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Effects of landscape change on corsac foxes in Mongolia

Myagmarjav Lkhagvasuren
University of Vermont

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EFFECTS OF LANDSCAPE CHANGE ON CORSAC FOXES IN MONGOLIA

A Thesis Presented

by

Myagmarjav Lkhagvasuren

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

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ABSTRACT

Landscape change affects the distribution of wildlife and represents a conservation concern, especially in Asia, which is experiencing rapid development. In Mongolia, mining, livestock grazing, infrastructure development and climate change represent major drivers of change that will impact habitats and few tools exist to predict how wildlife will respond. I examined the impacts of landscape change on the corsac fox (*Vulpes corsac*) in a steppe region of Mongolia. The corsac fox occurs widely throughout northern Asia, but has experienced declines in many regions and remains one the least studied canids. I addressed two questions: 1) how do common features of a landscape, such as habitats, topography, herder camps, and roads, shape the distribution of the species? and 2) how will changes in those features affect distribution in the future? I collected locations of foxes from radio-collared animals, scat surveys, and opportunistic sightings in Ikh Nart Nature Reserve, then used maximum likelihood methods and model selection techniques to develop a model that predicts occupancy probability. I then applied the model to simulations of landscape change. I collected 1,965 locations and examined 19 candidate models. The model with the most support indicated that occupancy is best described by the additive combination of shrublands, open plains, tall grasslands, and rocky habitat. Models with other covariates (camps, roads, and ruggedness) had little support. A Receiver-Operator-Characteristic plot of model performance had an Area Under the Curve of 77%, indicating that the model predicted occupancy better than expected by chance. Average occupancy across the reserve was 22% under current conditions. Incremental reductions in shrubland, open plains, and tall vegetation resulted in occupancy declines with average occupancy being 7%, 13%, and 14%, respectively, when these habitats were completely absent. The loss of all three habitats due to the desertification of the landscape through climate change resulted in an average occupancy of 7%. The results provide the first model of corsac fox occupancy, which can be used to quantitatively examine distribution and impacts of change in other parts of the species’ range. In Ikh Nart, results suggest that climate change poses the greatest threat to the species as it is expected to reduce high quality habitats and confine corsac foxes to areas with high competition from red foxes.
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CHAPTER 1: INTRODUCTION

1.1. Overview of research

Landscape change has been a major driving force that shapes the distribution of species (Fahrig 2003). Changes are often due to human activities and results in a variety of impacts on species (Reading et al. 2010). Large species, in particular, are typically most vulnerable to change because they occur in low density, require large home ranges, and have low fecundity (Simberloff 1998). In Asia, landscape change is occurring rapidly in many areas affecting the amount and distribution of natural habitats (Rigg 2004). Drivers of landscape change include infrastructure development, like roads, houses, and railway lines, intensive livestock grazing, mining of metals and minerals such as cooper, gold, and rare earth minerals, and the warming and drying effects of climate change (Reading et al. 2010). Understanding how species will respond to landscape change is an essential component of successful conservation.

My research examined corsac foxes (*Vulpes corsac*) and landscape change in Mongolia. I used data collected from radio-collared foxes in Ikh Nart Nature Reserve and maps of the distribution of habitats, topography, ger camps, and roads to develop a model that describes how these factors influence the probability of occurrence. I then used this model to predict how landscape changes will affect the distribution of the species.

Below is a literature review of the main topics and themes in the thesis. Following the review is a scientific article that describes the methods, results, and conclusions of my research written in manuscript format. I also included a comprehensive literature review and appendices of data used in the analysis.
CHAPTER 2: LITERATURE REVIEW

2.1. Landscape change

Changes in the amount and distribution of habitats in a landscape influence the abundance and distribution of wildlife species (Fahrig 2003). Changes may be due to natural processes, but often they are due to human activities (Yong-Zhong et al. 2004). The development of landscapes for agriculture, industry, and housing results in habitat conversion, loss, and fragmentation, and represents a major conservation focus (Lindenmayer and Fischer 2006). Landscape change may result in positive or negative effects on species (Lindenmayer and Fischer 2006). For example, in Australia, the clearing of eucalypt forests for agriculture increased the abundance of some bird species due to the installation of stock troughs across the landscape that provided consistent sources of water (Lindenmayer and Fischer 2006). This led to benefits for species such as Crested Pigeon (*Ocyphaps lophotes*), Galah (*Cacatua roseicapilla*) and Pied Butcherbird (*Cracticus nigrogularis*) (Saunders 1989). All three species were previously uncommon and did not occur in the dry areas between watercourses (Saunders 1989).

