops (see Jackson et al. 2006 for complete descriptions of each).

We estimated the amount of each habitat in the reserve each year from 2004 to 2020 (resulting in 17 values per habitat). Habitat amounts were first estimated using maximum likelihood image classification methods of a Landsat scene (WRS-2, Path 130, Row 28; eight spectral image bands; pixel resolution = 30 m x 30 m for bands 1-5 and band 7) taken on 02 August 2019. Thirty training sites per habitat type were then used to create a signature file for Maximum Likelihood Classification of Landsat imagery in ArcGIS (ESRI, Redlands, California, USA; Table 7). Next, the 2019 signature file was used for Maximum Likelihood Classification on one satellite image per year (2004-2020) from Ikh Nart during the same time of year (late July to early September, depending on which image was the clearest/most cloud-free) (Figure 6).

We recorded the density of livestock from the Mongolia Statistics and Information Service annual data for Bichigt bag (MSIS 2020), which is the smallest geopolitical boundary that encompasses the northern part of Ikh Nart. There is no information on the number of livestock actually in the reserve, in part because herders can move freely between Ikh Nart and the surrounding area and because inquiring directly about someone’s herd size is considered culturally taboo. Climate variables included precipitation and temperature (i.e., average precipitation, total precipitation, mean maximum daily temperature, mean minimum daily temperature, mean average daily temperature) for the months of April through June, which represent the time period that has the most significant influence on the timing and productivity of the growing season for livestock forage vegetation (Chang and Zachmann 2020).

A total of 23 candidate linear models were developed to explain the proportion of each habitat type as a function of livestock and climate variables (Appendix IV).

Candidate models included all single and additive combinations of these covariates. The underlying hypothesis of this model process is that broad-scale habitat distribution on the landscape at Ikh Nart would be most influenced by livestock and the selected climate variables. Model selection techniques were used to identify the models in the set that explained the amount of a given habitat (Burnham and Anderson 2002). Models within the cumulative weight of 0.95 were identified to use in model averaging and framework updating of model weights (Appendix I, Appendix II). Model averaging involved taking the habitat composition prediction from each model multiplied by its model weight and summing those new weighted prediction values. The link between livestock, climate, and habitat is necessary for predicting the effects of changing conditions on wildlife occupancy.

2.3.4. Objective 3: Constructing an Adaptive Resource Management Framework

2.3.4.1. Multi-Criteria Decision Analysis

We used multi-criteria decision analysis (MCDA) as the structure for the decision-making framework. MCDA supports decision-making by scoring different decision alternatives according to their effects on a set of objectives or criteria (Adem Esmail and Geneletti 2018). MCDA has been used with success in environmental planning scenarios, which often include several criteria, multiple decision alternatives, and stakeholders with differing viewpoints (Mustajoki et al. 2011).

Based on the values we elicited from our stakeholder workshop, we were able to create a Multi-Attribute Value Tree (Keeney and Raiffa 1976; Figure 7). The Multi-Attribute Value Tree from MCDA decomposes a decision problem into alternatives, sub-criteria, and higher-level criteria related to a goal (Keeney and Raiffa 1976).

2.3.4.2 Updating the Framework with Monitoring Data

We constructed the decision-making framework, then collected monitoring data for each species from June to August 2019. Monitoring data included conducting 2 detection/non-detection surveys of 124 sites for corsac fox, red fox, and agama (Murdoch et al. 2016, Murdoch et al. 2013), surveying 81 historically active marmot colonies for presence (Becchina 2020; S. Buyandelger, unpublished data), and collecting 2,697 presence-only radio-telemetry locations of argali (Denver Zoo, unpublished data).

All monitoring data were used to update the models for each species in the framework (Appendix I and II). The 2019 monitoring data were confronted to the original model set for each species that accounted for 95% of the weight of the model set. For instance, out of the original six models for red fox, there was one model, Ψ(RO + SH), *p*(cover), that accounted for 94% of the weight of the model set. However, with the 2019 monitoring data, Ψ(TV), *p*(cover), accounted for 97% of the data. To account for both the historic and 2019 occupancy values, we standardized the weights by taking the historic weight and dividing by the historic weight plus the 2019 weight.

	Models contributing 0.95 cumulative weight	Original Weight	Standardized Weight: $\frac{\text{Historic Wt}}{\text{(Historic Wt + 2019 Wt)}}$
Historic	Ψ(RO + SH), *p*(cover)	0.94	0.49
2019	Ψ(TV), *p*(cover)	0.97	0.51

These standardized weights were then multiplied by the predicted occupancy values, and the weighted occupancy values were summed to get an updated occupancy value.

	Models contributing 0.95 cumulative weight	Original Predicted Occupancy	Updated Occupancy: (Historic occ. * Historic stand. wt.) + (2019 occ. * 2019 stand. wt.)
Historic	Ψ(RO + SH), *p*(cover)	0.18	0.30
2019	Ψ(TV), *p*(cover)	0.42	

2.3.4.3 Scoring Livestock Density Alternatives

We used five different livestock densities, based on historic 2004 to 2019 and projected livestock data, as our potential decision alternatives: 1) minimum from historic livestock density (18 livestock/km^2), 2) low livestock density (29 livestock/ km^2), 3) medium livestock density (41 livestock/ km^2), 4) maximum from historic livestock density (52 livestock/km^2), and 5) projected future livestock density for 2025 (55 livestock/ km^2). We then used ‘habitat’ models to predict the consequence of each alternative (along with climate factors) on the amount of each habitat. Predicted habitat amounts were then used to estimate occupancy probability for each species. The models contributing 95% of cumulative weight among a set of candidate models (Appendix I) and probabilities were estimated using the logit link function. This resulted in a predicted occupancy probability for each species as a function of habitat amounts that were ultimately a function of livestock and climate conditions (Table 8. A.).

We calculated the difference in predicted occupancy for each species between the livestock density scenarios (Table 8. B.). Depending on how different species are valued by the decision-makers at Ikh Nart, weights can be assigned to each species that would then be multiplied by the percent change in occupancy to get an overall score for each species in each decision scenario. We generated utility scores for a number of different species weighting combinations, based on potential wildlife conservation priorities that included weighting each species equally, assigning all weight to one species, dividing weight equally between argali sheep and Siberian marmots, and dividing weight equally between both fox species (Table 9; Figure 8). These utility scores can be used to rank each density alternative for a single year time step. At the simplest level, the decision with the highest score would be the best. However, there may be certain thresholds that could be incorporated to ensure one species is not negatively impacted beyond a given point (e.g., marmots going extinct) while the other species benefit from a particular scenario (e.g., argali, foxes, and agamas expanding occupancy).

2.4. Results

2.4.1. Objective 1: Elicitation of Stakeholder Priorities

Out of the lists generated by the seven participant groups at the rangeland management workshop, nine management values were identified (Table 4). The elicited stakeholder prioritization of each value was then incorporated to calculate the weightings and generate rankings of the values. The top four values included forage condition for livestock, access to water, education, and healthy wildlife populations (Table 4). Education, as defined by the stakeholders, was not directly related to management and was removed from consideration in the decision-making framework.

2.4.2. Objective 2: Development of Models

2.4.2.1. Occupancy Modeling

For the original species occupancy studies, the top covariates for each species and their effects (+/-) were as follows: argali sheep—rocky outcrop (+) and water (+); corsac fox—tall grassland (+), shrubland (+), and open plain (+); red fox—rocky outcrop (+) and shrubland (+); agama—rocky outcrop (-) (Table 5). Using updated habitat classification maps and monitoring data for 2019, models with different covariates described patterns of species occupancy: argali—rocky outcrop (+) and road (-); corsac fox—shrubland (+) and rocky outcrop (-); red fox—tall vegetation (-); agama—open plains (+); and newly added Mongolian marmot—road (+) and shrubland (+) (Table 5;

Appendices I and II). Model weighting for the 2019 models was generally more equally distributed between multiple top models, whereas historic model sets generally had one or two models accounting for most of the model weight (Appendix I).

2.4.2.2. Livestock and Climate Impacts on Habitat Composition

The influence of livestock density decisions on predicted habitat proportions varied greatly depending on the habitat type (Figure 9). The predicted proportion of low-density shrub dropped sharply from 0.35 under the lowest livestock density management scenario to only 0.14 under the predicted future scenario for 2025. High density shrub, open plains, and tall vegetation all increased to some degree while proportion of rocky outcrop and ephemeral water remained consistent across management scenarios.

2.4.3. Objective 3: Constructing an Adaptive Resource Management Framework

2.4.3.1. Multi-Criteria Decision Analysis

The Multi-Attribute Value Tree (Figure 7) starts with our overall goal of sustainable cashmere production on the left-hand side, which is then broken down into three criteria for sustainability (ecological, economic, and social). These broad criteria are further decomposed into the top nine values identified by stakeholders at the rangeland management workshop (Table 4) as well as several additional sub-criteria we deemed important for consideration. While this study only focused on the value of wildlife to demonstrate how the framework works, we encourage further research to enrich our base framework to account for other values.

2.4.3.2. Updating the Framework with Monitoring Data

The predicted occupancy for species tended to remain relatively consistent across livestock density alternatives (Table 8. A., Figure 10). Increased livestock density showed a slight negative effect on corsac fox and marmot occupancy, while it actually showed a positive effect on agama occupancy probability (Table 8. B.). Argali and red fox occupancy had no measurable change from minimum livestock density to future predicted livestock density scenarios.

2.4.3.3. Scoring Livestock Density Alternatives

The optimal livestock density decision varied depending on the weighting scenario (Table 9; Figure 11). The minimum livestock density decision was the highest-scoring alternative for the scenario with equal weighting, for the 50:50 weighting of corsac and red foxes, and in the scenarios where all weight was assigned to Mongolian marmot, corsac fox, and red fox individually. In the cases where agama and argali received all of the weight, results were the opposite—the future density decision was the highest scoring in both scenarios. For the scenario where argali and Mongolian marmot were weighted 50:50, each of the alternatives performed almost equally well—this seems like a reasonable outcome as trends in livestock density had opposite effects on argali and marmot. Overall, the minimum livestock density decision alternative had the highest utility score summed across all weighting scenarios (510), while the future density decision alternative performed worst (utility score of 290). Sensitivity to weighting scenarios was high, with utility scores differing substantially depending on the priority weighting assigned to each species (Table 9; Figure 11).

2.5. Discussion

Mongolian steppe habitats and wildlife species are under threat from the combined forces of overgrazing and climate change (Hilker et al. 2014). Nearly 70% of Mongolian pasture land is classified as degraded with 6-10% of that habitat determined to be damaged beyond the point of rehabilitation (Oyuntulkhuur and Batkhishig 2019). Much of this degradation is due to the increasing number of goats on the landscape, fueled by ever-growing demand for cashmere wool (Bazha et al. 2012, Liu et al. 2013, Hilker et al. 2014). Multiple groups have invested in creating sustainable solutions to cashmere goat management that balance industry profit with herder livelihoods and environmental health (Oyuntulkhuur and Batkhishig 2019, UNDP Mongolia 2019a, UNDP Mongolia 2019b). Each group has a different approach and there is little consensus on what sustainable management entails or how to measure it. This has stymied efforts to create broadly accepted sustainable cashmere standards (UNDP Mongolia 2019b).

In our study, we demonstrate the use of an adaptive resource management framework for informing cashmere management decisions. The framework allowed us to explicitly measure performance of livestock density decision alternatives against values for five representative species at Ikh Nart Nature Reserve that reflect the state of environment at multiple scales. Monitoring data and updated imagery classification allowed us to update the framework to account for changing landscape conditions and fine-tune habitat composition and wildlife occupancy model performance. Comparing utility scores for each decision alternative allowed us to determine an optimal management decision to maximize our wildlife sustainable outcomes. The study builds on other existing sustainable cashmere initiatives by using empirical models as tools to predict future conditions and a structured decision making approach that is transparent, data driven, and adaptive to ongoing changes in the environment.

Our study shows that the management alternative with the minimum goat density (18 livestock/km^2) is expected to result in the best overall outcomes for wildlife. While the output values from our framework show relatively low amounts of change in occupancy over the next five years for the five species we examined, research has shown that even minor changes in species occupancy can have consequences for wildlife population viability (Brown et al. 2018). The reality that fewer livestock on the landscape leads to better outcomes for wildlife makes intuitive sense and minimizing the number of livestock permitted to graze in the nature reserve would likely have positive outcomes for wildlife.

Despite the logic of that finding, utility score sensitivity to the weighting of different species was high and two of our species, argali sheep and toad-headed agama, were shown to have higher utility scores for the management alternatives with greater livestock densities. It is unclear why this would be the case for argali given the variables that drive occupancy (Murdoch et al. 2017). For agama, this increase appears to be attributed to the increase in open habitat (Murdoch et al. 2013). Habitat composition models showed a stark increase of open plains habitat and decrease of low-density shrub habitat with greater densities of livestock on the landscape; however, there may be other factors that influenced this outcome. For instance, there is no bare ground classification in the original habitat map. As such, much of the bare ground was classified as short grass steppe or semi-shrub steppe. Past studies have shown that increases in goat density actually lead to more shrubs and less grassland, so not accounting for bare ground could be one explanation for this unexpected result and skew perception of the landscape to be healthier than it may actually be (Liu et al. 2013).

Ikh Nart landscape is highly variable, and the ARM process will be useful for identifying which factors most influence the landscape and reducing uncertainty in model predictions over time. For instance, we recognize our habitat composition modeling process is an over-simplification of the factors that shape habitat on the landscape, but intend for this model to serve an illustrative process of how adaptive resource management can be applied in this scenario and for our framework to serve as a foundation for future research efforts. The relationship between climate, livestock, and habitat is still not fully understood and determining the most descriptive habitat composition models will provide an opportunity to better understand the landscape and species outside the five representative ones in this study.

Other top values identified by stakeholders were not considered in our framework but could be incorporated into the decision-making framework in the future (see Figure 4, Figure 7, Figure 12). For instance, water and quality forage are the most critical resources for people and wildlife in Ikh Nart, with stakeholders identifying sufficient water and sufficient quantity/quality of forage as their top two priorities (Table 4). To my knowledge, hydrology of the Ikh Nart area has not been studied to date. Numerous factors could be contributing to its scarcity, including over-grazing, geomorphology of the region, mining, tourists, and climate change. Models for how each of these factors influence ground water and springs could be incorporated into the decision-making framework to reduce uncertainty in those relationships. Similarly, incorporating models related to forage condition could reveal ecological thresholds that decision-makers must maintain to reduce impacts on environmental elements (Martin et al. 2009). Including water and forage-related elements in the framework is critical for advancing informative management decisions.

It is also critical for the framework to include other components of sustainability (economic and social values). If elements of herder livelihoods and culture were accounted for as attributes in the framework and utility scores, there would likely be a different optimal decision alternative that balances outcomes for both environment (wildlife) and humans. Incorporating values related to social and economic criteria is imperative to a truly sustainable decision-making process (Mustajoki et al. 2011, Ranger et al. 2016) and our framework has the flexibility to incorporate these components once they are created.

With the current decision alternatives, most likely the decision that brings the greatest long-term benefit to wildlife and the landscape in aggregate would be maintaining the lowest number of livestock on the landscape as possible. However, if managers were to do that given current conditions, herders would likely not be able to make an adequate living and this would have deep cultural/social ramifications, not just financial ones. There are tradeoffs that come with each management action and the desired outcomes. Likely one action will not be the best for all, but with the ARM framework and utility scoring, we have a tool that can help to quantify the degree to which each decision fulfills each goal. There is also a transparent process showing how that outcome was determined, which will allow mangers to make a decision that best maximizes all possible outcomes or allows managers to make a different management decision knowing what the subsequent tradeoffs will be. Finally, ARM provides for ‘double-loop’ learning, where managers can periodically revisit management objectives and criteria (Conroy and Peterson 2013).

This study serves as a pilot to demonstrate the utility of a framework for informing decision-making for livestock management. Future studies can build from this foundation to develop a broader management framework that incorporates multiple dimensions of sustainability (ecological, economic, and social). Such a framework will be key to supporting Ikh Nart rangeland management goals (Garroutte and Wingard 2019) and could contribute more broadly to the efforts to develop a sustainable cashmere certification program.

CONCLUSIONS

This study demonstrated the application of an adaptive resources management framework for informing management decisions on livestock density at the Ikh Nart Nature Reserve in Mongolia. The project focused solely on the ecological (wildlife) components to demonstrate the workflow of the decision-making framework. We focused on wildlife for this pilot ARM framework, as wildlife have been the focus of research in the region for many years and published tools, models, and data exist for numerous species. Using models of the relationship between livestock density, habitat composition, and wildlife species occupancy, we were able to determine the optimal management decision for the given ecological priorities—minimum livestock density.

Ecology is only one component of sustainability, however, and wildlife was only one of the top management values identified by stakeholders. Stakeholders ranked water and forage condition higher than any of the subsequent values, including wildlife. In order to make an informed management decision that is holistic, effective, and that local stakeholders adopt, addressing other priority areas will be necessary. Bringing in social and economic aspects into the framework would also lead to better decisions and stronger support among stakeholders.

Current events have only highlighted the need for an adaptive way to inform cashmere goat management in Mongolia. With the price of cashmere decreasing approximately 40% from $38 per kg in 2019 to $24-27 per kg in 2020 (Spina 2021), greater risk of extreme weather patterns, such as dzuds, and potential opening of tariff-free import of cashmere to the US through the Third Neighbor Trade Agreement, these pressures may force herders to continue to increase their herds. Incorporating these elements into our management framework would help managers at Ikh Nart adapt management strategies over time.

Ikh Nart is a multi-use landscape, and stakeholders broadly support the various uses of the reserve (Garroutte and Wingard 2019). As such, incorporating factors such as access to water, rangeland quality, herder livelihoods, and animal/human health are imperative for a more comprehensive ARM framework. An MCDA workflow exercise using attributes from the Multi-Attribute Value Tree (Figure 7) shows the potential effects of incorporating other components in the decision-making framework (Figure 12). The workflow demonstrates the influence of two hypothetical livestock density decision scenarios (Minimum and Medium) on the value of cashmere and livestock/wildlife/ human health in addition to wildlife occupancy. Two different weighting scenarios were also examined: weighting each attribute equally, versus prioritizing income by weighting the value of cashmere 0.5 and the two other attributes 0.25 each (Figure 12).