Red foxes (*Vulpes vulpes*) also thrive in highly developed urban centers due to rich food resources and a lack of competitors and predators (Sillero-Zubiri et al. 2004). Negative effects include reductions in abundance, increased isolation of populations and even local or regional extirpation and range-wide extinction (Fahrig 1997). For example, the clearing of eucalypt forests mentioned above benefited some species, but overall resulted in the extinction of 90% of bird species in the region (Lindenmayer and Fischer 2006).

Effects on species, whether positive or negative, are often classified as direct or indirect (Fahrig 1997). Direct effects include changes in species abundance and
distribution, and genetic diversity (Fahrig 2003). For example, the installation of roads in Florida, USA directly impacts bear (*Ursus americanus floridanus*) distribution, abundance, and movements, and effectively acts as a genetic barrier (Dixon et al. 2007). From 2000 to 2005 at least 711 bear mortalities were documented road kills in Florida (Dixon et al. 2007). Indirect effects may include the consequences of trophic cascades. Some form of landscape change may impact one species that, in turn, leads to indirect consequence for another species. For example, the reintroduction of wolves (*Canis lupus*) in Yellowstone National Park, USA, resulted in direct impacts on elk (*Cervus canadensis*), but indirect effects on plant communities, especially trees in riparian areas that were over-browsed in the absence of wolves (Ripple et al. 2001). Protected areas represent a common approach to providing refugia for wildlife and shielding species from the direct threats of landscape change (White et al. 1997). However, Franklin (1993) acknowledged that protected areas only cover a small portion of the world’s natural landscapes and most are not large enough to protect species with large home range requirements or those that disperse or migrate to other areas. Thus, focusing conservation on unprotected regions is an essential aspect of wildlife conservation.

Brandt et al. (1999) studied three aspects of land-use dynamics in Danish agriculture, including changes in urban fringe, the dynamics of small biotopes, and marginalization. Each major change was affected by one or more of the five major types of sources that can affect landscape changes: socioeconomic, political, technological, natural and cultural driving sources (Brandt et al. 1999). In addition to human impacts, one of the most challenging and hard to control impacts on landscape change is climate change. In the last 100 years global temperature have increased by 0.6°C (Justus and
And over next 100 years average global temperatures are projected to increase from 1.8°C to 7.1°C (Justus and Fletcher 2001). This will result is enormous changes to terrestrial, freshwater, and marine environments. For example, an increase of 2°C in air temperature triggered snowmelt runoff, glacier melt runoff and total streamflow in Western Himalayan regions by 4-18%, 33-38% and 6-12%, respectfully (Singh and Kumar 1995). Few tools exist to predict how species will respond to these changes, especially in northern and central Asia.

2.2. Landscape change in Mongolia

Mongolia lies in a unique biogeographic region. It is situated at the confluence of three major biomes including taiga forests that extend from Russia in the north, grassland steppe that extends from Kazakhstan from the west, and desert that extends from China to the south. Mongolia is a landlocked country with a total area of approximately 150 million ha (386 million acres). There are six ecological zones in Mongolia: alpine (3.0% of total area), mountain taiga (4.1% of total area), forest steppe (25.1% of total area), steppe (26.1% of total area), desert steppe (27.2% of total area) and desert (14.5% of total area) (Batjargal 1997, Angerer et al. 2008). As it is a landlocked country, Mongolia has a continental climate with a harsh and extremely cold winter and warm summer. The average air temperature of Mongolia is 0.7°C (Batima et al. 2005). January is the coldest month, with average temperatures of -15°C to -35°C. July is the warmest month, with average temperatures of 15°C to 25°C (Batima et al. 2005). However, in parts of the Gobi Desert, temperatures can exceed 45°C. Annual mean precipitation varies by region: 300-400 mm in Khangai, Khentii, and Khuvsgul mountain ranges, 150-220 mm in the steppe,
100-150 mm in the desert-steppe and 50-100 mm in desert, and fall mostly (85-90%) during the summer months (Batima et al. 2005). Mongolia receives an average of 230-260 days of sunshine (Dagvadorj et al. 2009).

Climate change represents a major source of future landscape change. Global air temperature has increased by 0.3°C to 0.7°C from 1986 to 2005 (Pachauri et al. 2014). Similar temperature increases have been observed in Mongolia. Annual mean temperature increased by 1.9°C in the same period (Gomboluudev 2007). Precipitation has also increased by 10% in terms of a country-wide spatial average (Gomboluudev 2007). However, in July, 90% of yearly precipitation is lost to evapotranspiration (Marin 2010). Only 3% of the remaining 10% infiltrates into the soil and contributes ground water (Marin 2010).

Climate change is expected to result in hotter and drier conditions (Dagvadorj et al. 2009). These effects will influence the distribution of habitats and thus the distribution of wildlife species (Fahrig 2003). However, even though there is uncertainty about the precise impacts of climate change, impacts are expected to be large. Angerer et al. (2008) estimated that Net Primary Production in Mongolia will be reduced by 5-30% in the forest steppe and steppe zones by 2080. They predicted that mountain taiga and forest steppe will be greatly reduced and altogether replaced by steppe vegetation in some regions. The area of steppe, desert steppe, and desert might increase in size and shift northward (Angerer et al. 2008). Other studies suggest that Mongolia is on a trajectory toward being more desert-like. Batjargal (1997) estimated that 90% of Mongolia’s total area is vulnerable to desertification based on definitions of the International Convention to Combat Desertification. The Institute of GeoEcology in Mongolia also reported that as
of 2012, 78.2% of Mongolia’s territory are exposed to medium or high-speed desertification (UNEP 2002).

Over 40% of the Mongolian landscape is classified as rangeland. Rangeland includes: forest steppe, steppe, desert steppe, and desert zones (Marin 2010). Due to desertification and vegetation loss rangeland productivity has decreased by 20-30% in last 40 years. Yet, while rangeland productivity is decreasing livestock numbers have increased since 2002 (Angerer et al. 2008). The National Statistical Office of Mongolia reported 51.9 million livestock counted at the end 2014, an increase of 15.1% since 2013. Livestock is an essential part of Mongolian economy and everyday life (UNEP 2002). Unfortunately due to high numbers of livestock and the expanding human population, overgrazing has become a large source of landscape change in Mongolia and contributes to desertification (Marin 2010). Continued overgrazing over a long period of time leads to land degradation and accelerated soil erosion by wind, increased stress on biological activities in soil and decreased soil fertility (Yong-Zhong et al. 2004). Furthermore, food overlap between livestock, especially goats and sheep, and native herbivores in Mongolia is of great concern (Campos-Arceiz et al. 2004, Wingard et al. 2011b). For example, Mongolian gazelle (Procapra gutturosa) diet was similar to the diet of goats and sheep (64.6% of the diet was dicotyledonous plants for Mongolia gazelle and 65.6% for goats and sheep). However, diet overlap between gazelles and horses was only moderate (Pianka’s index: 0.437%) (Campos-Arceiz et al. 2004). Goats and sheep represent the majority of total livestock in Mongolia (42.3% goats and 44.7% sheep) (National Statistical Office of Mongolia, 2014). A similar study implemented in Ikh Nart Nature Reserve examined argali sheep (Ovis ammon) and livestock diet overlap. Results showed
during summer, diet overlap was 72% and during winter it increased to 95% (Wingard et al. 2011a).

2.3. Wildlife in Mongolia

Approximately 1.75 million species have been discovered and described but it’s believed that there are many more species in the world (Groom et al. 1997). Because of the increase in global human population and subsequent impacts on resources, biodiversity on Earth is declining massively and this decline has become one of the most important topics in the field of conservation biology (Marin 2010). As of 2012, some studies suggest that 25% of all mammal species could be extinct in 20 years (Brown 2012).

The loss of biodiversity (including wildlife) has emerged as a major issue in Mongolia. Mongolia currently harbors 138 mammal species, over 2,800 plant species, 486 species of birds, 76 species of fish, 22 species of reptiles and eight species of amphibians (Clark et al. 2006b). As the human population grows and expands rapidly in Mongolia (with a rate as high as 2.3 percent per year) living organisms and natural environments are affected (Clark et al. 2006b). Several factors influence the loss of wildlife in Mongolia such as climate change, desertification, livestock grazing, infrastructure development, mining, and harvesting (Marin 2010).