The workflow illustrates how the ideal outcome changes depending on what values are incorporated in the framework and how they are weighted. Continued conversation with stakeholders and scientists is critical to determine appropriate value and weight for each criterion. These relationships are not necessarily linear. For instance, economically, the price of cashmere could directly influence the number of goats herders would like to keep, with higher prices allowing herders to maintain smaller herds, however, weather variability and loan obligations may incentivize herders to maintain larger herds for contingency.

Rangeland management at Ikh Nart realistically requires more fine-scale management strategies than regulating overall goat density on the landscape. Strategies that are more feasible include limiting grazing in ecologically vulnerable sites in the reserve or during key wildlife behavioral periods (e.g., breeding season), rotational grazing depending on vegetation conditions, and incentivizing herders to limit livestock numbers through fines on herds over a certain size limit.

To inform these more nuanced management strategies, research should focus on better understanding the relationships between livestock and the landscape at Ikh Nart. I recommend a future study radio-collar livestock to more precisely estimate space use and livestock effects on vegetation communities at a finer scale. This research will help determine the best spatial and temporal management solutions for compromise between herders and wildlife.

Management of Ikh Nart is complex and multi-dimensional despite its small size. This study shows that ARM can increase transparency and assist in quantification of intangible values, ideally leading to stakeholder buy-in and a more informed management strategy. Such a tool is necessary not only for managers, but also for fashion brands to be able to verify the cashmere they source and market their product to end-line consumers. If the ARM decision-making framework proves to be successful in our study area, other organizations could develop similar models based on their own unique sustainable cashmere efforts and socio/ecological contexts.

TABLES

Table 1. Institutions currently funding or operating “sustainable cashmere” projects in Mongolia (UNDP Mongolia 2019a).

Institution	Project Name	Location (Aimag)
Asian Development Bank (ADB)	Supporting Agriculture Value Chain Project	Arkhangai, Bayankhongor, Khuvsgul, Umnugovi, Zhavkan
Agronomists and Veterinarians Without Borders (AVSF)	1) Sustainable Cashmere-Fibre Supply Chain in Mongolia Project, 2) Sustainable Textile Production and EcoLabelling in Mongolia (STeP EcoLab) Project	Bayankhongor
Swiss Development Corporation (SDC)	Green and Gold Animal Health Project	All aimags except for Ulaanbaatar
Sustainable Fibre Alliance (SFA)	Sustainable Cashmere Project	Arkhangai, Bayankhongor, Dornod, Dornogovi, Khneti Umnugovi, Uvurkhangai Zhavkan
United Nations Development Program (UNDP)	Piloting the Sustainable Cashmere Value Chain Business Model Project	Dornod
Wildlife Conservation Society (WCS)[1]	Sustainable Cashmere Project	Umnugovi

[1] In conjunction with The Natural Capital Project, Oyu Tolgoi, and Kering

Table 2. Comparisons of institutions currently operating “sustainable cashmere” projects in Mongolia. Each project is rated as to whether they explicitly state a working definition of cashmere in their promotional material (Definition), include explicit and measureable elements of sustainability (Specific Measures), and include ecological, social, and economic elements in their approach. A + indicates the project meets a criterion, - means it is lacking, and * means unclear or vague.

Institution	Definition	Specific Measures	Ecological	Social	Economic
ADB	*	-	-	+	+
AVSF	*	*	+	+	+
SDC	*	*	+	+	+
SFA	*	+	+	+	+
UNDP	*	*	*	+	+
WCS	*	+	+	*	*

Table 3. Stakeholder analysis to determine key parties to involve in the decision-making process related to sustainable cashmere production in the Ikh Nart Nature Reserve region, Mongolia. Stakeholders were given a rating of “low”, “medium”, or “high” depending on the perceived influence they have on the decision and the perceived influence the decision will have on the stakeholder.

Potential stakeholder	Ability of the decision to affect the stakeholder	Stakeholder ability to affect the decision
Individual herders	High	Medium
Herder Collective units[1]	High	High
Soum (county) officials	High	High
Aimag (province) officials	Medium	High
Ikh Nart Scientific Authority	Medium	High
Ikh Nart research staff	Medium	Medium
Industry representatives	Medium	Low

[1] Groups of herders self-organized to advocate for specific practices and be able to apply for grant funding.

Table 4. Stakeholder values elicited during a sustainable rangeland management workshop in the Ikh Nart Nature Reserve region of Mongolia. Seven participant groups compiled lists of values. Then individual workshop participants voted on their first, second, and third priority rankings. Individual rankings were tabulated to generate a value weight and determine the final overall ranking.

Value	Description	Groups that listed value	First priority	Second priority	Third priority	Weights	Final ranking
Sufficient water	Ensuring actions promote the amount of available and accessible water sources.	7	32	7	4	28.50	1
Sufficient quality and quantity of pasture	Ensuring sure actions promote both the quality and quantity of forage in pasture for livestock.	7	3	18	1	11.50	2
Alternative livelihoods	Ensuring actions promote tourism, which was brought up as the best alternative livelihood strategy.	6	0	1	1	0.75	9
Wildlife populations	Ensuring actions promote the existence of wildlife populations, particularly argali sheep and Mongolian marmot.	5	1	6	8	5.75	4
Livestock productivity	Ensuring that the actions promote livestock health, which promotes productivity and quality.	6	2	3	5	4.25	6
Wildlife, livestock, human health	Ensuring that actions promote the health of livestock, which is needed to promote the health of people and wildlife.	6	1	5	7	5.00	5
Education/policy	Developing opportunities for herders to be informed about and engaged in conservation education and effective policies.	4	4	5	15	9.25	3

Physical landscape	Ensuring that any activities promote the physical viewscapes, the rocky outcroppings, and the beauty of Ikh Nart landscapes.	2	2	1	0	2.00	8
Nomadic culture	Ensuring that any actions promote the opportunity for herders to maintain their livelihoods in a sustainable way, promotes herders traditional practices and knowledge about sustainable grazing practices, and promotes their culture and seat at the table.	4	2	1	6	3.50	7

Table 5. Details of species occupancy models used in the development of a decision-making framework for sustainable cashmere production in the Ikh Nart region of Mongolia. The framework used models previously developed and models updated with monitoring data.

Species	Scientific name	Data type	Model type	Analytical program	Original top model covariates	Updated top model covariates	Source
Argali sheep	*Ovis ammon*	Presence-only	Single season occupancy model	MaxLike package for R	Rocky outcrop (+) Water (+)	Rocky outcrop (+) Road (-)	Murdoch et al. 2017
Corsac fox	*Vulpes corsac*	Presence-only Detection/Non-detection	Single season occupancy model	MaxLike package for R Unmarked package for R	Tall grassland (+) Shrubland (+) Open plain (+)	Shrubland (+) Rocky outcrop (-)	Lkhagvasuren et al. 2016
Red fox	*Vulpes vulpes*	Detection/Non-detection	Single season occupancy model	Program PRESENCE Unmarked package for R	Rocky outcrop (+) Shrubland (+) Percent vegetation cover (-)[1]	Tall vegetation (-) Percent vegetation cover (-)[1]	Murdoch et al. 2016
Toad-headed agama	*Phrynocephalus versicolor*	Detection/Non-detection	Single season occupancy model	Program PRESENCE Unmarked package for R	Rocky outcrop (-) Temperature (polynomial)[1]	Open plains (+) Temperature (polynomial)[1]	Murdoch et al. 2013
Mongolian marmot	*Marmota sibirica*	Detection/Non-Detection	Single season occupancy model	Generalized Linear Model selection in R	---	Road (+) Shrubland (+)	Becchina 2020 S. Buyandelger, unpublished data

[1] Detection probability covariate in the model.

Table 6. Description of variables used to model occupancy probability for five focal wildlife species in the Ikh Nart Nature Reserve region of Mongolia.

Category	Variable	Code	Description	Measure in models	Species with variable in analysis
Habitat types	High density shrub	HDS	Open areas with > 100 shrubs/ha.	Proportion within 250 m	
	Low density shrub	LDS	Areas with < 100 shrubs/ha mixed with patchy rock or talus.	Proportion within 250 m	
	Rocky outcrop	RO	Areas with rock outcrops and sparse vegetation cover.	Proportion within 250 m	Argali, corsac fox, red fox, agama
	Shortgrass steppe	SGS	Areas dominated by short grasses and forbs.	Proportion within 250 m	
	Semi shrub steppe	SSS	Areas dominated by turfy semi-shrubs interspersed with bare ground.	Proportion within 250 m	
	Tall vegetation	TV	Areas with vegetation > 1 m in height including grasses, shrubs or stands of trees.	Proportion within 250 m	Argali, corsac fox, red fox, agama
	Shrubland	SH	Combination of HDS and LDS.	Proportion within 250 m	Argali, corsac fox, red fox, agama
	Open Plain	OP	Combination of SGS and SSS.	Proportion within 250 m	Argali, corsac fox, red fox, agama
Human features	Ger	GER	Traditional Mongolian yurts belonging to herders dispersed across Ikh Nart.	Distance to nearest ger in meters	Argali, corsac fox, red fox, agama
	Road	ROAD	Dirt roads that run through the nature reserve.	Distance to nearest road in meters	Argali, corsac fox, red fox, agama
Physical/ abiotic factors	Ruggedness	RUGG	Topographic ruggedness determined by DEM, slope, and aspect characteristics.	Index from 1 (lowest) to 9 (highest)	Argali, corsac fox, red fox, agama
	Spring	SPR	Natural freshwater springs.	Distance to nearest spring in meters	Argali
	Marmot colony	M	Active marmot colony.	Yes/No	Corsac fox, red fox, agama
Detection probability	Temperature	temp	Air temperature at time of survey.	Degrees Celsius (˚C)	Agama
	Cover	cover	Vegetative cover within survey plot at time of survey.	Percent	Corsac fox, red fox

Table 7. A) Distribution of training sites by habitat type for classification of a Landsat image of the Ikh Nart Nature Reserve region (LC08_L1TP_130028_20190802). B) Number of pixels and proportions of each habitat type in the classified image — SGS and SSS were merged into one habitat type (OPEN) as were TG and TREE (TV).

A.

Habitat Type	Training Sites
HDS	57
LDS	46
RO	39
SGS	56
SSS	13
TG	39
TREE	36
WTR	14
Total	*300*

B.

Habitat Type	Pixels	Proportion
HDS	183,938	0.23
LDS	114,645	0.14
RO	54,473	0.07
OPEN	394,130	0.49
TV	52,033	0.06
WTR	10,865	0.01
Total	*810,084*	*1.00*

Table 8. A) Predicted occupancy probability for each species under each livestock density alternative. B) The difference in predicted occupancy for each species between the livestock density alternatives.

A.

Species	Predicted occupancy based on density scenarios				
	Minimum	Low	Medium	Maximum	Future
Argali	0.40	0.40	0.40	0.40	0.40
Corsac	0.28	0.28	0.28	0.28	0.28
Agama	0.76	0.77	0.78	0.79	0.79
Red	0.70	0.69	0.69	0.69	0.69
Marmot	0.03	0.02	0.02	0.02	0.02

B.

Species	Change in occupancy across alternatives				
	Minimum	Low	Medium	Maximum	Future
Argali	0.00	0.00	0.00	0.00	0.00
Corsac	0.00	0.00	0.00	0.00	0.00
Agama	0.00	0.01	0.02	0.03	0.03
Red	0.00	0.00	0.00	0.00	0.00
Marmot	0.00	0.00	-0.01	-0.01	-0.01

Table 9. A) Species priority weighting based on example wildlife conservation goals that include weighting each species equally, assigning all weight to one species, dividing weight equally between argali sheep and Mongolian marmots, and dividing weight equally between corsac foxes and red foxes. B) Weights multiplied by the percent change in occupancy to get an overall utility score for each species priority weighting in each decision alternative (Figure 11).

A.

Weighting Scenario	Weight assigned for each species				
	Argali	Mongolian marmot	Red fox	Corsac fox	Agama
Equal	20	20	20	20	20
Argali	100	0	0	0	0
Marmot	0	100	0	0	0
Corsac fox	0	0	0	100	0
Red fox	0	0	100	0	0
Agama	0	0	0	0	100
Argali and marmot	50	0	0	0	50
Corsac and red fox	0	0	50	50	0

B.

Weighting Scenario	Utility scores based on livestock density alternatives and species priority weighting				
	Minimum	Low	Medium	Maximum	Future
Equal	60	53	47	41	40
Argali	0	31	62	93	100
Marmot	100	64	33	5	0
Corsac fox	100	69	38	7	0
Red fox	100	69	38	7	0
Agama	0	32	64	94	100
Argali and marmot	50	48	48	49	50
Corsac and red fox	100	69	38	7	0
Sum	***510***	***435***	***367***	***303***	***290***

FIGURES

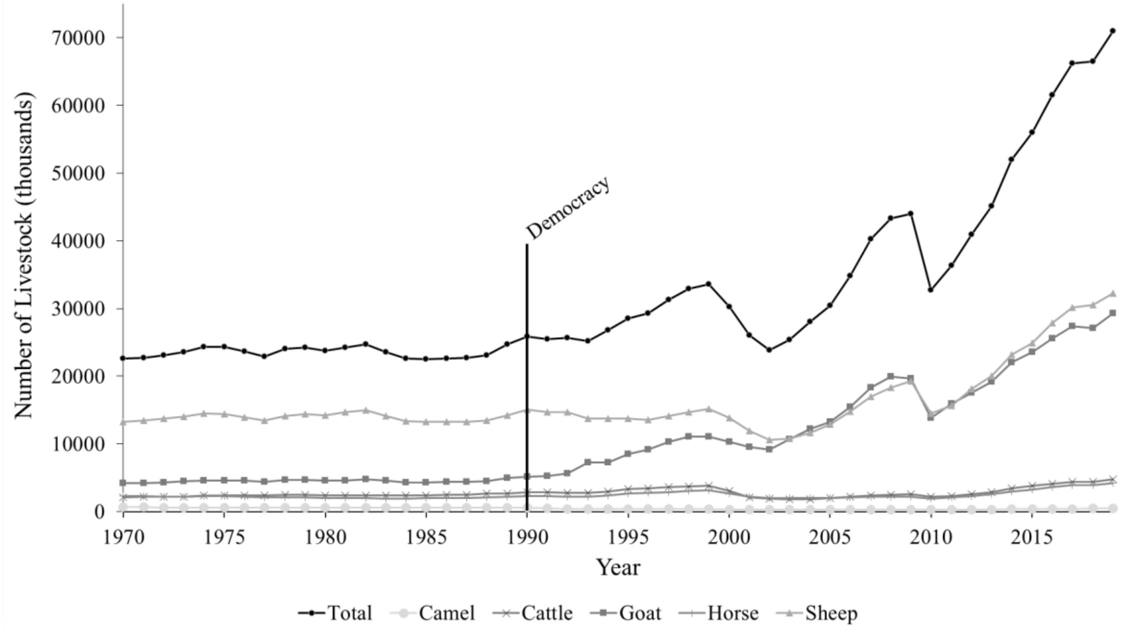


Figure 1. Annual numbers of the five main types of livestock—camel, cattle, goat, horse, sheep—as well as total livestock in Mongolia from 1970 to 2019 (MSIS 2020). The vertical bar indicates the start of democracy in Mongolian following the democratic revolution and collapse of the Soviet Union.

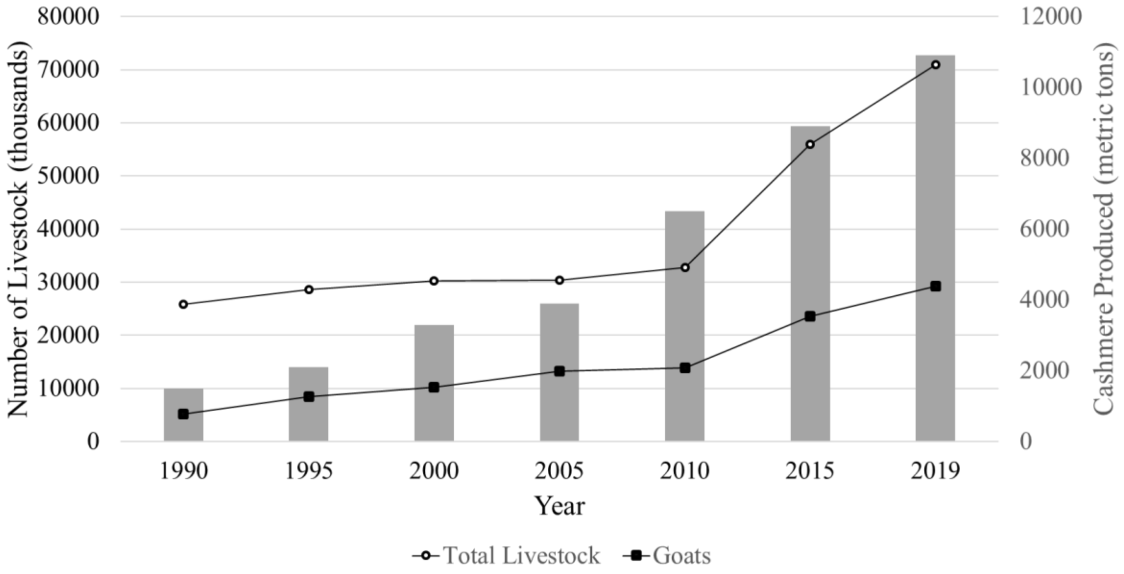


Figure 2. Trends of cashmere produced per year compared to annual goat and total livestock numbers in Mongolia from 1990 to 2019 (NSO Mongolia 2020).