Human development such as houses, roads, and other infrastructure developments are a major threat to wildlife in Mongolia (Reading et al. 2010). Development leads to habitat fragmentation, which can have a variety of impacts on species. For example, railroads development has created barriers to the migration of Mongolian gazelles (Ito et
Most gazelle occur in the eastern Mongolian steppe, and the total population in Mongolia decreased from 1.5 million in 1940 to 300,000 – 500,000 in 2004 and the current population trend is unknown (Mallon 2008). The railroad that crosses from Russia through Mongolia to China has been implicated as a source of decline. Ito et al. (2004) studied seasonal movements of two radio-collared female Mongolian gazelles in Dornogobi, Mongolia. Even though their sample size was small, their study showed that the two radio-collared gazelles never crossed the railroad (Ito et al. 2004).

Illegal and legal mining represents an important source of local and national revenue, but also a source of landscape change that impacts wildlife (Murdoch et al. 2010a). Mining is expanding rapidly in Mongolia due to the rapid growth of the economy (Murdoch et al. 2010a). Mining occurs for metals such as gold and copper as well as other high value minerals such as rare earth minerals (Murdoch et al. 2010a). Mining occurs at a variety of spatial scales – for example, the Erdenet mine in Orkhon Aimag is one of the largest copper mines in the world. Small-scale mining also occurs and resulted in a culture of ‘ninja’ miners in some regions – those being illegal miners that surreptitiously mine small areas quickly to avoid detection (Murdoch et al. 2010a). In Ikh Nart Nature Reserve, ninja miners typically extract amethyst that is sold in local markets. Many forms of mining both uses and pollutes large amount of water, releases chemicals into the environment, and destroys pasture lands (Murdoch et al. 2010a).

Illegal miners pose a threat to wildlife in protected areas. In Great Gobi A Strictly Protected Area, illegal gold miners use potassium cyanide to extract gold, which pollutes areas where wildlife, especially IUCN Critically Endangered wild camels (*Camelus bactrianus*) feed (Yadamsuren et al. 2012).
Legal structures exist to protected wildlife and recover populations (Wingard and Odgerel 2001). However, law enforcement is lacking and represents a major challenge to wildlife conservation (Wingard and Zahler 2006). Unfortunately protected areas and local departments also suffer from a lack of staff, equipment, and limited operating budgets. Furthermore, gaps in laws, regulations, and low civil penalties make efficient conservation management difficult (Zahler et al. 2004).

However, many actions are being taken to protect wildlife in Mongolia. One has been to increase the number of protected areas in the country. Mongolia has a rich history of protected area creation and management. For example, Chinggis Khan created Mongolia’s first protected area to conserve game species about 800 years ago, which today represents one of the world’s oldest continuously protected area still in existence, the Bogdkhan Mountain Strictly Protected Area. In 1992, during the UN conference on Environment and Development in Rio de Janeiro in Brazil, the Mongolian government committed that at least 30% of the total land area of Mongolia would be protected under a Protected Areas Network (UNEP 2002). Today, Mongolia has one of the largest protected area systems in the world that includes nearly 100 areas covering approximately 27 million hectares or 18% of the country. The government expects to reach 30% coverage by 2030 (Reading et al. 1999).

Despite a developing protected area system, many species of wildlife continue to decline (Clark et al. 2006a, Clark et al. 2006b). Mammals in particular have experienced notable declines. The Mongolian Red List of Mammals (Clark et al. 2006b) used IUCN criteria to evaluate the 128 native mammal species in the country. Here, 16% were categorized as regionally threatened, of which 2% were listed as Critically Endangered
(CR), 11% Endangered (EN), 3% Vulnerable (VU), 6% Near Threatened (NT).

Surprisingly, 37% were classified as Data Deficient (DD), indicating that not enough information was available to reach an effective classification. The relatively high percentage of Data Deficient species indicates more studies should be done, especially in areas with high species richness such as the Northern Hangai mountain range, Hovsgol and Khentii mountain ranges (Clark et al. 2006b). One species, the Asiatic wild dog (Cuon alpinus), was also categorized as Regionally Extinct (RE) in Mongolia. The Przewalski’s horse (Equus ferus przewalski), which was once extinct in the wild, represents a notable conservation success as it was successfully reintroduced in two regions during 1992 and 1993 (Dierendonck et al. 1996).