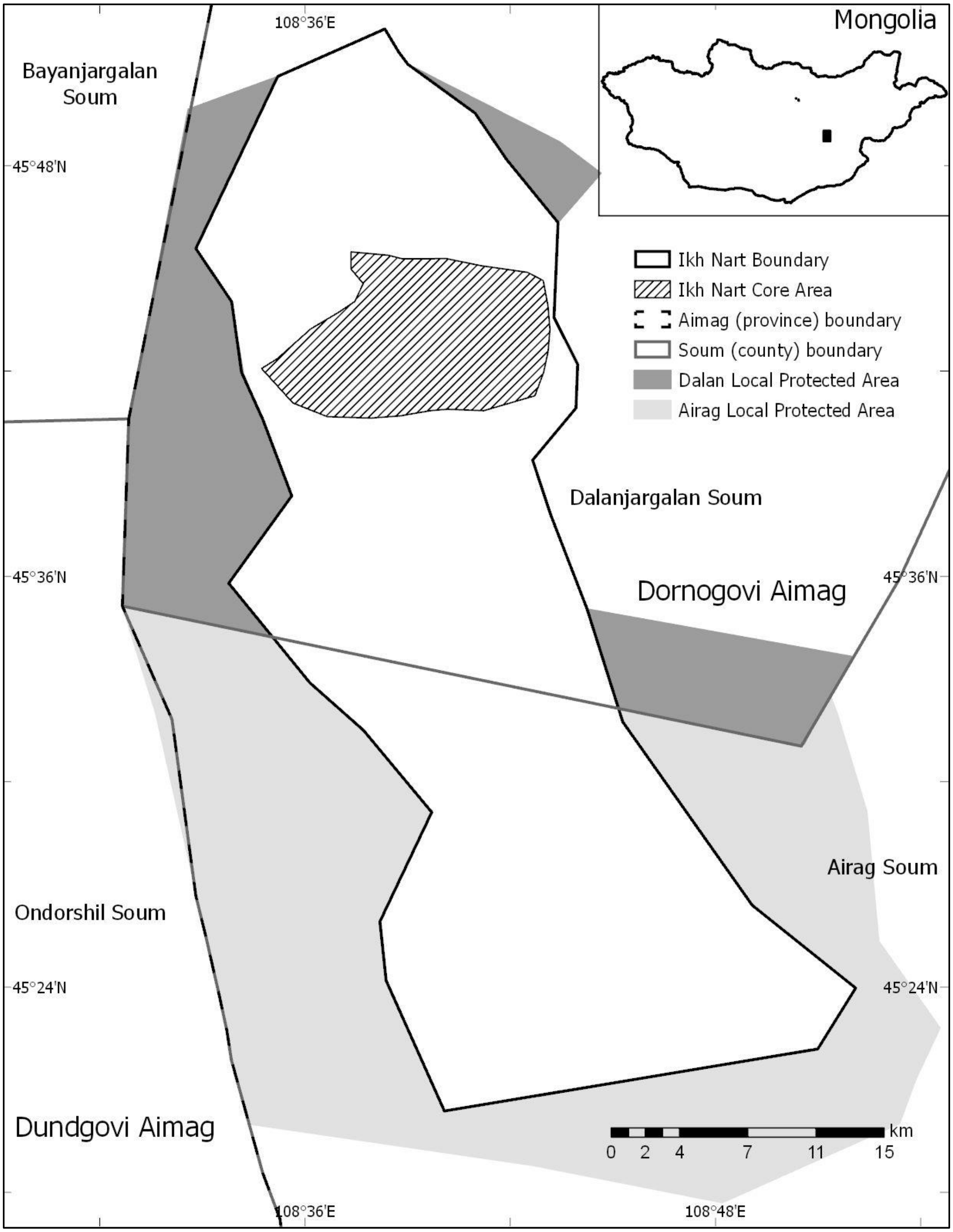


Figure 3. Map of Ikh Nart Nature Reserve and associated protected areas relative to country, Aimag, and Soum boundaries.

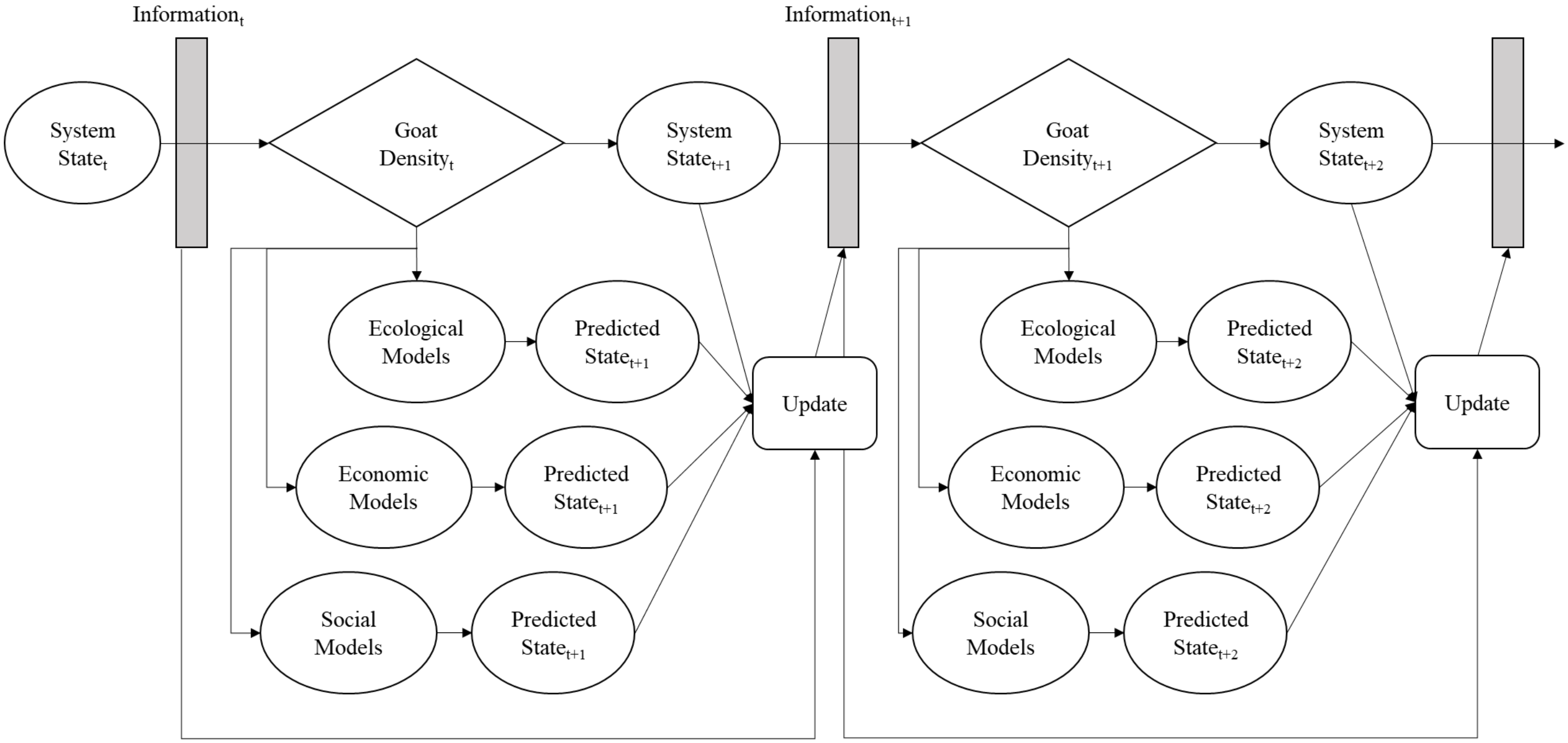


Figure 4. Influence diagram of an Adaptive Resource Management (ARM) decision structure developed for goat density with ecological, economic, and social models of system dynamics (adapted from Conroy and Peterson 2013). Annual monitoring data provides 'information' (grey boxes) that is compared with model predictions to update models. Updating allows decisions to adapt to changing conditions over time.

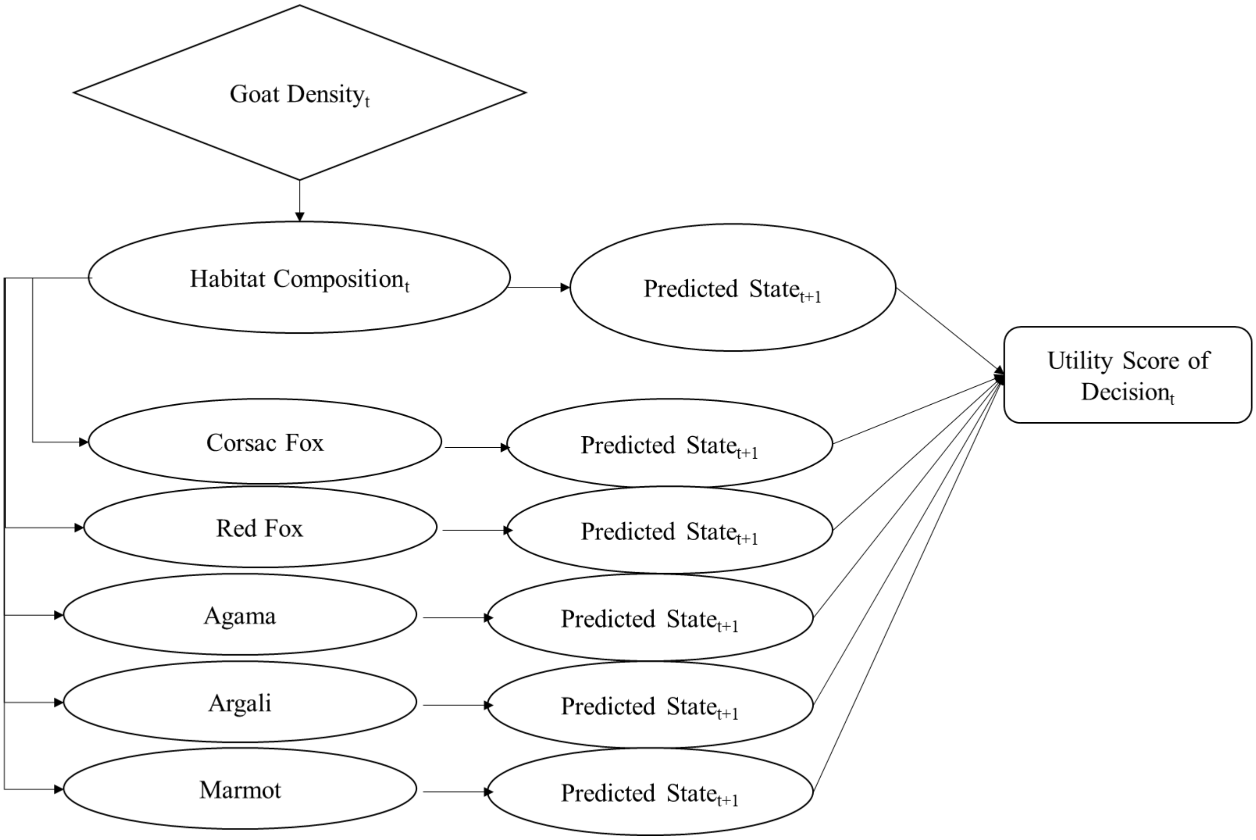


Figure 5. Conceptual influence diagram for a single-year time step of the ecological models in the decision framework for goat density in Ikh Nart Nature Reserve, Mongolia (see Figure 4). The goat density decision affects habitat composition, which can then be input into models to generate predicted states of occupancy for the species of interest and future habitat composition. These predicted occupancy and habitat composition states are used to calculate a utility score to illustrate how well the decision alternative meets management objectives. Subsequent monitoring will provide data to update the model structure in the next time step.

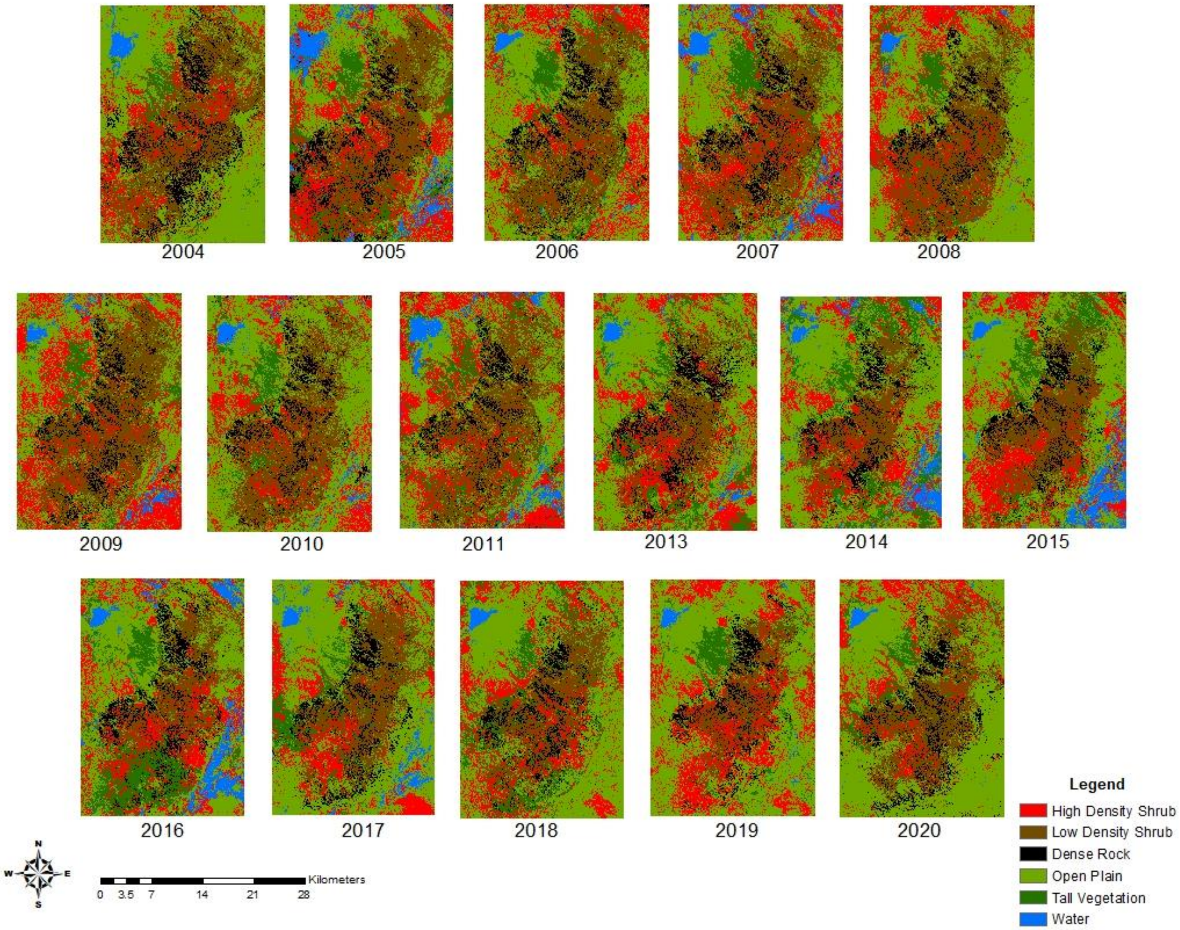


Figure 6. Habitat classification maps for each year from 2004 to 2020, except for 2012 (too low quality of an image due to Landsat 7 scan line corrector issues).

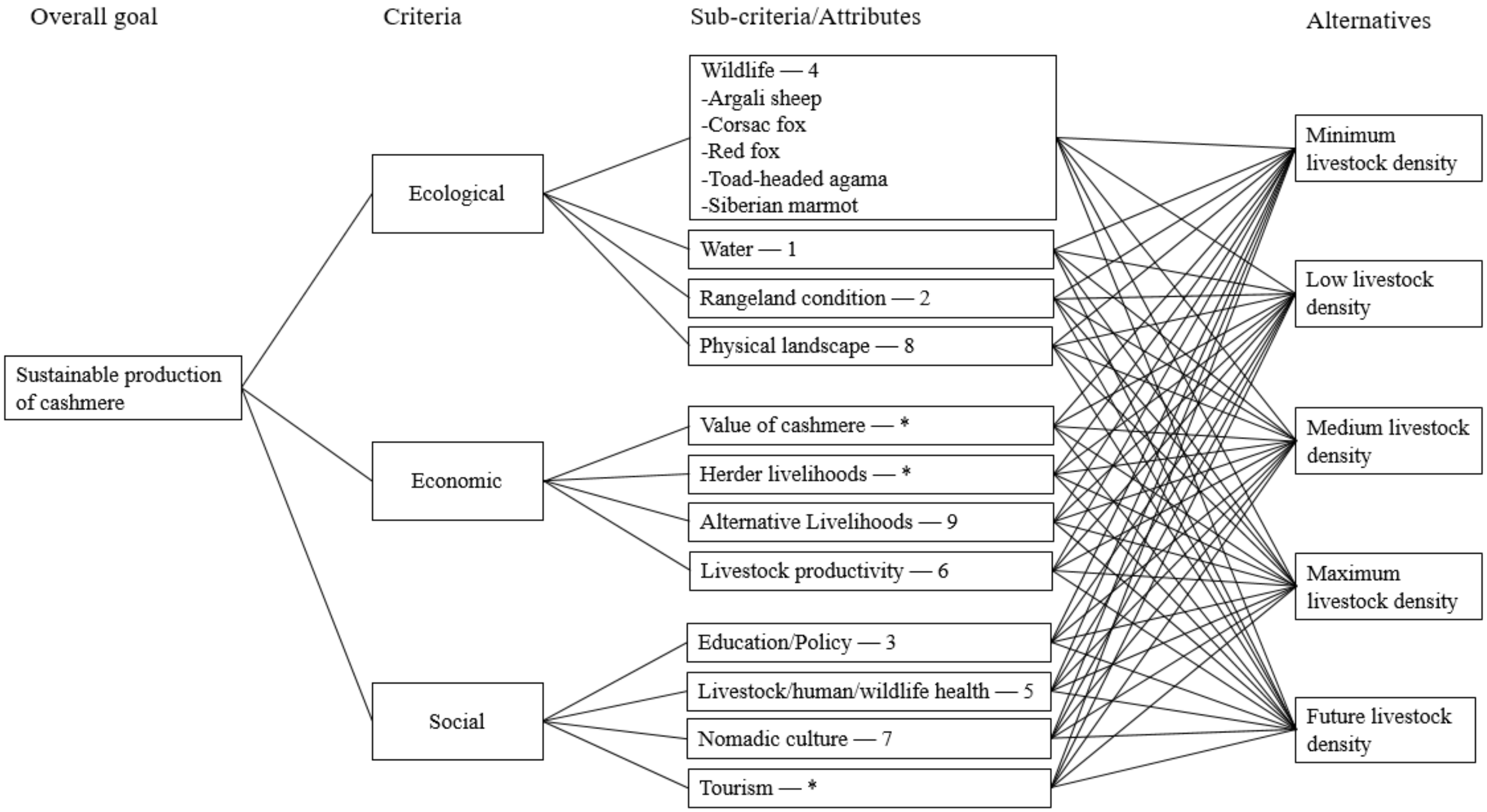


Figure 7. Multi-Attribute Value Tree for sustainable cashmere production at Ikh Nart. The tree starts with the overall goal of sustainable cashmere production on the left side, which is then broken down into three sustainability criteria. These broad criteria are further decomposed into the top nine values identified by stakeholders (Table 4), numbered in rank order in the attribute boxes, as well as several additional criteria (*) we deemed critical for consideration.

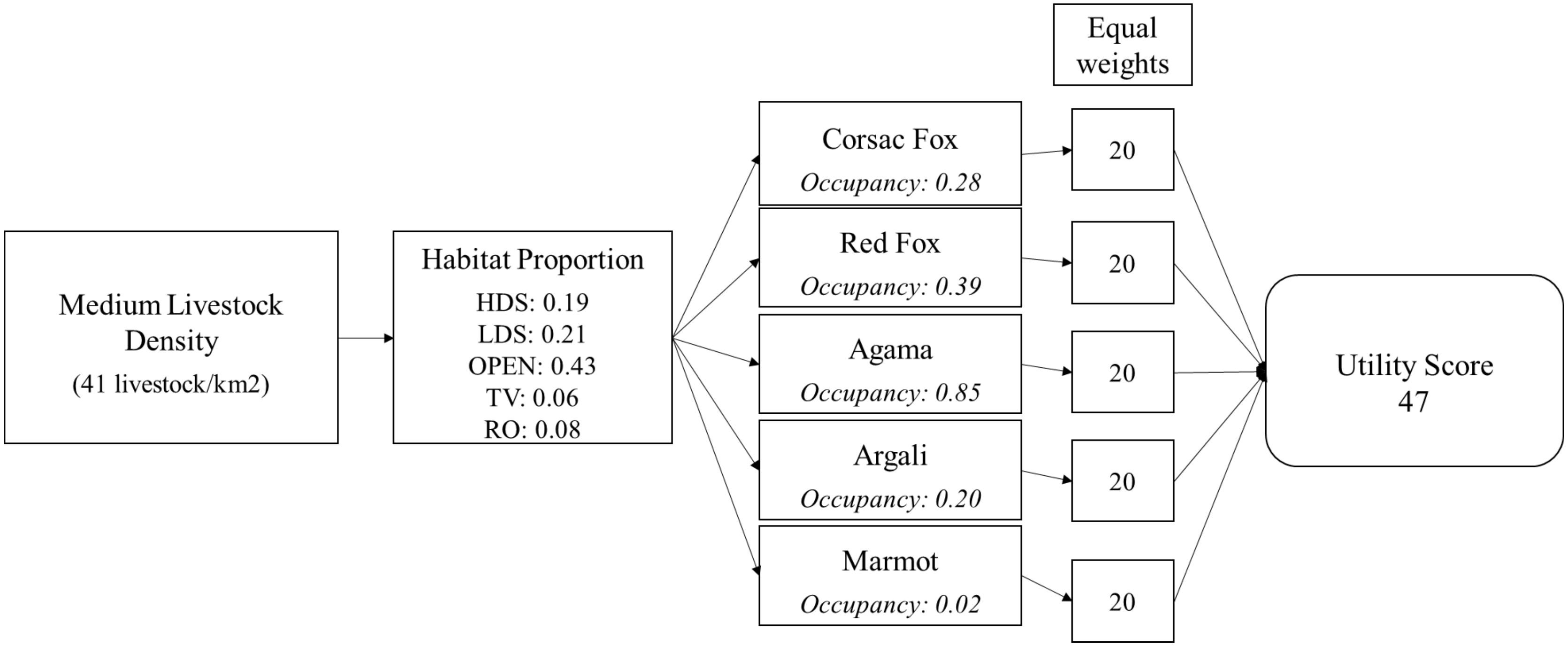


Figure 8. The workflow for calculating the utility score for a single livestock management decision (medium density) and one weighting assigned (equal across all species) for the wildlife criteria. Utility scores were calculated by taking the difference in predicted occupancy for each species between the livestock density scenarios and multiplying that by the assigned weight.

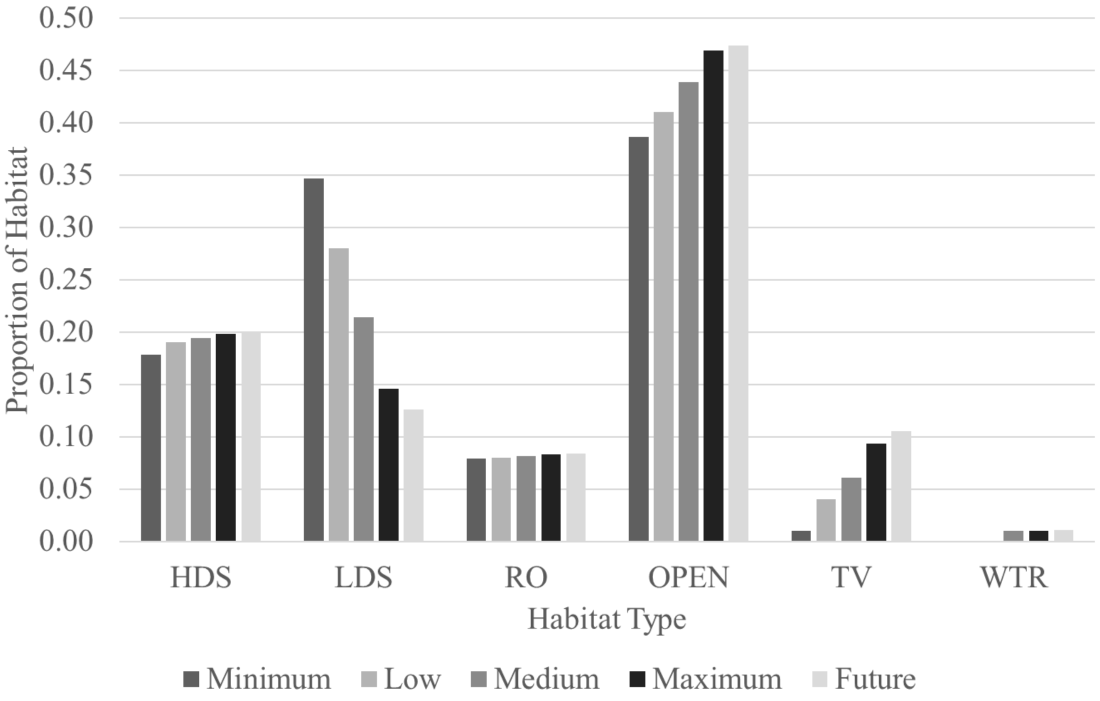


Figure 9. Predicted proportion of each habitat type based on livestock density decision scenarios.

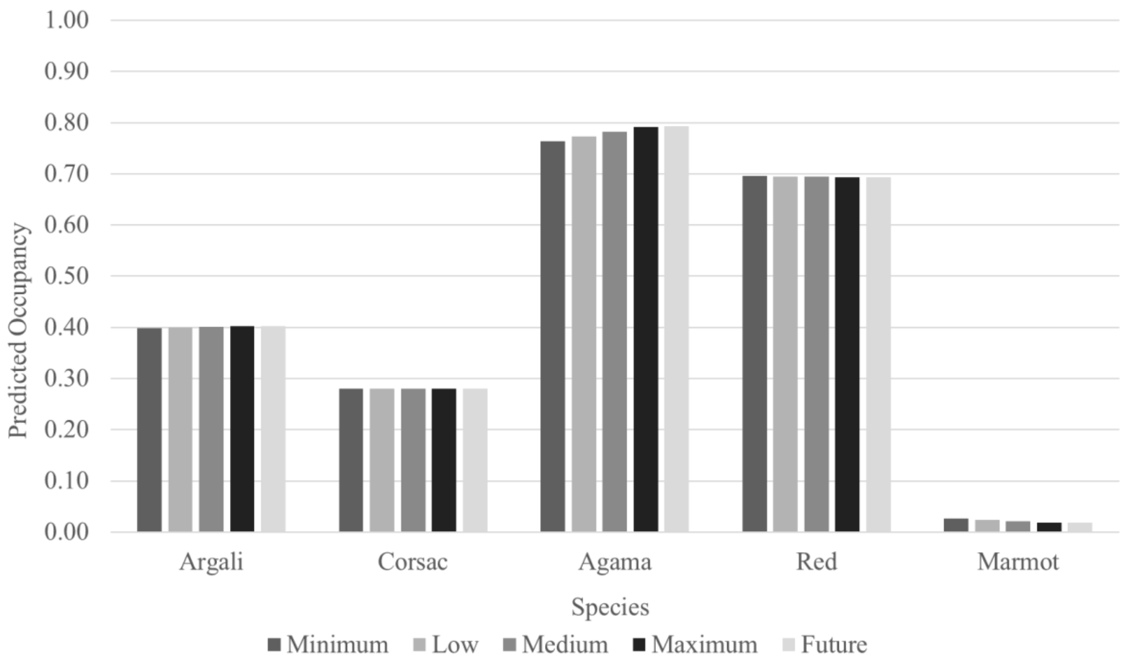


Figure 10. Species occupancy based on 2019 top species models and different livestock density decisions.

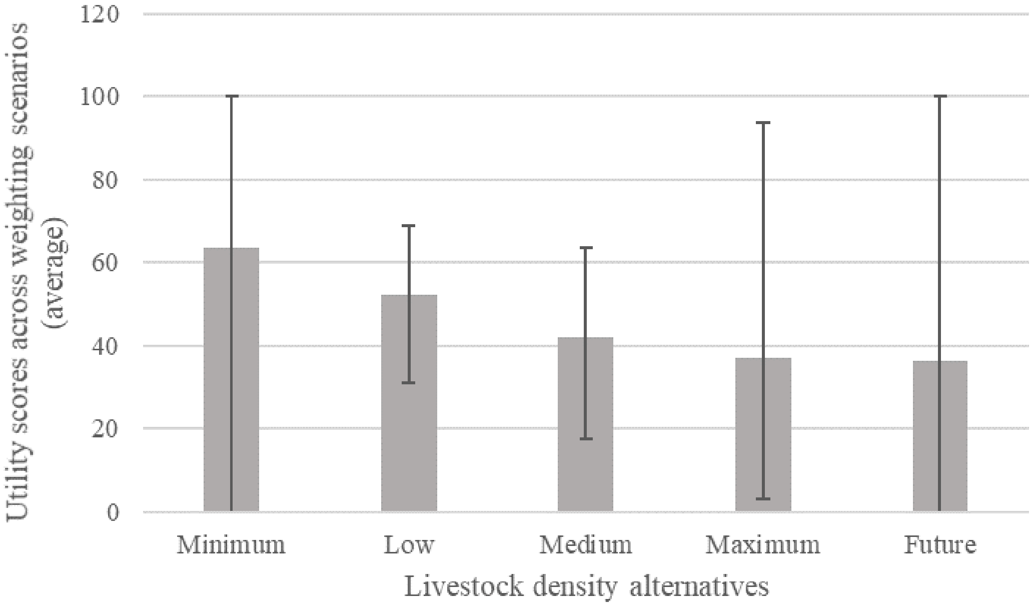
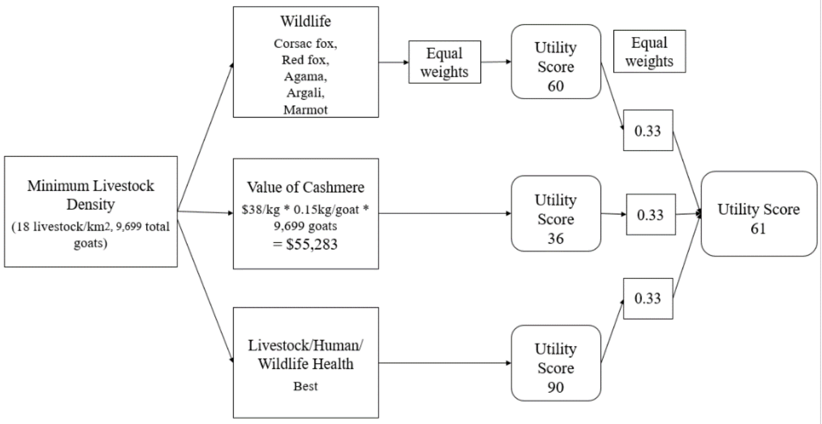
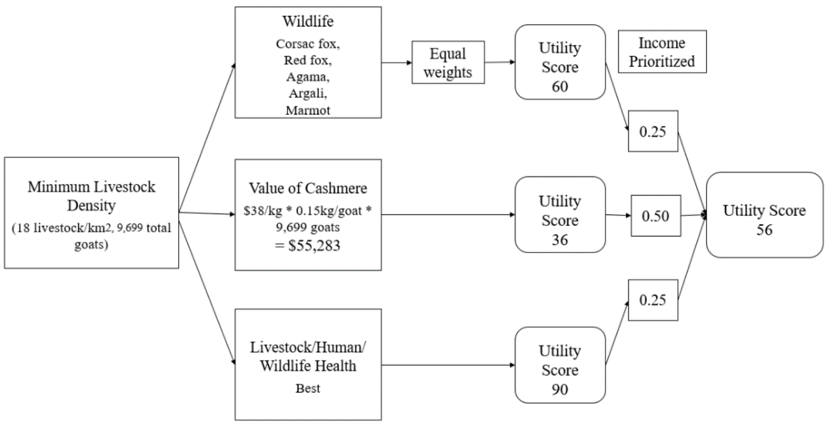


Figure 11. Average utility scores taken from all species priority weightings for each livestock density decision alternative (Table 9). Bars indicate utility score sensitivity to the weight assigned to each species, displaying the range of utility score values from the priority weightings in Table 9.

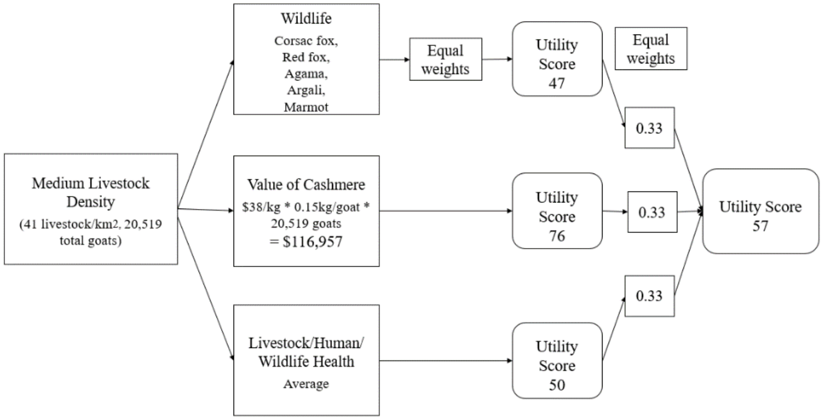
a. Minimum density, equal weights



b. Minimum density, income prioritized



c. Medium density, equal weights



d. Medium density, income prioritized

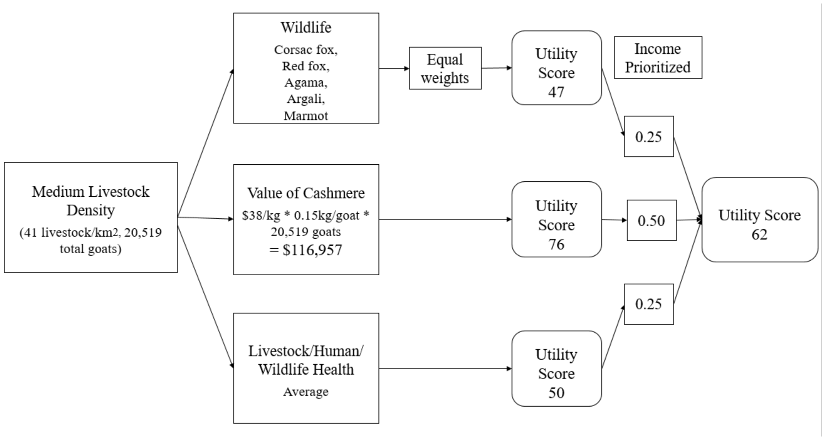


Figure 12. Workflow for two different livestock management decisions (minimum and medium density) and two weighting assignments (equal across all species, and income prioritized: value of cashmere 0.50 with the other attributes 0.25 each) for the wildlife, value of cashmere, and livestock/human/wildlife health criteria. Wildlife scores were calculated by taking the difference in predicted occupancy for each species between the livestock density scenarios and multiplying that by the assigned weight. Value of cashmere scores were based on a value proportion from No Herding ($0) to a future density scenario ($153,281). Livestock/human/wildlife health scores were based on rankings of predicted health from poor in the future density scenario to best in the minimum density scenario.

REFERENCES

Addison, J., and C. Brown. 2014. A multi-scaled analysis of the effect of climate, commodity prices and risk on the livelihoods of Mongolian pastoralists. Journal of Arid Environments 109:54-64.

Adem Esmail, B., and D. Geneletti. 2018. Multi-criteria decision analysis for nature conservation: A review of 20 years of applications. Methods in Ecology and Evolution 9:42-53.

Bazha, S. N., P. D. Gunin, E. V. Danzhalova, Y. I. Drobyshev, and A. V. Prishcepa. 2012. Pastoral degradation of steppe ecosystems in central Mongolia. Pages 289-319 *in* M. J. A. Werger and M. A. van Staalduinen, editors. Eurasian Steppes. Ecological Problems and Livelihoods in a Changing World. Springer Netherlands, Dordrecht.

Becchina, R. A. 2020. Recovering endangered Siberian marmot (*Marmota sibirica*): status and distribution in a steppe region of Mongolia. UVM Honors College Senior Theses.

Berger, J., B. Buuveibaatar, and C. Mishra. 2013. Globalization of the cashmere market and the decline of large mammals in Central Asia. Conservation Biology 27:679-689.