Another approach used to protect species in Mongolia has involved promoting the conservation of surrogate species such as flagship, keystone, and umbrella species (Caro and O'Doherty 1999). Keystone species are species whose impact on its community or ecosystem are unexpectedly large relative to its biomass or abundance (Heywood 1995). Flagship species are ‘charismatic’ and popular species that draw conservation attention more easily, and by doing so serve to protect other species and the environment (Groom et al. 1997). Umbrella species are species that have large area requirements, and by virtue of protecting those species, all other species under their ‘umbrella’ will also indirectly receive protection (Simberloff 1998). Barua (2011) reviewed 557 news articles containing the following terms: “flagship species”, “keystone species” and “umbrella species”. A total of 60% of articles on keystone species, 55% on flagship and 63% on umbrella species were about studies on mammals (Barua 2011), many of which were carnivores. In Mongolia, conservationists have used argali sheep as a flagship and
umbrella species to promote wildlife conservation in Ilg Nart Nature Reserve. Snow leopard (*Panthera uncia*) have also been used as a flagship to promote ecosystem conservation in the Tost Mountains (McCarthy and Chapron 2003). Similarly, Przewalski’s horse has been an effective flagship for Hustai National Park (King 2002). The Siberian marmot (*Marmota sibirica*) is an IUCN Endangered species (globally and regionally in Mongolia) and has been described as a keystone species (Murdoch, 2013). Some parks are advocating their protection, which may ultimately affect several other species and biological processes.

2.4. Corsac fox

The corsac fox (*Vulpes corsac*) is distributed in across northern and central Asia, including parts of the Middle East (Heptner and Naumov 1998, Murdoch 2014). They occur in Russia, Islamic Republic of Iran, Kazakhstan, Turkmenistan, Afghanistan, Tajikistan, Kyrgyzstan and Mongolia (Murdoch 2014). In Mongolia they mainly inhabit steppe and semi-desert habitats (Clark et al., 2006; Murdoch, 2007). The species is common in Mongolia, Turkmenistan, Kazakhstan and northern China, although in Tajikistan and Uzbekistan the species is rare (Murdoch 2014). It is listed as globally Least Concern on IUCN Red List, and is not listed on CITES Appendices, even though trade in their furs and body parts represents a growing concern (Wingard and Zahler 2006). In Mongolia, the species is listed as IUCN Near Threatened because populations are declining and appear to be on a trajectory toward extinction (Clark et al., 2006). Corsac foxes are territorial and home range sizes vary depending on landscape condition (Murdoch et al., 2006). Corsac foxes are opportunistic foragers and hunters (Murdoch et
Their diet consists of small rodent species and fruits and seeds, especially when animal prey are scarce (Murdoch et al., 2009). One of the main threats to this species is over-harvesting (Murdoch et al., 2010) for fur and body parts (Murdoch et al., 2006). Hunting traditionally occurred during Soviet times and was strictly regulated. More than 1.1 million corsac fox furs were sold in the Soviet Union from 1932-1972 (Wingard and Zahler 2006). A moratorium on corsac fox harvesting was initiated in 1973 and continued until the collapse of the Soviet Union in 1990. Corsac hunting is now widespread and common throughout Mongolia. Other threats include reductions in habitat quality, mainly caused by landscape development and overgrazing (Mallon 1985). The IUCN Red List indicated the need for further studies on the impacts of land use/development (Clark et al. 2006b).

2.5. Corsac fox in Ikh Nart Nature Reserve

The corsac fox represents one of the least studied canids, despite being relatively common (Sillero-Zubiri et al., 2004). However several studies were conducted on their behavior and ecology in Ikh Nart Nature Reserve. Ikh Nart is a relatively small protected area (666 km²), located in Dornogobi province, Mongolia (45°43´N, 108°39´E) (Reading et al. 2006b). First established in 1996, Ikh Nart protects a unique landscape and one of Mongolia’s largest populations of argali sheep. Ikh Nart’s landscape includes several habitat types such as rocky outcrops, grassland, shrublands, semi-shrublands and forblands (Jackson et al. 2006). The reserve is managed and protected by two Soum centers, Dalanjargalan and Airag. The average elevation is approximately 1,200 m. Climate is arid with temperatures ranging from -40°C to 40°C and average annual
precipitation is <200 mm. At least 33 mammal species occur in the reserve, including five species listed by the IUCN as regionally Endangered (EN): argali sheep, Asiatic wild ass (*Equus hemionus*), Mongolian gazelle (*Procapra gutturosa*) and Siberian marmot or Vulnerable (VU): goitered gazelle (*Gazella subgutturosa*) (Reading et al. 2006b). Also four species are listed as regionally IUCN Near Threatened (NT), including Siberian ibex (*Ibex sibirica*), grey wolf (*Canis lupus*), red fox, corsac fox, Eurasian lynx (*Lynx lynx*), and Pallas’ cat (*Otocolobus manul*) occur in the reserve (Murdoch et al. 2006). Under The Mongolian Law on Fauna and Flora argali sheep, Siberian ibex, Asiatic wild ass, goitered gazelle, Eurasian lynx, and marbled polecat are listed as Rare (Murdoch et al. 2006). In Ikh Nart no mammal species listed as Very Rare (Murdoch et al. 2006).