Bone, M., D. Johnson, P. Kelaidis, M. Kintgen, L. G. Vickerman, and D. B. Gardens. 2015. Steppes: the plants and ecology of the world's semi-arid regions. Timber Press, Portland, Oregon, USA.

Brown, M. L., T. M. Donovan, R. M. Mickey, G. S. Warrington, W. S. Schwenk, and D. M. Theobald. 2018. Predicting effects of future development on a territorial forest songbird: methodology matters. Landscape Ecology 33:93-108.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Second edition edition. Springer, New York, USA.

Chang, T., and L. Zachmann. 2020. Applying advanced geospatial analyses and modeling to understand the biophysical drivers of the spatiotemporal patterns of grassland phenology across grassland ecosystems in Mongolia and northern New Mexico. A report submitted to the Denver Zoo. Conservation Science Partners, Truckee, California, USA.

Chen, H.-L., and L. D. Burns. 2006. Environmental analysis of textile products. Clothing and Textiles Research Journal 24:248-261.

Conroy, M. J., M. W. Miller, and J. E. Hines. 2002. Identification and synthetic modeling of factors affecting American black duck populations. Wildlife Monographs:1-64.

Conroy, M. J., and J. T. Peterson. 2013. Decision making in natural resource management: a structured, adaptive approach. John Wiley & Sons, West Sussex, United Kingdom.

Dagvadorj, D., Z. Batjargal, and L. Natsagdorj. 2014. Mongolia second assessment report on climate change-2014. Ministry of Environment and Green Development of Mongolia, Ulaanbaatar, Mongolia.

Danforth, W. 2017. Export expansion and goat growth: cashmere quality declines threaten industry gains. Mongolia International Capital Corporation, Ulaanbaatar, Mongolia.

Davie, H. S., P. A. Stokowski, L. Ankhbayar, and J. D. Murdoch. 2014. Herders and wolves in post-soviet society: an ethnographic study in Mongolia's Ikh Nart Nature Reserve. Human Dimensions of Wildlife 19:319-333.

Freeman, M. C., G. R. Buell, L. E. Hay, W. B. Hughes, R. B. Jacobson, J. W. Jones, S. A. Jones, J. H. Lafontaine, K. R. Odom, J. T. Peterson, J. W. Riley, J. S. Schindler, C. Shea, and J. D. Weaver. 2013. Linking river management to species conservation using dynamic landscape-scale models. River Research and Applications 29:906-918.

Freeman, R. E. 2010. Strategic management: a stakeholder approach. Cambridge University Press, Cambridge, United Kingdom.

Garroutte, E., and G. Wingard. 2019. Ikh Nart rangeland management strategy: 2019 report. Denver Zoological Foundation, Denver, Coloardo, USA.

Hilker, T., E. Natsagdorj, R. H. Waring, A. Lyapustin, and Y. Wang. 2014. Satellite observed widespread decline in Mongolian grasslands largely due to overgrazing. Global Change Biology 20:418-428.

Jackson, D. S., J. D. Murdoch, and B. Mandakh. 2006. Habitat classification using Landsat 7ETM+ imagery of the Ikh Nart Nature Reserve and surrounding areas in Dornogobi and Dundgobi aimags, Mongolia. Mongolian Journal of Biological Sciences 4:33-40.

Keeney, R. L., and H. Raiffa. 1976. Decisions with multiple objectives: Preferences and value tradeoffs. John Wiley & Sons, Inc., New York.

Kerven, C., B. McGregor, and S. Toigonbaev. 2009. Cashmere-producing goats in Central Asia and Afghanistan. Animal Genetic Resources Information 45:15-27.

Kozlowski, A., M. Bardecki, and C. Searcy. 2012. Environmental impacts in the fashion industry: a life-cycle and stakeholder framework. Journal of Corporate Citizenship 45:17-36.

Liu, Y. Y., J. P. Evans, M. F. McCabe, R. A. M. De Jeu, A. I. J. M. Van Dijk, A. J. Dolman, and I. Saizen. 2013. Changing climate and overgrazing are decimating Mongolian steppes. PLoS ONE 8:e57599.

Lkhagvasuren, M., J. D. Murdoch, T. Munkhzul, and A. M. Strong. 2016. Predicting the effects of habitat loss on corsac fox occupancy in Mongolia. Journal of Mammalogy 97:1153-1163.

Lozano, R. 2008. Envisioning sustainability three-dimensionally. Journal of cleaner production 16:1838-1846.

Martin, J., M. C. Runge, J. D. Nichols, B. C. Lubow, and W. L. Kendall. 2009. Structured decision making as a conceptual framework to identify thresholds for conservation and management. Ecological Applications 19:1079-1090.

Masson-Delmotte, V., P. Zhai, H. Pörtner, D. Roberts, J. Skea, P. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, and R. Pidcock. 2018. IPCC, 2018: summary for policymakers. IPCC: Geneva, Switzerland, 2018 1.

MSIS. 2020. Mongolian Statistical Information Service. National Statistics Office of Mongolia, http://1212.mn/.

Murdoch, J. D., H. Davie, M. Galbadrah, T. Donovan, and R. P. Reading. 2013. Do Siberian marmots influence toad-headed agama occupancy? Examining the influence of marmot colonies and three steppe habitats in Mongolia. Journal of Arid Environments 92:76-80.

Murdoch, J. D., H. Davie, M. Galbadrah, and R. P. Reading. 2016. Factors influencing red fox occupancy probability in central Mongolia. Mammalian Biology 81:82-88.

Murdoch, J. D., T. Munkhzul, S. Amgalanbaatar, and R. P. Reading. 2006. Checklist of mammals in Ikh Nart Nature Reserve. Mongolian Journal of Biological Sciences 4:69-74.

Murdoch, J. D., R. P. Reading, S. Amgalanbaatar, G. Wingard, and B. Lkhagvasuren. 2017. Ecological interactions shape the distribution of a cultural ecosystem service: Argali sheep (*Ovis ammon*) in the Gobi-Steppe of Mongolia. Biological Conservation 209:315-322.

Murphy, D. J. 2018. “We’re living from loan-to-loan”: pastoral vulnerability and the cashmere-debt cycle in Mongolia. Pages 7-30 *in* D. C. Wood, editor. Individual and Social Adaptations to Human Vulnerability. Emerald Publishing Limited, Bingley, United Kingdom.

Mustajoki, J., H. Saarikoski, M. Marttunen, A. Ahtikoski, V. Hallikainen, T. Helle, M. Hyppönen, M. Jokinen, A. Naskali, S. Tuulentie, M. Varmola, E. Vatanen, and A.-L. Ylisirniö. 2011. Use of decision analysis interviews to support the sustainable use of the forests in Finnish Upper Lapland. Journal of Environmental Management 92:1550-1563.

Myers, N., and J. Kent. 2003. New consumers: the influence of affluence on the environment. Proceedings of the National Academy of Sciences 100:4963-4968.

Nichols, J. D., M. C. Runge, F. A. Johnson, and B. K. Williams. 2007. Adaptive harvest management of North American waterfowl populations: a brief history and future prospects. Journal of Ornithology 148:343-349.

Nixson, F., and B. Walters. 2006. Privatization, income distribution, and poverty: the Mongolian experience. World Development 34:1557-1579.

NSO Mongolia. 2018. Mongolian statistical yearbook 2017. National Statistics Office of Mongolia, Ulaanbaatar, Mongolia.

NSO Mongolia. 2020. Mongolian statistical yearbook 2019. National Statistics Office of Mongolia, Ulaanbaatar, Mongolia.

Oyuntulkhuur, B., and B. Batkhishig. 2019. Roadmap to sustainability in cashmere value chain.*in* Sustainability in the Cashmere Sector. Sustainable Fibre Alliance, Ulaanbaatar, Mongolia.

Ranger, S., J. Kenter, R. Bryce, G. Cumming, T. Dapling, E. Lawes, and P. Richardson. 2016. Forming shared values in conservation management: An interpretive-deliberative-democratic approach to including community voices. Ecosystem Services 21:344-357.

Reading, R., D. Kenny, and B. Steinhauer-Burkart. 2011. Ikh Nart Nature Reserve. ECO Nature Edition, Ulaanbaatar, Mongolia.

Reading, R. P., J. D. Murdoch, S. Amgalanbaatar, S. Buyandelger, H. Davie, M. Jorgensen, D. Kenny, T. Munkhzul, G. Onloragcha, L. Rhodes, J. Schneider, T. Selenge, E. Stotz, and G. Wingard. 2016. From “paper park” to model protected area: the transformation of Ikh Nart Nature Reserve, Mongolia. PARKS 22:41-54.

Reed, M. S., A. Graves, N. Dandy, H. Posthumus, K. Hubacek, J. Morris, C. Prell, C. H. Quinn, and L. C. Stringer. 2009. Who's in and why? A typology of stakeholder analysis methods for natural resource management. Journal of Environmental Management 90:1933-1949.

Spina, M. 2021. Annual cashmere market report 2020. The Schneider Group.

Sternberg, T. 2008. Environmental challenges in Mongolia's dryland pastoral landscape. Journal of Arid Environments 72:1294-1304.

Sternberg, T. 2010. Unraveling Mongolia's extreme winter disaster of 2010. Nomadic Peoples 14:72-86.

Sustainable Fibre Alliance. 2017. Rangeland stewardship: code of practice. Sustainable Fibre Alliance, Ulaanbaatar, Mongolia.

UNDP Mongolia. 2019a. Comparative analysis of sustainable cashmere projects in Mongolia. United Nations Development Program. Ulaanbaatar, Mongolia.

UNDP Mongolia. 2019b. Sustainable Cashmere from Mongolia: A market assessment. United Nations Development Program. Ulaanbaatar, Mongolia.

van Eeden, L., C. Dickman, E. Ritchie, and T. Newsome. 2017. Shifting public values and what they mean for increasing democracy in wildlife management decisions. Biodiversity & Conservation 26:2759-2763.

Walters, C. J. 1986. Adaptive management of renewable resources. Macmillan Publishers Ltd.

Wildlife Conservation Society Mongolia. 2019. Initiatives: sustainable and wildlife-friendly cashmere value chain. Wildlife Conservation Society, Ulaanbaatar, Mongolia.

Wingard, J. R. 2001. Compendium of environmental law and practice in Mongolia., GTZ Commercial and Civil Law Reform Project, Ulaanbaatar, Mongolia.

World Bank. 2003. From goats to coats: institutional reform in Mongolia's cashmere sector. World Bank, Poverty Reduction and Economic Managment Unit, East Asia and Pacific Region, Washington, D.C. USA.

APPENDICES

Appendix I. Model selection results for occupancy models of focal wildlife species in the Ikh Nart region from original studies and with 2019 updates. Values for ΔAIC represent the relative support of each model in the set (values < 2 indicate strong empirical support). Weight values represent the relative weight of evidence that a given model is the best in the set, and k is the number of parameters in the model. Covariates include amounts of habitats (RO = rocky, TV = tall vegetation, SH = shrubland, OP = open plain, M = marmot colony, SPR = freshwater spring) and human features in the landscape (GER = distance to nearest ger, ROAD = distance to nearest road). All models predict occupancy probability (Ψ) and some include a parameter for detection probability (p). In some cases, models include the effect of covariates on detection (e.g., cover = vegetation cover at the time of a survey, TEMP = air temperature at time of survey). Only top ranking models reported in published papers are shown. Updated model selection results include complete model sets unless indicated otherwise.

a. Argali sheep, *Ovis ammon*, top five models (Murdoch et al. 2017).

Model	**ΔAIC**	**Weight**	**k**
Ψ(RO + SPR + RO ∗ SPR)	0.0	1.00	4
Ψ(RO + SPR)	110.8	0.00	3
Ψ(SH + SPR + SH ∗ SPR)	326.1	0.00	4
Ψ(SH + SPR)	492.4	0.00	3
Ψ(GER + SPR + GER ∗ SPR)	572.3	0.00	4

a.1. Argali sheep, *Ovis ammon*, complete model set (Murdoch et al. 2017).

Model	ΔAIC	Weight	k
Ψ(RO + SPR + RO * SPR)	0.00	1	4
Ψ(RO + SPR)	32.63	0	3
Ψ(SH + SPR + SH * SPR)	51.56	0	4
Ψ(SH + SPR)	89.67	0	3
Ψ(GER + SPR + GER * SPR)	127.31	0	4
Ψ(ROAD + SPR + ROAD * SPR)	152.58	0	4
Ψ(OP + SPR + OP * SPR)	164.71	0	4
Ψ(OP + SPR)	185.14	0	3
Ψ(TV + SPR)	185.42	0	3
Ψ(TV + SPR + TV * SPR)	191.17	0	4
Ψ(RUGG + SPR + RUGG * SPR)	192.50	0	4
Ψ(RUGG + SPR)	201.25	0	3
Ψ(SPR)	210.60	0	2
Ψ(ROAD + RO + ROAD * RO)	571.31	0	4
Ψ(RO + ROAD)	574.47	0	3
Ψ(RO + SH + OP)	623.83	0	4
Ψ(RO + SH + TV + OP)	625.91	0	5
Ψ(RO + OP + TV)	626.22	0	4
Ψ(GER + RO + GER * RO)	627.91	0	4
Ψ(RO + GER)	630.14	0	3
Ψ(RO + OP)	634.50	0	3
Ψ(RO + SH + TV)	634.73	0	4
Ψ(RO + OP + RO * OP)	635.12	0	4
Ψ(RO + TV)	652.74	0	3
Ψ(RO + TV + RO * TV)	652.83	0	4
Ψ(RO + SH)	652.92	0	3
Ψ(RO + SH + RO * SH)	654.21	0	4
Ψ(RO + RUGG)	654.72	0	3
Ψ(RUGG + RO + RUGG * RO)	654.86	0	4
Ψ(RO)	661.15	0	2
Ψ(TV + SH + OP)	743.71	0	4
Ψ(SH + ROAD)	850.98	0	3
Ψ(ROAD + SH + ROAD * SH)	851.81	0	4
Ψ(TV + SH)	891.63	0	3
Ψ(SH + TV + SH * TV)	892.43	0	4
Ψ(SH + OP + SH * OP)	911.98	0	4
Ψ(SH + OP)	918.06	0	3
Ψ(ROAD + OP + ROAD * OP)	940.77	0	4
Ψ(GER + SH + GER * SH)	954.10	0	4
Ψ(RUGG + SH + RUGG * SH)	955.88	0	4
Ψ(SH + GER)	957.13	0	3
Ψ(SH + RUGG)	969.47	0	3
Ψ(SH)	970.58	0	2
Ψ(OP + ROAD)	991.23	0	3
Ψ(ROAD + TV + ROAD * TV)	1000.00	0	4
Ψ(OP + TV + OP * TV)	1002.41	0	4
Ψ(TV + ROAD)	1009.89	0	3
Ψ(ROAD + RUGG + ROAD * RUGG)	1011.70	0	4
Ψ(RUGG + ROAD)	1014.25	0	3
Ψ(GER + OP + GER * OP)	1018.52	0	4
Ψ(RUGG + OP + RUGG * OP)	1019.24	0	4
Ψ(TV + OP)	1020.54	0	3
Ψ(OP + RUGG)	1023.50	0	3
Ψ(GER + ROAD)	1024.03	0	3
Ψ(OP)	1024.47	0	2
Ψ(OP + GER)	1024.59	0	3
Ψ(GER + ROAD + GER * ROAD)	1025.35	0	4
Ψ(ROAD)	1026.14	0	2
Ψ(TV + GER)	1062.02	0	3
Ψ(GER + TV + GER * TV)	1062.19	0	4
Ψ(TV + RUGG)	1099.77	0	3
Ψ(RUGG + TV + RUGG * TV)	1101.18	0	4
Ψ(TV)	1104.19	0	2
Ψ(RUGG + GER)	1108.69	0	3
Ψ(GER + RUGG + GER * RUGG)	1109.90	0	4
Ψ(GER)	1112.14	0	2
Ψ(RUGG)	1117.76	0	2

a.2. Argali sheep, *Ovis ammon*, updated model set, 2019.

Model	ΔAIC	Weight	k
Ψ(ROAD + RO + ROAD * RO)	0	1	4
Ψ(RO + SPR + RO * SPR)	159.33	0	4
Ψ(RO + ROAD)	192.92	0	3
Ψ(RO + SPR)	201.69	0	3
Ψ(RO + TV + RO * TV)	543.51	0	4
Ψ(GER + RO + GER * RO)	704.34	0	4
Ψ(RO + GER)	797.89	0	3
Ψ(RO + OP + TV)	866.41	0	4
Ψ(RO + SH + TV + OP)	866.76	0	5
Ψ(RO + SH + TV)	868.30	0	4
Ψ(RO + TV)	870.90	0	3
Ψ(RO + SH + RO * SH)	874.22	0	4
Ψ(RO + SH + OP)	887.22	0	4
Ψ(RUGG + RO + RUGG * RO)	888.53	0	4
Ψ(RO + OP + RO * OP)	907.87	0	4
Ψ(RO + SH)	912.42	0	3
Ψ(SH + SPR + SH * SPR)	913.69	0	4
Ψ(RO + RUGG)	928.83	0	3
Ψ(RO)	936.94	0	2
Ψ(RO + OP)	937.75	0	3
Ψ(SH + SPR)	937.81	0	3
Ψ(OP + SPR + OP * SPR)	1070.77	0	4
Ψ(GER + SPR + GER * SPR)	1093.26	0	4
Ψ(ROAD + SPR + ROAD * SPR)	1143.67	0	4
Ψ(TV + SPR)	1170.11	0	3
Ψ(OP + SPR)	1179.42	0	3
Ψ(RUGG + SPR)	1234.24	0	3
Ψ(SPR)	1235.30	0	2
Ψ(RUGG + SPR + RUGG * SPR)	1236.19	0	4
Ψ(TV + SH + OP)	1269.91	0	4
Ψ(TV + SPR + TV * SPR)	1611.46	0	4
Ψ(SH + OP + SH * OP)	1641.79	0	4
Ψ(SH + OP)	1642.09	0	3
Ψ(ROAD + OP + ROAD * OP)	2156.74	0	4
Ψ(OP + ROAD)	2298.09	0	3
(ROAD + SH + ROAD * SH)	2476.42	0	4
Ψ(ROAD + TV + ROAD * TV)	2555.37	0	4
Ψ(GER + ROAD + GER * ROAD)	2557.96	0	4
Ψ(SH + ROAD)	2567.91	0	3
Ψ(OP + GER)	2574.58	0	3
Ψ(GER + OP + GER * OP)	2574.90	0	4
Ψ(GER + ROAD)	2600.42	0	3
Ψ(TV + ROAD)	2640.18	0	3
Ψ(RUGG + ROAD)	2727.76	0	3
Ψ(ROAD + RUGG + ROAD * RUGG)	2728.58	0	4
Ψ(ROAD)	2741.06	0	2
Ψ(TV + OP)	2748.92	0	3
Ψ(OP + TV + OP * TV)	2889.54	0	4
Ψ(GER + SH + GER * SH)	2947.13	0	4
Ψ(RUGG + OP + RUGG * OP)	2955.85	0	4
Ψ(GER + TV + GER * TV)	2960.94	0	4
Ψ(OP + RUGG)	2961.84	0	3
Ψ(OP)	2987.78	0	2
Ψ(SH + GER)	3070.00	0	3
Ψ(TV + GER)	3091.14	0	3
Ψ(SH + TV + SH * TV)	3136.25	0	4
Ψ(GER + RUGG + GER * RUGG)	3203.57	0	4
Ψ(TV + RUGG)	3273.41	0	3
Ψ(RUGG + GER)	3281.86	0	3
Ψ(TV + SH)	3289.10	0	3
Ψ(TV)	3292.05	0	2
Ψ(RUGG + TV + RUGG * TV)	3299.71	0	4
Ψ(GER)	3303.74	0	2
Ψ(SH + RUGG)	3441.82	0	3
Ψ(RUGG + SH + RUGG * SH)	3538.21	0	4
Ψ(SH)	3665.67	0	2
Ψ(RUGG)	3677.53	0	2

b. Corsac fox, *Vulpes corsac* (Lkhagvasuren et al. 2016).

Original

Model	**ΔAIC**	**Weight**	**k**
Ψ(TV + SH + OP)	0	1	4
Ψ(TV + SH + OP + RO)	12.9	0	5
Ψ(RUGG)	74.6	0	2
Ψ(TV + SH)	82.6	0	3
Ψ(TV + SH + RO)	84.6	0	4
Ψ(SH + OP)	523.7	0	3
Ψ(SH + OP + RO)	525.3	0	4
Ψ(SH + RO)	530.7	0	3
Ψ(SH)	530.8	0	2
Ψ(TV + OP + RO)	910.1	0	4
Ψ(TV + RO)	964.5	0	3
Ψ(TV + OP)	1,206.7	0	3
Ψ(TV)	1,217.7	0	2
Ψ(OP + RO)	1,242.9	0	3
Ψ(RO)	1,338.1	0	2
Ψ(GER + ROAD)	1,700.6	0	3
Ψ(GER)	1,714.9	0	2
Ψ(OP)	1,734.0	0	2
Ψ(ROAD)	1,752.1	0	2

Updated, 2019, using Murdoch et al. 2016 Red Fox Model Set

Model	**ΔAIC**	**Weight**	**k**
Ψ(RO + SH), *p*(cover)	0.00	0.4458	5
Ψ(GER + ROAD), p(cover)	1.88	0.1743	5
Ψ(TV), *p*(cover)	2.23	0.1461	4
Ψ(M), *p*(cover)	2.55	0.1243	4
Ψ(.), *p*(cover)	3.44	0.0799	3
Ψ(OP), *p*(cover)	5.42	0.0296	4

Original Corsac Data with Red Fox Model Set

Model	**ΔAIC**	**Weight**	**k**
Ψ(M), *p*(cover)	0	0.8013	4
Ψ(RO + SH), *p*(cover)	2.89	0.1884	5
Ψ(TV), *p*(cover)	9.99	0.0054	4
Ψ(.), *p*(cover)	11.46	0.0026	3
Ψ(GER + ROAD), *p*(cover)	12.86	0.0013	5
Ψ(OP), *p*(cover)	13.57	0.0009	4

c. Red fox, *Vulpes vulpes* (Murdoch et al. 2016).

Original

Model	**ΔAIC**	**Weight**	**k**
Ψ(RO + SH), *p*(cover)	0	0.9376	5
Ψ(OP), *p*(cover)	6.83	0.0308	4
Ψ(TV), *p*(cover)	8.74	0.0119	4
Ψ(GER + ROAD), *p*(cover)	9.68	0.0074	5
Ψ(M), *p*(cover)	9.93	0.0065	4
Ψ(.), *p*(cover)	10.2	0.0057	3

Updated, 2019

Model	**ΔAIC**	**Weight**	**k**
Ψ(TV), *p*(cover)	0.00	0.9783	4
Ψ(RO + SH), *p*(cover)	8.00	0.0179	5
Ψ(.), *p*(cover)	12.74	0.0017	3
Ψ(OP), *p*(cover)	13.27	0.0013	4
Ψ(M), *p*(cover)	14.66	0.0006	4
Ψ(GER + ROAD), *p*(cover)	16.84	0.0002	5

d. Toad-headed agama, *Phrynocephalus versicolor* (Murdoch et al. 2013).

Original

Model	ΔAIC	Weight	k
Ψ(RO), p(temp + temp^2)	0	0.3678	5
Ψ(RO + OP), p(temp + temp^2)	2	0.1353	6
Ψ(RO + SH), p(temp + temp^2)	2	0.1353	6
Ψ(RO + M + M*RO), p(temp + temp^2)	2.57	0.1018	7
Ψ(RO + OP + SH), p(temp + temp^2)	3.41	0.0669	7
Ψ(RO + SH + M), p(temp + temp^2)	3.6	0.0608	7
Ψ(RO + OP + M), p(temp + temp^2)	3.62	0.0602	7
Ψ(RO + OP + SH + M), p(temp + temp^2)	4.92	0.0314	8
Ψ(OP + SH), p(temp + temp^2)	5.14	0.0281	6
Ψ(OP + SH + M), p(temp + temp^2)	6.81	0.0122	7
Ψ(SH + M + M*SH), p(temp + temp^2)	15.97	0.0001	7
Ψ(M), p(temp + temp^2)	18.86	0	5
Ψ(SH), p(temp + temp^2)	19.11	0	5
Ψ(OP + M + M*OP), p(temp + temp^2)	20.86	0	7
Ψ(OP), p(temp + temp^2)	21.25	0	5
Ψ(.), p(temp + temp^2)	21.37	0	4

Updated, 2019

Model	ΔAIC	Weight	k
Ψ(OP), p(temp + temp^2)	0.00	0.3306	5
Ψ(RO+OP), p(temp + temp^2)	1.63	0.1466	6
Ψ(OP+SH), p(temp + temp^2)	2.20	0.1100	6
Ψ(RO+SH), p(temp + temp^2)	2.28	0.1058	6
Ψ(RO+OP+M), p(temp + temp^2)	3.56	0.0558	7
Ψ(RO+OP+SH), p(temp + temp^2)	3.60	0.0548	7
Ψ(RO+SH+M), p(temp + temp^2)	4.08	0.0430	7
Ψ(OP+SH+M), p(temp + temp^2)	4.15	0.0414	7
Ψ(OP+M+M*OP), p(temp + temp^2)	4.18	0.0408	7
Ψ(RO+OP+SH+M), p(temp + temp^2)	5.57	0.0204	8
Ψ(SH), p(temp + temp^2)	6.01	0.0163	5
Ψ(RO), p(temp + temp^2)	6.20	0.0149	5
Ψ(.),p(temp + temp^2)	7.33	0.0085	4
Ψ(M), p(temp + temp^2))	8.11	0.0057	5
Ψ(RO+M+M*RO), p(temp + temp^2)	9.49	0.0029	7
Ψ(SH+M+M*SH), p(temp + temp^2)	9.66	0.0026	7

e. Mongolian marmot, *Marmota sibirica* (Becchina 2020).

Top models out of 77 total candidate models.

Model	**ΔAIC**	**Weight**	**k**
Ψ(ROAD + SH colony)	0	0.3601	3
Ψ(ROAD + TV colony)	2.62	0.0972	3
Ψ(ROAD + SH 250 m)	2.88	0.0851	3
Ψ(ROAD + SPR)	2.99	0.0809	3
Ψ(ROAD + TV 250 m)	3.28	0.0698	3
Ψ(ROAD + SH 1 km)	3.41	0.0656	3
Ψ(ROAD)	3.98	0.0492	2
Ψ(ROAD + OP 1 km)	4.71	0.0341	3
Ψ(ROAD + TV 1 km)	5.17	0.0272	3
Ψ(ROAD + RUGG 1 km)	5.19	0.0269	3
Ψ(ROAD + OP 250 m)	5.59	0.0220	3
Ψ(ROAD + OP colony)	5.71	0.0207	3
Ψ(ROAD + RUGG 250 m)	5.72	0.0206	3

Appendix II. Original parameter estimates (β) along with standard errors (SE) and 95% upper (UCI) and lower (LCI) confidence intervals for top-ranking occupancy models for focal wildlife species in the Ikh Nart region, Mongolia.

a. Argali sheep, *Ovis ammon* (Murdoch et al. 2017).

Top-ranking model: $\Psi(\text{RO} + \text{SPR} + \text{RO} * \text{SPR})$

Parameter	**β estimate**	**SE**	**UCI**	**LCI**
Ψ intercept	−4.89	0.13	−4.62	−5.15
Rocky outcrop	−0.30	0.09	−0.12	−0.49
Distance to water	−2.26	0.08	−2.10	−2.42
Interaction	−0.98	0.12	−0.75	−1.21

b. Corsac fox, *Vulpes corsac* (Lkhagvasuren et al. 2016).

Top-ranking model: $\Psi(\text{TG} + \text{SH} + \text{OP})$

Parameter	**β estimate**	**SE**	**UCI**	**LCI**
Ψ intercept	−2.38	0.11	−2.18	−2.59
Tall grassland	1.37	0.10	1.56	1.18
Shrubland	1.95	0.08	2.11	1.78
Open plain	0.70	0.08	0.85	0.55

c. Red fox, *Vulpes vulpes* (Murdoch et al. 2016).

Top-ranking model: $\Psi(\text{rock} + \text{shrub}), p(\text{cover})$

Parameter	**β estimate**	**SE**	**UCI**	**LCI**
Ψ intercept	−2.392	0.745	−0.932	−3.853
Rocky outcrop	0.093	0.039	0.169	0.017
Shrubland	0.034	0.013	0.059	0.009
p intercept	−0.578	0.346	0.100	−1.256
Cover	−0.017	0.007	−0.002	−0.031

d. Toad-headed agama, *Phrynocephalus versicolor* (Murdoch et al. 2013).

Top-ranking model: $\Psi(\text{ro}), p(\text{temp} + \text{temp}^2)$

Parameter	**β estimate**	**SE**	**UCI**	**LCI**
Ψ intercept	2.927	0.458	3.823	2.030
Rocky outcrop	-7.679	1.857	-4.038	-11.320
p intercept	-6.060	1.608	-2.909	-9.211
Temperature	5.585	1.401	8.330	2.839
Temperature^2	-1.034	0.301	-0.445	-1.623

Appendix III. Updated parameter estimates (β) along with standard errors (SE) and 95% upper (UCI) and lower (LCI) confidence intervals for all occupancy models for focal wildlife species in the Ikh Nart region, Mongolia.

a. Argali sheep, *Ovis ammon*, 2019. Top six models in order of model performance.

Model	**Parameter**	**β estimate**	**SE**	**UCI**	**LCI**
Ψ(ROAD + RO + ROAD * RO)	Ψ intercept	-3.07	0.07	-2.93	-3.22
	Rocky outcrop	-1.28	0.07	-1.15	-1.41
	Road	1.26	0.06	1.38	1.15
	Rock * Road	-0.83	0.08	-0.66	-1.00
Ψ(RO + SPR + RO * SPR)	Ψ intercept	-3.86	0.14	-3.59	-4.13
	Rocky outcrop	-0.94	0.04	-0.87	-1.02
	Springs	0.33	0.04	0.41	0.25
	Rock * Springs	-0.26	0.05	-0.17	-0.35
Ψ(RO + ROAD)	Ψ intercept	-3.51	0.08	-3.35	-3.67
	Rocky outcrop	1.23	0.05	1.33	1.13
	Road	-1.43	0.06	-1.30	-1.55
Ψ(RO + SPR)	Ψ intercept	-6.05	1.49	-3.12	-8.98
	Rocky outcrop	0.44	0.03	0.50	0.38
	Springs	-1.02	0.03	-0.95	-1.09
Ψ(RO + TV + RO * TV)	Ψ intercept	-2.53	0.07	-2.39	-2.68
	Rocky outcrop	1.67	0.07	1.81	1.52
	Tall vegetation	0.96	0.08	1.11	0.81
	Rock * Tall veg	1.97	0.16	2.28	1.65
Ψ(GER + RO + GER * RO)	Ψ intercept	-2.75	0.10	-2.56	-2.94
	Ger	-0.73	0.08	-0.57	-0.88
	Rocky outcrop	1.83	0.11	2.04	1.62
	Ger * Rock	1.00	0.12	1.23	0.77

b. Corsac fox, *Vulpes corsac*, 2019. In order of model performance.

Model	**Parameter**	**β estimate**	**SE**	**UCI**	**LCI**
Ψ(RO + SH), *p*(cover)	Ψ intercept	-0.95	0.77	0.56	-2.47
	Rocky outcrop	-0.03	0.02	0.01	-0.08
	Shrubland	0.02	0.01	0.05	0.00
	p intercept	-0.47	0.77	1.03	-1.98
	Cover	-0.01	0.01	0.01	-0.04
Ψ(TV), *p*(cover)	Ψ intercept	0.75	1.62	3.93	-2.42
	Tall vegetation	-0.07	0.06	0.05	-0.18
	p intercept	-1.16	0.93	0.66	-2.98
	Cover	0.00	0.01	0.02	-0.03
Ψ(M), *p*(cover)	Ψ intercept	-0.38	0.59	0.77	-1.53
	Marmot	8.20	35.28	77.35	-60.95
	p intercept	-0.57	0.82	1.03	-2.17
	Cover	-0.01	0.01	0.02	-0.03
Ψ(.), *p*(cover)	Ψ intercept	0.23	1.04	2.27	-1.81
	p intercept	-1.04	0.86	0.65	-2.72
	Cover	-0.01	0.01	0.02	-0.03
Ψ(OP), *p*(cover)	Ψ intercept	0.38	1.19	2.71	-1.95
	Open plains	0.00	0.01	0.02	-0.03
	p intercept	-1.01	0.86	0.69	-2.70
	Cover	-0.01	0.01	0.02	-0.03
Ψ(GER + ROAD), *p*(cover)	Ψ intercept	70.00	78.64	224.14	-84.14
	Ger	-9.39	10.71	11.60	-30.39
	Road	-15.75	18.02	19.58	-51.07
	p intercept	-1.53	0.46	-0.62	-2.44
	Cover	-0.01	0.01	0.01	-0.03

Original Corsac Fox Data using Murdoch et al. 2016 Red Fox Model Set.

Model	**Parameter**	**β estimate**	**SE**	**UCI**	**LCI**
Ψ(M), *p*(cover)	Ψ intercept	-1.18	0.64	0.08	-2.43
	Marmot	3.39	3.18	9.61	-2.84
	p intercept	-1.92	0.58	-0.78	-3.06
	Cover	0.00	0.01	0.02	-0.02
Ψ(RO + SH), *p*(cover)	Ψ intercept	0.77	2.50	5.67	-4.13
	Rocky outcrop	-0.31	0.26	0.19	-0.82
	Shrubland	0.07	0.09	0.24	-0.10
	p intercept	-2.17	0.42	-1.34	-3.00
	Cover	0.00	0.01	0.02	-0.02
Ψ(TV), *p*(cover)	Ψ intercept	-0.26	0.61	0.93	-1.45
	Tall vegetation	0.38	0.61	1.57	-0.82
	p intercept	-1.93	0.49	-0.96	-2.90
	Cover	0.00	0.01	0.01	-0.02
Ψ(.), *p*(cover)	Ψ intercept	0.27	0.78	1.79	-1.25
	p intercept	-1.82	0.57	-0.70	-2.94
	Cover	0.00	0.01	0.01	-0.02
Ψ(GER + ROAD), *p*(cover)	Ψ intercept	0.06	0.94	1.90	-1.78
	Ger	-0.04	0.06	0.07	-0.15
	Road	0.14	0.12	0.36	-0.09
	p intercept	-1.75	0.53	-0.71	-2.79
	Cover	0.00	0.01	0.01	-0.02
Ψ(OP), *p*(cover)	Ψ intercept	0.36	1.06	2.45	-1.72
	Open plains	0.00	0.02	0.03	-0.04
	p intercept	-1.83	0.57	-0.70	-2.95
	Cover	0.00	0.01	0.01	-0.02

c. Red fox, *Vulpes vulpes,* 2019. In order of model performance.

Model	**Parameter**	**β estimate**	**SE**	**UCI**	**LCI**
Ψ(TV), *p*(cover)	Ψ intercept	0.83	0.60	2.01	-0.36
	Tall vegetation	-0.18	0.08	-0.01	-0.34
	p intercept	-1.56	0.59	-0.40	-2.71
	Cover	0.03	0.01	0.05	0.00
Ψ(RO + SH), *p*(cover)	Ψ intercept	-1.15	0.57	-0.03	-2.27
	Rocky outcrop	0.04	0.03	0.09	-0.01
	Shrubland	0.01	0.01	0.03	0.00
	p intercept	-1.38	0.60	-0.21	-2.55
	Cover	0.03	0.01	0.05	0.00
Ψ(.), *p*(cover)	Ψ intercept	0.05	0.35	0.74	-0.63
	p intercept	-1.48	0.61	-0.28	-2.68
	Cover	0.03	0.01	0.05	0.00
Ψ(OP), *p*(cover)	Ψ intercept	0.32	0.42	1.15	-0.51
	Open plains	-0.01	0.01	0.01	-0.03
	p intercept	-1.34	0.63	-0.11	-2.57
	Cover	0.03	0.01	0.05	0.00
Ψ(M), *p*(cover)	Ψ intercept	0.04	0.35	0.73	-0.65
	Marmot colony	1.12	3.00	7.01	-4.76
	p intercept	-1.49	0.62	-0.28	-2.69
	Cover	0.03	0.01	0.05	0.00
Ψ(GER + ROAD), *p*(cover)	Ψ intercept	0.14	0.54	1.19	-0.92
	Ger	-0.10	0.21	0.31	-0.50
	Road	0.06	0.25	0.54	-0.43
	p intercept	-1.45	0.62	-0.24	-2.67
	Cover	0.03	0.01	0.05	0.00

d. Toad-headed agama, *Phrynocephalus versicolor*, 2019. In order of model performance.