A study of corsac fox behavior and ecology was conducted from 2004 to 2008 in Ikh Nart Nature Reserve (Murdoch 2009). The study radio-collared 18 corsac foxes along with 17 red foxes. Average home range size was 6.5 km$^2$ for corsacs and ranged from 2.2 – 9.7 km$^2$ seasonally (Murdoch, 2009). Corsac foxes mainly selected steppe habitats, including shrublands dominated by peashrub (*Caragana pygmaea*), tall grasslands dominated by needlegrass (*Acnatherum splendens*), and open plains that consisted of gently rolling terrain dominated by semi-shrubs, short grasses, and forbs (Murdoch 2009). Corsacs were largely nocturnal, and were rarely active during twilight or diurnal hours (Murdoch 2009). Annual survival probability was 0.34. Most mortality (60%) was caused by human hunting, 30% was caused by predation by larger competitor species, and 10% was due to unknown reasons (Murdoch et al. 2010b). Red foxes killing corsac foxes was an interesting mortality factor, which reflected interference competition between the species (Murdoch et al. 2010b). Corsac foxes diet overlap highly (94%) with
red foxes during the breeding (winter) season when prey was scarce (Murdoch et al. 2010a). This high overlap probably leads to greater competition with red foxes (all corsac mortalities due to red foxes occurred during this season) (Murdoch et al. 2010b).

Similarly, Kamler et al. (2003) studied survival of swift foxes (Vulpes velox) in the Western Great Plains of North America. They monitored 42 swift foxes, and 12 deaths occurred during the study. Coyote (Canis latrans) predation accounted for 4 (33%) of total death (Kamler et al. 2003).

Corsac fox often used subterranean dens during daytime hours, presumably to avoid the harsh climate conditions of steppe environments (Murdoch et al. 2009b). Although they may excavate their own dens, often times they will use the burrows of Siberian marmot (Murdoch et al. 2009b). Siberian marmots are considered a keystone species in steppe environments. Marmots’ burrows act as shelter and habitat for small mammals, insects and reptiles, are important prey for larger species, and may assist soil renewal and plant community dynamics (Murdoch et al. 2009b). Murdoch et al. (2009b) observed that corsacs used marmot dens of 53% of the occasions that dens were used. Corsacs may also use marmot burrows as shelter and refuge from larger carnivores such as wolves and red foxes (Vulpes vulpes) (Murdoch et al. 2009b, Murdoch et al. 2010b)

Murdoch et al. (2009) examined sexual dimorphism of corsac foxes and red foxes. Among 18 adult corsac foxes no significant difference was observed in body weight or any other body measurement between females and males (Murdoch et al. 2009a). However there was no clear explanation for the lack of difference. Possible explanations include illegal hunting which occurs intensively during winter reduces effect of selective mechanism (Murdoch et al. 2009a).
2.6. Occupancy modeling

An occupancy model is a mathematical expression that can be used to predict the probability a species will occur in a particular location (MacKenzie et al. 2006). The definition of occupancy is the proportion of area, patches, or sample units that are occupied (MacKenzie et al. 2002, MacKenzie et al. 2006). Occupancy modeling requires very simple information: detection and non-detection data. These data are often generated for carnivores from surveys using camera traps, scent stations, or visual observations (MacKenzie et al. 2006). Occupancy modeling uses the multinomial maximum likelihood function to estimate model parameters (MacKenzie et al. 2002) and is helpful in wildlife studies because it accounts for imperfect detection by estimating the probability of detection when estimating occupancy probability (MacKenzie et al., 2002).

Multiple surveys of sites allow for the estimate of a detection probability (Murdoch et al. 2009a, Harmson et al. 2010). The occupancy modeling approach involves developing multiple apriori models, confronting them with the data, then using model selection techniques to determine the best model in the set (MacKenzie et al. 2006, Burnham and Anderson, 2002). Akaike’s Information Criterion is often used as the method to rank the relative support of each model (Burnham and Anderson 2002).

Murdoch et al. (2013) used an occupancy modeling approach to examine the influence of Siberian marmot (*Marmota sibirica*) on toad headed agama (*Phrynocephalus versicolor*) occupancy in Ikh Nart Nature Reserve. Three habitat types (rocky outcrop, open plains and shrublands) and marmot burrows were used in models to explain occupancy probability and temperature was used to explain detection probability. Detection probability of agama was 64% among 124 sites and naïve occupancy
probability was 85% across all sites. Agama occupancy was best described by the proportion of rocky habitat surrounding a given site in the landscape. Rocky habitat had a strong negative impact on occupancy. Agama detection was also highest at approximately 27°C.

Another study developed an occupancy model for red foxes in Ikh Nart (Murdoch et al. 2015). They estimated the percent coverage of four different habitats and developed six candidate models using percent vegetation cover as a detection covariate. Detection probability among 122 sites was 31%. Habitats including shrublands and rocky outcrops that provided the most cover and concealment from predators were the parameters in the top model (Murdoch et al. 2015).

Murdoch et al. (2014) used the agama and red fox models to evaluate the relative quality of the Ikh Nart landscape. They assessed the occupancy probability of red foxes and toad headed agamas in three areas: 1) inside the reserve, 2) inside the reserve’s core protected area and 3) outside the reserve. For red foxes, occupancy probability varied from 0.084 to 0.997 and for agamas it varied from 0.022 to 0.949 (Murdoch et al. 2014). Study result showed landscape quality was highest in the core area of the reserve and lowest outside of the reserve for red foxes, and highest outside the reserve and lowest in the core area of the reserve for toad headed agamas (Murdoch et al. 2014).

### 2.7. Presence-only data

The occupancy modeling approach described above requires both detection and non-detection data, which is generated through multiple surveys. However, detection non-detection data are not always practical to collect. Occupancy models can be
developed using presence-only data, like animal locations. This approach can be implemented when direct absence data are not available (Royle et al. 2012). Presence-only models generally require larger sample sizes and assume that detection probability is constant (Royle et al. 2012).

There are several presence-only occupancy modeling techniques. Two common types include MaxEnt and MaxLike. MaxEnt uses maximum entropy methods and MaxLike uses maximum likelihood methods (Royle et al. 2012, Fitzpatrick et al. 2013). In my study, I used MaxLike to estimate model parameters. Fitzpatrick et al. (2013) examined the difference between these two approaches on six different species of ants in New England. They and concluded that MaxLike results in better estimates of a species distribution than MaxEnt. MaxEnt is sensitive to the specification of the background prevalence (Royle et al. 2012). On the other hand MaxLike still shows occupancy even when the probability was extremely low (Fitzpatrick et al. 2013). Furthermore, even though MaxEnt is widely used for modeling species distributions, it does not estimate the actual probability of occurrence, rather a surrogate measure that is often equated with occupancy, which complicates interpretation. MaxLike uses presence-only data and spatially referenced covariates and provides likelihood-based approach to modeling species distribution (Royle et al. 2012). Species distribution maps can be created by plotting the expected values of occurrence probability (Royle et al. 2012). One weakness of presence-only data is it does not estimate probability of detection, and if probability of detection is affected by the same covariates as probability of occurrence, then there is bias (Royle et al. 2012).
2.8. Data sources

My research focused on how landscape patterns affect corsac fox occupancy in Ikh Nart Nature Reserve, Mongolia. I used four types of habitat classes to model occupancy: rocky outcrops, shrublands, open plains, and tall vegetation. These habitat maps were classified by Jackson et al. (2006) using a five-band multispectral composite Landsat 7ETM+ image, with overall classification accuracy of 90.5%, $K_{hat}$ statistics of 88.8% and user’s accuracy of $>85\%$ per class (Jackson et al. 2006). Also I used topographic ruggedness. A spatially explicit ruggedness layer of Ikh Nart was built by Bragin et al. (2013) by using 90 m Shuttle Radar Topography Mission (SRTM), digital elevation model (DEM) and ArcGIS Spatial Analyst (Bragin et al. 2013). For anthropogenic factors I used herders’ camp (ger) locations and a road system developed by a previous study by H. Davie (Davie et al. 2014a). Corsac fox locations included scats, sightings, captures, and radio-telemetry points were estimated by various previous studies (Murdoch 2009).