Model	**Parameter**	**β estimate**	**SE**	**UCI**	**LCI**
ψ(OP), *p*(temp + temp^2)	Ψ intercept	0.10	0.33	0.75	-0.54
	Open plains	2.74	1.16	5.01	0.46
	p intercept	0.98	0.24	1.46	0.50
	Temperature	1.74	2.06	5.78	-2.30
	Temperature^2	-1.22	2.04	2.77	-5.22
ψ(RO + OP), *p*(temp + temp^2)	Ψ intercept	0.27	0.39	1.04	-0.50
	Rocky outcrop	-0.84	1.07	1.27	-2.94
	Open plains	2.48	1.17	4.77	0.18
	p intercept	0.99	0.24	1.46	0.51
	Temperature	1.71	2.08	5.78	-2.37
	Temperature^2	-1.19	2.05	2.83	-5.22
ψ(OP + SH), *p*(temp + temp^2)	Ψ intercept	0.00	0.71	1.39	-1.40
	Open plains	2.83	1.29	5.35	0.31
	Shrubland	0.15	0.90	1.91	-1.62
	p intercept	0.98	0.24	1.46	0.50
	Temperature	1.74	2.06	5.79	-2.30
	Temperature^2	-1.22	2.04	2.77	-5.22
ψ(RO + SH), *p*(temp + temp^2)	Ψ intercept	2.30	0.75	3.76	0.83
	Rocky outcrop	-2.90	1.21	-0.53	-5.27
	Shrubland	-2.09	0.98	-0.18	-4.01
	p intercept	0.99	0.24	1.47	0.51
	Temperature	1.60	2.10	5.71	-2.51
	Temperature^2	-1.08	2.07	2.98	-5.14
ψ(RO + OP + M), *p*(temp + temp^2)	Ψ intercept	0.28	0.39	1.06	-0.49
	Rocky outcrop	-0.85	1.07	1.25	-2.95
	Open plains	2.33	1.16	4.59	0.06
	Marmot	6.02	46.96	98.05	-86.01
	p intercept	1.00	0.24	1.47	0.52
	Temperature	1.75	2.08	5.83	-2.34
	Temperature^2	-1.23	2.06	2.80	-5.26
ψ(RO + OP + SH), *p*(temp + temp^2)	Ψ intercept	0.92	1.33	3.52	-1.68
	Rocky outcrop	-1.48	1.65	1.76	-4.72
	Open plains	1.81	1.74	5.22	-1.60
	Shrubland	-0.75	1.42	2.04	-3.53
	p intercept	0.99	0.24	1.47	0.51
	Temperature	1.63	2.09	5.73	-2.46
	Temperature^2	-1.12	2.06	2.92	-5.16
ψ(RO + SH + M), *p*(temp + temp^2)	Ψ intercept	2.19	0.73	3.62	0.75
	Rocky outcrop	-2.79	1.20	-0.44	-5.13
	Shrubland	-1.96	0.96	-0.08	-3.85
	Marmot	6.05	40.19	84.82	-72.71
	p intercept	1.00	0.24	1.47	0.52
	Temperature	1.65	2.10	5.77	-2.47
	Temperature^2	-1.12	2.08	2.94	-5.19
ψ(OP + SH + M), *p*(temp + temp^2)	Ψ intercept	0.01	0.71	1.40	-1.39
	Open plains	2.69	1.27	5.18	0.20
	Shrubland	0.16	0.90	1.91	-1.60
	Marmot	5.97	47.32	98.71	-86.78
	p intercept	0.99	0.24	1.46	0.51
	Temperature	1.77	2.07	5.82	-2.29
	Temperature^2	-1.25	2.04	2.76	-5.25

ψ (OP + M + M * OP), p (temp + temp^2)	Ψ intercept	0.12	0.33	0.76	-0.53
	Open plains	2.59	1.14	4.83	0.35
	Marmot	4.54	7095.78	13912.00	-13902.93
	Marmot*Open	4.09	7877.57	15443.83	-15435.66
	p intercept	0.99	0.24	1.46	0.51
	Temperature	1.76	2.07	5.81	-2.29
	Temperature^2	-1.24	2.04	2.77	-5.24
ψ(RO + OP + SH + M), p(temp + temp^2)	Ψ intercept	0.94	1.32	3.53	-1.65
	Rocky outcrop	-1.50	1.65	1.74	-4.73
	Open plains	1.66	1.73	5.05	-1.73
	Shrubland	-0.74	1.42	2.04	-3.52
	Marmot	7.26	86.88	177.54	-163.03
	p intercept	1.00	0.24	1.47	0.52
	Temperature	1.67	2.09	5.77	-2.44
	Temperature^2	-1.15	2.07	2.90	-5.20
ψ(SH), p(temp + temp^2)	Ψ intercept	1.58	0.52	2.59	0.57
	Shrubland	-1.38	0.77	0.13	-2.88
	p intercept	0.94	0.25	1.42	0.46
	Temperature	2.16	1.98	6.04	-1.73
	Temperature^2	-1.58	1.97	2.29	-5.45
ψ(RO), p(temp + temp^2)	Ψ intercept	1.08	0.29	1.66	0.50
	Rocky outcrop	-1.90	1.02	0.09	-3.90
	p intercept	0.96	0.25	1.44	0.48
	Temperature	2.18	2.04	6.19	-1.82
	Temperature^2	-1.63	2.03	2.35	-5.61
ψ(.), p(temp + temp^2)	Ψ intercept	0.88	0.27	1.40	0.36
	p intercept	0.92	0.25	1.41	0.43
	Temperature	2.40	1.98	6.28	-1.48
	Temperature^2	-1.82	1.97	2.04	-5.68
ψ (M), p(temp + temp^2)	Ψ intercept	0.84	0.26	1.35	0.33
	Marmot	6.56	28.57	62.54	-49.43
	p intercept	0.94	0.25	1.42	0.45
	Temperature	2.38	1.99	6.28	-1.52
	Temperature^2	-1.80	1.98	2.08	-5.68
ψ (RO + M + M * RO), p(temp + temp^2)	Ψ intercept	1.04	0.29	1.61	0.47
	Rocky outcrop	-1.84	1.02	0.16	-3.83
	Marmot	7.71	77.59	159.79	-144.38
	Marmot*Rock	0.08	5248.25	10286.45	-10286.29
	p intercept	0.97	0.24	1.45	0.49
	Temperature	2.16	2.05	6.18	-1.87
	Temperature^2	-1.60	2.04	2.39	-5.59
ψ (SH + M + M * SH), p(temp + temp^2)	Ψ intercept	1.49	0.51	2.49	0.49
	Shrublands	-1.26	0.76	0.24	-2.76
	Marmot	7.62	125.81	254.21	-238.97
	Marmot*Shrub	0.51	1600.78	3137.99	-3136.96
	p intercept	0.95	0.24	1.43	0.47
	Temperature	2.16	1.99	6.06	-1.75
	Temperature^2	-1.58	1.98	2.30	-5.46

e. Mongolian marmot, *Marmota sibirica*, Becchina 2020. Top model.

Parameter	**β estimate**	**SE**	**UCI**	**LCI**
Ψ intercept	0.41	0.26	0.92	-0.12
ROAD	-2.16	0.63	-0.93	-3.39
SH	1.88	0.81	3.47	0.29

Appendix IV. Model selection results for linear models of habitat amount (proportion in the landscape) for six habitat types—high density shrub (HDS) low density shrub (LDS), open plains (OP), tall vegetation (TV), rocky outcrop (RO), water (WTR)—in the northern Ikh Nart Nature Reserve and the surrounding region of Bichigt bag, Mongolia. Values for ΔAIC represent the relative support of each model in the set (values < 2 indicate strong empirical support). Weight values represent the relative weight of evidence that a given model is the best in the set, and k is the number of parameters in the model. Covariates include Bichigt bag livestock density, measured in livestock per km^2 (livestock) and local climate variables for the months of April through June (Precip_Ave = average precipitation, Precip_Total = total precipitation, Temp_Max = mean maximum daily temperature, Temp_Min = mean minimum daily temperature, Temp_Ave = mean average daily temperature).

a. High Density Shrub (HDS)

Model	ΔAIC	Weight	Cumulative Weight	k
Livestock	0.00	0.1412	0.14	3
Precip_Ave	0.06	0.1370	0.28	3
Precip_Total	0.21	0.1271	0.41	3
Temp_Max	0.34	0.1190	0.52	3
Temp_Min	0.38	0.1168	0.64	3
Temp_Ave	0.53	0.1085	0.75	3
Livestock + Precip_Ave	3.09	0.0301	0.78	4
Livestock + Precip_Total	3.43	0.0254	0.81	4
Temp_Max + Precip_Ave	3.53	0.0241	0.83	4
Temp_Max + Precip_Total	3.66	0.0227	0.85	4
Temp_Min + Precip_Ave	3.81	0.0210	0.87	4
Temp_Min + Precip_Total	3.87	0.0204	0.89	4
Livestock + Temp_Ave	3.94	0.0197	0.91	4
Livestock + Temp_Min	4.03	0.0188	0.93	4
Livestock + Temp_Max	4.04	0.0187	0.95	4
Temp_Ave + Precip_Ave	4.07	0.0185	0.97	4
Temp_Ave + Precip_Total	4.20	0.0173	0.99	4
Livestock + Temp_Max + Precip_Ave	8.04	0.0025	0.99	5
Livestock + Temp_Min + Precip_Ave	8.11	0.0024	0.99	5
Livestock + Temp_Ave + Precip_Ave	8.14	0.0024	0.99	5
Livestock + Temp_Max + Precip_Total	8.34	0.0022	1.00	5
Livestock + Temp_Min + Precip_Total	8.38	0.0021	1.00	5
Livestock + Temp_Ave + Precip_Total	8.49	0.0020	1.00	5

b. Low Density Shrub (LDS)

Model	**ΔAIC**	**Weight**	**Cumulative Weight**	**k**
Livestock + Temp_Max	0.00	0.2136	0.21	4
Livestock + Temp_Min	1.21	0.1165	0.33	4
Livestock + Temp_Ave	1.33	0.1099	0.44	4
Livestock	1.43	0.1045	0.54	3
Livestock + Precip_Total	1.72	0.0905	0.64	4
Livestock + Precip_Ave	1.84	0.0853	0.72	4
Livestock + Temp_Min + Precip_Ave	2.05	0.0767	0.80	5
Livestock + Temp_Max + Precip_Ave	2.40	0.0643	0.86	5
Livestock + Temp_Max + Precip_Total	3.18	0.0436	0.90	5
Livestock + Temp_Min + Precip_Total	3.54	0.0365	0.94	5
Livestock + Temp_Ave + Precip_Ave	3.58	0.0357	0.98	5
Livestock + Temp_Ave + Precip_Total	4.47	0.0229	1.00	5
Temp_Max	24.11	0.0000	1.00	3
Temp_Min	24.88	0.0000	1.00	3
Temp_Ave	25.06	0.0000	1.00	3
Precip_Ave	25.18	0.0000	1.00	3
Precip_Total	25.26	0.0000	1.00	3
Temp_Max + Precip_Total	27.96	0.0000	1.00	4
Temp_Max + Precip_Ave	28.14	0.0000	1.00	4
Temp_Min + Precip_Ave	28.89	0.0000	1.00	4
Temp_Min + Precip_Total	28.91	0.0000	1.00	4
Temp_Ave + Precip_Ave	29.08	0.0000	1.00	4
Temp_Ave + Precip_Total	29.08	0.0000	1.00	4

c. Open Plains (OP)

Model	**ΔAIC**	**Weight**	**Cumulative Weight**	**k**
Livestock	0.00	0.1789	0.18	3
Temp_Ave	0.23	0.1599	0.34	3
Livestock + Temp_Ave	0.64	0.1299	0.47	4
Temp_Max	0.94	0.1117	0.58	3
Temp_Min	1.46	0.0861	0.67	3
Livestock + Temp_Min	2.09	0.0628	0.73	4
Livestock + Temp_Max	2.54	0.0502	0.78	4
Livestock + Precip_Ave	4.01	0.0241	0.80	4
Livestock + Precip_Total	4.03	0.0238	0.83	4
Temp_Ave + Precip_Total	4.06	0.0235	0.85	4
Temp_Ave + Precip_Ave	4.22	0.0217	0.87	4
Temp_Max + Precip_Total	4.86	0.0157	0.89	4
Temp_Max + Precip_Ave	4.89	0.0155	0.90	4
Precip_Total	5.14	0.0137	0.92	3
Livestock + Temp_Ave + Precip_Total	5.15	0.0136	0.93	5
Livestock + Temp_Ave + Precip_Ave	5.18	0.0134	0.94	5
Precip_Ave	5.27	0.0128	0.96	3
Temp_Min + Precip_Ave	5.48	0.0115	0.97	4
Temp_Min + Precip_Total	5.51	0.0114	0.98	4
Livestock + Temp_Min + Precip_Ave	7.04	0.0053	0.99	5
Livestock + Temp_Min + Precip_Total	7.07	0.0052	0.99	5
Livestock + Temp_Max + Precip_Ave	7.28	0.0047	1.00	5
Livestock + Temp_Max + Precip_Total	7.44	0.0043	1.00	5

d. Tall Vegetation (TV)

Model	**ΔAIC**	**Weight**	**Cumulative Weight**	**k**
Livestock + Temp_Min	0.00	0.3543	0.35	4
Livestock + Temp_Max	0.88	0.2282	0.58	4
Livestock + Temp_Ave	0.95	0.2206	0.80	4
Livestock + Temp_Min + Precip_Ave	5.02	0.0287	0.83	5
Livestock + Temp_Min + Precip_Total	5.04	0.0286	0.86	5
Livestock + Temp_Max + Precip_Ave	5.63	0.0212	0.88	5
Livestock + Temp_Ave + Precip_Ave	5.79	0.0196	0.90	5
Livestock + Temp_Max + Precip_Total	5.84	0.0191	0.92	5
Livestock + Temp_Ave + Precip_Total	5.85	0.0191	0.94	5
Temp_Ave	6.43	0.0143	0.95	3
Temp_Min	6.64	0.0128	0.97	3
Livestock	7.33	0.0091	0.98	3
Temp_Max	8.22	0.0058	0.98	3
Temp_Ave + Precip_Ave	9.68	0.0028	0.98	4
Precip_Total	9.78	0.0027	0.99	3
Precip_Ave	9.88	0.0025	0.99	3
Temp_Ave + Precip_Total	10.17	0.0022	0.99	4
Temp_Min + Precip_Ave	10.35	0.0020	0.99	4
Temp_Min + Precip_Total	10.62	0.0018	1.00	4
Livestock + Precip_Total	10.66	0.0017	1.00	4
Livestock + Precip_Ave	11.25	0.0013	1.00	4
Temp_Max + Precip_Ave	11.72	0.0010	1.00	4
Temp_Max + Precip_Total	12.20	0.0008	1.00	4

e. Rock (RO)

Model	**ΔAIC**	**Weight**	**Cumulative Weight**	**k**
Livestock	0.00	0.1968	0.20	3
Temp_Ave	0.83	0.1302	0.33	3
Temp_Min	1.15	0.1110	0.44	3
Temp_Max	1.28	0.1038	0.54	3
Precip_Total	1.33	0.1012	0.64	3
Precip_Ave	1.40	0.0976	0.74	3
Livestock + Precip_Total	3.66	0.0315	0.77	4
Livestock + Precip_Ave	3.83	0.0291	0.80	4
Livestock + Temp_Ave	3.90	0.0280	0.83	4
Livestock + Temp_Max	3.94	0.0275	0.86	4
Livestock + Temp_Min	4.04	0.0261	0.88	4
Temp_Ave + Precip_Total	4.36	0.0222	0.91	4
Temp_Ave + Precip_Ave	4.76	0.0183	0.92	4
Temp_Min + Precip_Total	4.96	0.0165	0.94	4
Temp_Max + Precip_Total	5.08	0.0155	0.96	4
Temp_Min + Precip_Ave	5.16	0.0149	0.97	4
Temp_Max + Precip_Ave	5.27	0.0141	0.98	4
Livestock + Temp_Ave + Precip_Total	8.23	0.0032	0.99	5
Livestock + Temp_Ave + Precip_Ave	8.62	0.0026	0.99	5
Livestock + Temp_Min + Precip_Total	8.67	0.0026	0.99	5
Livestock + Temp_Max + Precip_Total	8.71	0.0025	1.00	5
Livestock + Temp_Max + Precip_Ave	8.83	0.0024	1.00	5
Livestock + Temp_Min + Precip_Ave	8.87	0.0023	1.00	5

f. Water (WTR)

Model	**ΔAIC**	**Weight**	**Cumulative Weight**	**k**
Temp_Ave	0.00	0.1761	0.18	3
Livestock + Temp_Ave	0.21	0.1587	0.33	4
Livestock + Temp_Max	0.95	0.1094	0.44	4
Temp_Min	1.06	0.1036	0.55	3
Livestock + Temp_Min	1.57	0.0803	0.63	4
Temp_Max	1.67	0.0765	0.70	3
Livestock	2.76	0.0443	0.75	3
Temp_Ave + Precip_Ave	3.29	0.0339	0.78	4
Precip_Total	3.43	0.0317	0.81	3
Precip_Ave	3.52	0.0303	0.84	3
Temp_Ave + Precip_Total	3.69	0.0278	0.87	4
Temp_Min + Precip_Ave	4.87	0.0154	0.89	4
Livestock + Temp_Ave + Precip_Ave	4.96	0.0147	0.90	5
Livestock + Temp_Ave + Precip_Total	5.05	0.0141	0.92	5
Temp_Min + Precip_Total	5.07	0.0140	0.93	4
Temp_Max + Precip_Ave	5.16	0.0133	0.94	4
Temp_Max + Precip_Total	5.62	0.0106	0.95	4
Livestock + Temp_Max + Precip_Ave	5.69	0.0102	0.97	5
Livestock + Temp_Max + Precip_Total	5.90	0.0092	0.97	5
Livestock + Precip_Total	6.46	0.0070	0.98	4
Livestock + Temp_Min + Precip_Ave	6.62	0.0064	0.99	5
Livestock + Temp_Min + Precip_Total	6.63	0.0064	0.99	5
Livestock + Precip_Ave	6.79	0.0059	1.00	4

Appendix V. Parameter estimates (β) along with standard errors (SE) and 95% upper (UCI) and lower (LCI) confidence intervals for linear models of each habitat's distribution in northern Ikh Nart Nature Reserve and the surrounding area, Mongolia.

a. High Density Shrub (HDS). Top models, contributing 0.95 cumulative weight.

Model	**Parameter**	**β estimate**	**SE**	**UCI**	**LCI**
Livestock	Intercept	0.16	0.03	0.23	0.10
	Livestock Density	0.00	0.00	0.00	0.00
Precip_Ave	Intercept	0.17	0.02	0.21	0.13
	Average Precipitation	0.00	0.00	0.00	0.00
Precip_Total	Intercept	0.18	0.02	0.21	0.14
	Total Precipitation	0.00	0.00	0.00	0.00
Temp_Max	Intercept	0.13	0.13	0.42	-0.16
	Maximum Temperature	0.00	0.01	0.02	-0.01
Temp_Min	Intercept	0.16	0.05	0.28	0.05
	Minimum Temperature	0.00	0.01	0.02	-0.01
Temp_Ave	Intercept	0.19	0.10	0.39	-0.02
	Average Temperature	0.00	0.01	0.01	-0.01
Livestock + Precip_Ave	Intercept	0.14	0.04	0.23	0.05
	Livestock Density	0.00	0.00	0.00	0.00
	Average Precipitation	0.00	0.00	0.00	0.00
Livestock + Precip_Total	Intercept	0.15	0.04	0.23	0.07
	Livestock Density	0.00	0.00	0.00	0.00
	Total Precipitation	0.00	0.00	0.00	0.00
Max_Temp + Precip_Ave	Intercept	0.07	0.15	0.40	-0.26
	Maximum Temperature	0.00	0.01	0.02	-0.01
	Average Precipitation	0.00	0.00	0.00	0.00
Temp_Max + Precip_Total	Intercept	0.07	0.16	0.41	-0.28
	Maximum Temperature	0.00	0.01	0.02	-0.01
	Total Precipitation	0.00	0.00	0.00	0.00
Temp_Min + Precip_Ave	Intercept	0.14	0.06	0.28	0.01
	Minimum Temperature	0.00	0.01	0.02	-0.01
	Average Precipitation	0.00	0.00	0.00	0.00
Temp_Min + Precip_Total	Intercept	0.14	0.06	0.28	0.00
	Minimum Temperature	0.00	0.01	0.02	-0.01
	Total Precipitation	0.00	0.00	0.00	0.00
Livestock + Temp_Ave	Intercept	0.19	0.10	0.41	-0.03
	Livestock Density	0.00	0.00	0.00	0.00
	Average Temperature	0.00	0.01	0.01	-0.02
Livestock + Temp_Min	Intercept	0.16	0.06	0.28	0.04
	Livestock Density	0.00	0.00	0.00	0.00
	Minimum Temperature	0.00	0.01	0.02	-0.02
Livestock + Temp_Max	Intercept	0.16	0.15	0.48	-0.16
	Livestock Density	0.00	0.00	0.00	0.00
	Maximum Temperature	0.00	0.01	0.02	-0.02

b. Low Density Shrub (LDS). Top models, contributing 0.95 cumulative weight.

Model	Parameter	β estimate	SE	UCI	LCI
Livestock + Temp_Max	Intercept	0.20	0.10	0.42	-0.02
	Livestock Density	-0.01	0.00	0.00	-0.01
	Maximum Temperature	0.01	0.01	0.02	0.00
Livestock + Temp_Min	Intercept	0.36	0.04	0.45	0.27
	Livestock Density	-0.01	0.00	0.00	-0.01
	Minimum Temperature	0.01	0.01	0.03	0.00
Livestock + Temp_Ave	Intercept	0.29	0.07	0.45	0.14
	Livestock Density	-0.01	0.00	0.00	-0.01
	Average Temperature	0.01	0.01	0.02	0.00
Livestock	Intercept	0.43	0.02	0.48	0.37
	Livestock Density	-0.01	0.00	0.00	-0.01
Livestock + Precip_Total	Intercept	0.46	0.03	0.52	0.40
	Livestock Density	-0.01	0.00	0.00	-0.01
	Total Precipitation	0.00	0.00	0.00	0.00
Livestock + Precip_Ave	Intercept	0.46	0.03	0.53	0.40
	Livestock Density	-0.01	0.00	0.00	-0.01
	Average Precipitation	0.00	0.00	0.00	0.00
Livestock + Temp_Min + Precip_Ave	Intercept	0.40	0.04	0.49	0.31
	Livestock Density	-0.01	0.00	-0.01	-0.01
	Minimum Temperature	0.01	0.01	0.02	0.00
	Average Precipitation	0.00	0.00	0.00	0.00
Livestock + Temp_Max + Precip_Ave	Intercept	0.26	0.11	0.50	0.03
	Livestock Density	-0.01	0.00	-0.01	-0.01
	Maximum Temperature	0.01	0.01	0.02	0.00
	Average Precipitation	0.00	0.00	0.00	0.00
Livestock + Temp_Max + Precip_Total	Intercept	0.27	0.11	0.52	0.01
	Livestock Density	-0.01	0.00	0.00	-0.01
	Maximum Temperature	0.01	0.01	0.02	0.00
	Total Precipitation	0.00	0.00	0.00	0.00
Livestock + Temp_Min + Precip_Total	Intercept	0.40	0.05	0.50	0.30
	Livestock Density	-0.01	0.00	0.00	-0.01
	Minimum Temperature	0.01	0.01	0.02	0.00
	Total Precipitation	0.00	0.00	0.00	0.00

c. Open Plains (OP). Top models, contributing 0.95 cumulative weight.

Model	**Parameter**	**β estimate**	**SE**	**UCI**	**LCI**
Livestock	Intercept	0.25	0.05	0.36	0.15
	Livestock Density	0.00	0.00	0.01	0.00
Temp_Ave	Intercept	0.00	0.16	0.34	-0.34
	Average Temperature	0.03	0.01	0.05	0.00
Livestock + Temp_Ave	Intercept	0.01	0.14	0.33	-0.30
	Livestock	0.00	0.00	0.01	0.00
	Average Temperature	0.02	0.01	0.04	0.00
Temp_Max	Intercept	-0.11	0.22	0.37	-0.60
	Maximum Temperature	0.02	0.01	0.04	0.00
Temp_Min	Intercept	0.18	0.09	0.38	-0.01
	Minimum Temperature	0.03	0.01	0.06	0.00
Livestock + Temp_Min	Intercept	0.16	0.08	0.35	-0.03
	Livestock Density	0.00	0.00	0.01	0.00
	Minimum Temperature	0.02	0.01	0.05	-0.01
Livestock + Temp_Max	Intercept	0.00	0.23	0.50	-0.50
	Livestock Density	0.00	0.00	0.01	0.00
	Maximum Temperature	0.01	0.01	0.04	-0.01
Livestock + Precip_Ave	Intercept	0.24	0.07	0.39	0.10
	Livestock Density	0.00	0.00	0.01	0.00
	Average Precipitation	0.00	0.00	0.01	-0.01
Livestock + Precip_Total	Intercept	0.25	0.06	0.39	0.12
	Livestock Density	0.00	0.00	0.01	0.00
	Total Precipitation	0.00	0.00	0.00	0.00
Temp_Ave + Precip_Total	Intercept	-0.05	0.19	0.38	-0.47
	Average Temperature	0.03	0.01	0.06	0.00
	Total Precipitation	0.00	0.00	0.00	0.00
Temp_Ave + Precip_Ave	Intercept	-0.02	0.18	0.38	-0.42
	Average Temperature	0.03	0.01	0.05	0.00
	Average Precipitation	0.00	0.00	0.01	-0.01
Temp_Max + Precip_Total	Intercept	-0.16	0.27	0.44	-0.75
	Maximum Temperature	0.02	0.01	0.05	0.00
	Total Precipitation	0.00	0.00	0.00	0.00
Temp_Max + Precip_Ave	Intercept	-0.15	0.26	0.43	-0.72
	Maximum Temperature	0.02	0.01	0.05	0.00
	Average Precipitation	0.00	0.00	0.01	-0.01
Precip_Total	Intercept	0.38	0.03	0.45	0.31
	Total Precipitation	0.00	0.00	0.00	0.00
Livestock + Temp_Ave + Precip_Total	Intercept	-0.05	0.18	0.35	-0.44
	Livestock Density	0.00	0.00	0.01	0.00
	Average Temperature	0.02	0.01	0.05	-0.01
	Total Precipitation	0.00	0.00	0.00	0.00
Livestock + Temp_Ave + Precip_Ave	Intercept	-0.03	0.17	0.34	-0.40
	Livestock Density	0.00	0.00	0.01	0.00
	Average Temperature	0.02	0.01	0.05	0.00
	Average Precipitation	0.00	0.00	0.01	0.00

d. Tall Vegetation (TV). Top models, contributing 0.95 cumulative weight.

Model	Parameter	β estimate	SE	UCI	LCI
Livestock + Temp_Min	Intercept	0.15	0.03	0.23	0.08
	Livestock Density	0.00	0.00	0.00	0.00
	Minimum Temperature	-0.02	0.01	-0.01	-0.03
Livestock + Temp_Max	Intercept	0.36	0.09	0.55	0.16
	Livestock Density	0.00	0.00	0.00	0.00
	Maximum Temperature	-0.02	0.00	-0.01	-0.03
Livestock + Temp_Ave	Intercept	0.25	0.06	0.38	0.12
	Livestock Density	0.00	0.00	0.00	0.00
	Average Temperature	-0.02	0.00	-0.01	-0.03
Livestock + Temp_Min + Precip_Ave	Intercept	0.15	0.04	0.24	0.07
	Livestock Density	0.00	0.00	0.00	0.00
	Minimum Temperature	-0.02	0.01	-0.01	-0.03
	Average Precipitation	0.00	0.00	0.00	0.00
Livestock + Temp_Min + Precip_Total	Intercept	0.15	0.04	0.24	0.06
	Livestock Density	0.00	0.00	0.00	0.00
	Minimum Temperature	-0.02	0.01	-0.01	-0.03
	Total Precipitation	0.00	0.00	0.00	0.00
Livestock + Temp_Max + Precip_Ave	Intercept	0.38	0.10	0.60	0.15
	Livestock Density	0.00	0.00	0.00	0.00
	Maximum Temperature	-0.02	0.00	-0.01	-0.03
	Average Precipitation	0.00	0.00	0.00	0.00
Livestock + Temp_Ave + Precip_Ave	Intercept	0.26	0.07	0.42	0.11
	Livestock Density	0.00	0.00	0.00	0.00
	Average Temperature	-0.02	0.00	-0.01	-0.03
	Average Precipitation	0.00	0.00	0.00	0.00
Livestock + Temp_Max + Precip_Total	Intercept	0.37	0.11	0.60	0.13
	Livestock Density	0.00	0.00	0.00	0.00
	Maximum Temperature	-0.02	0.01	0.00	-0.03
	Total Precipitation	0.00	0.00	0.00	0.00
Livestock + Temp_Ave + Precip_Total	Intercept	0.27	0.07	0.43	0.10
	Livestock Density	0.00	0.00	0.00	0.00
	Average Temperature	-0.02	0.01	0.00	-0.03
	Total Precipitation	0.00	0.00	0.00	0.00
Temp_Ave	Intercept	0.24	0.08	0.41	0.07
	Average Temperature	-0.01	0.01	0.00	-0.02

e. Rocky Outcrop (RO). Top models, contributing 0.95 cumulative weight.

Model	**Parameter**	**β estimate**	**SE**	**UCI**	**LCI**
Livestock	Intercept	0.09	0.01	0.12	0.07
	Livestock Density	0.00	0.00	0.00	0.00
Temp_Ave	Intercept	0.11	0.03	0.18	0.03
	Average Temperature	0.00	0.00	0.00	-0.01
Temp_Min	Intercept	0.09	0.02	0.13	0.05
	Minimum Temperature	0.00	0.00	0.00	-0.01
Temp_Max	Intercept	0.10	0.05	0.21	-0.01
	Maximum Temperature	0.00	0.00	0.00	-0.01
Precip_Total	Intercept	0.08	0.01	0.10	0.07
	Total Precipitation	0.00	0.00	0.00	0.00
Precip_Ave	Intercept	0.08	0.01	0.10	0.07
	Average Precipitation	0.00	0.00	0.00	0.00
Livestock + Precip_Total	Intercept	0.10	0.01	0.13	0.07
	Livestock Density	0.00	0.00	0.00	0.00
	Total Precipitation	0.00	0.00	0.00	0.00
Livestock + Precip_Ave	Intercept	0.10	0.01	0.13	0.07
	Livestock Density	0.00	0.00	0.00	0.00
	Average Precipitation	0.00	0.00	0.00	0.00
Livestock + Temp_Ave	Intercept	0.11	0.03	0.18	0.03
	Livestock Density	0.00	0.00	0.00	0.00
	Average Temperature	0.00	0.00	0.00	-0.01
Livestock + Temp_Max	Intercept	0.08	0.05	0.19	-0.03
	Livestock Density	0.00	0.00	0.00	0.00
	Maximum Temperature	0.00	0.00	0.01	-0.01
Livestock + Temp_Min	Intercept	0.09	0.02	0.14	0.05
	Livestock Density	0.00	0.00	0.00	0.00
	Minimum Temperature	0.00	0.00	0.01	-0.01
Temp_Ave + Precip_Total	Intercept	0.12	0.04	0.22	0.03
	Average Temperature	0.00	0.00	0.00	-0.01
	Total Precipitation	0.00	0.00	0.00	0.00
Temp_Ave + Precip_Ave	Intercept	0.11	0.04	0.20	0.02
	Average Temperature	0.00	0.00	0.00	-0.01
	Average Precipitation	0.00	0.00	0.00	0.00
Temp_Min + Precip_Total	Intercept	0.10	0.02	0.15	0.04
	Minimum Temperature	0.00	0.00	0.01	-0.01
	Total Precipitation	0.00	0.00	0.00	0.00

f. Water (WTR). Top models, contributing 0.95 cumulative weight.

Model	Parameter	β estimate	SE	UCI	LCI
Temp_Ave	Intercept	0.14	0.06	0.27	0.01
	Average Temperature	-0.01	0.00	0.00	-0.02
Livestock + Temp_Ave	Intercept	0.14	0.06	0.26	0.02
	Livestock Density	0.00	0.00	0.00	0.00
	Average Temperature	-0.01	0.00	0.00	-0.02
Livestock + Temp_Max	Intercept	0.21	0.08	0.39	0.02
	Livestock Density	0.00	0.00	0.00	0.00
	Maximum Temperature	-0.01	0.00	0.00	-0.02
Temp_Min	Intercept	0.08	0.03	0.15	0.00
	Minimum Temperature	-0.01	0.01	0.00	-0.02
Livestock + Temp_Min	Intercept	0.07	0.03	0.14	0.00
	Livestock Density	0.00	0.00	0.00	0.00
	Minimum Temperature	-0.01	0.01	0.00	-0.02
Temp_Max	Intercept	0.14	0.09	0.34	-0.05
	Maximum Temperature	-0.01	0.00	0.00	-0.01
Livestock	Intercept	0.01	0.02	0.05	-0.04
	Livestock Density	0.00	0.00	0.00	0.00
Temp_Ave + Precip_Ave	Intercept	0.16	0.07	0.31	0.01
	Average Temperature	-0.01	0.00	0.00	-0.02
	Average Precipitation	0.00	0.00	0.00	0.00
Precip_Total	Intercept	0.02	0.01	0.05	0.00
	Total Precipitation	0.00	0.00	0.00	0.00
Precip_Ave	Intercept	0.03	0.01	0.06	0.00
	Average Precipitation	0.00	0.00	0.00	0.00
Temp_Ave + Precip_Total	Intercept	0.16	0.07	0.32	-0.01
	Average Temperature	-0.01	0.00	0.00	-0.02
	Total Precipitation	0.00	0.00	0.00	0.00
Temp_Min + Precip_Ave	Intercept	0.09	0.04	0.18	0.00
	Minimum Temperature	-0.01	0.01	0.00	-0.02
	Average Precipitation	0.00	0.00	0.00	0.00
Livestock + Temp_Ave + Precip_Ave	Intercept	0.16	0.06	0.30	0.01
	Livestock Density	0.00	0.00	0.00	0.00
	Average Temperature	-0.01	0.00	0.00	-0.02
	Average Precipitation	0.00	0.00	0.00	0.00
Livestock + Temp_Ave + Precip_Total	Intercept	0.16	0.07	0.31	0.01
	Livestock Density	0.00	0.00	0.00	0.00
	Average Temperature	-0.01	0.00	0.00	-0.02
	Total Precipitation	0.00	0.00	0.00	0.00
Temp_Min + Precip_Total	Intercept	0.08	0.04	0.18	-0.01
	Minimum Temperature	-0.01	0.01	0.00	-0.02
	Total Precipitation	0.00	0.00	0.00	0.00
Temp_Max + Precip_Ave	Intercept	0.17	0.10	0.40	-0.05
	Maximum Temperature	-0.01	0.00	0.00	-0.02
	Average Precipitation	0.00	0.00	0.00	0.00
Temp_Max + Precip_Total	Intercept	0.16	0.11	0.40	-0.08
	Maximum Temperature	-0.01	0.00	0.00	-0.02
	Total Precipitation	0.00	0.00	0.00	0.00