2.9. Literature Cited


CHAPTER 3: EFFECTS OF LANDSCAPE CHANGE ON CORSAC FOXES IN MONGOLIA
3.1. Abstract

Landscape change affects the distribution of wildlife and represents a conservation concern, especially in Asia, which is experiencing rapid development. In Mongolia, mining, livestock grazing, infrastructure development and climate change represent major drivers of change that will impact habitats and few tools exist to predict how wildlife will respond. I examined the impacts of landscape change on the corsac fox (*Vulpes corsac*) in a steppe region of Mongolia. The corsac fox occurs widely throughout northern Asia, but has experienced declines in many regions and remains one of the least studied canids. I addressed two questions: 1) how do common features of a landscape, such as habitats, topography, herder camps, and roads, shape the distribution of the species? and 2) how will changes in those features affect distribution in the future? I collected locations of foxes from radio-collared animals, scat surveys, and opportunistic
sightings in Ikh Nart Nature Reserve, then used maximum likelihood methods and model selection techniques to develop a model that predicts occupancy probability. I then applied the model to simulations of landscape change. I collected 1,965 locations and examined 19 candidate models. The model with the most support indicated that occupancy is best described by the additive combination of shrublands, open plains, tall grasslands, and rocky habitat. Models with other covariates (camps, roads, and ruggedness) had little support. A Receiver-Operator-Characteristic plot of model performance had an Area Under the Curve of 77%, indicating that the model predicted occupancy better an expected by chance. Average occupancy across the reserve was 22% under current conditions. Incremental reductions in shrubland, open plains, and tall vegetation resulted in occupancy declines with average occupancy being 7%, 13%, and 14%, respectively, when these habitats were completely absent. The loss of all three habitats due to the desertification of the landscape through climate change resulted in an average occupancy of 1%. The results provide the first model of corsac fox occupancy, which can be used to quantitatively examine distribution and impacts of change in other parts of the species’ range. In Ikh Nart, results suggest that climate change poses the greatest threat to the species as it is expected to reduce high quality habitats and confine corsac foxes to areas with high competition from red foxes.

Key words: corsac, Mongolia, occupancy model, steppe, *Vulpes corsac,*
Абстракт

Ландшафтын өөрчлөлт нь маши хүрдэцтэй хөгжиг буй Ази 30 гэх мэт бусэд амьдарч буй зэрэг ан амьтын тархалтат маши хүчтэй нөлөө үзүүлдэг богоод байгаль хамгааллын нэгэн чухал сэдэв юм. Монгол оронд зэрэг амьтын амьдрах оргинд нөлөөлөх гол хүчнээс зүйлүүлэдүү уул урхай, мал аж ахуй, ээд бутэц болон уур амьсгалын өөрчлөлтүүд зэрэг хүчнээс буй амьдрал багтаж байна. Гэвч харамсалтай нь онгоогийн байдал бүр Монгол оронд буй зэрэг амьтлын өөрчлөлт орчны нэгэн чухал сэдэв юм. Монгол оронд зэрлэг амьтаа бүтэц болон уул урхай, мал аж ахуй, дэд бүтэц болон уур амьсгалын өөрчлөлтүүд зэрэг хүчнээс буй амьдрал багтаж байна. Гэвч харамсалтай нь онгоогийн байдал бүр Монгол оронд зэрлэг амьтлын өөрчлөлт орчны нэгэн чухал сэдэв юм. Монгол оронд зэрлэг амьтлын амьдрал бүтэц болон уул урхай, мал аж ахуй, дэд бүтэц болон уур амьсгалын өөрчлөлтүүд зэрэг хүчнээс буй амьдрал багтаж байна. Гэвч харамсалтай нь онгоогийн байдал бүр Монгол оронд зэрлэг амьтлын өөрчлөлт орчны нэгэн чухал сэдэв юм. Монгол оронд зэрлэг амьтлын амьдрал бүтэц болон уул урхай, мал аж ахуй, дэд бүтэц болон уур амьсгалын өөрчлөлтүүд зэрэг хүчнээс буй амьдрал багтаж байна. Гэвч харамсалтай нь онгоогийн байдал бүр Монгол оронд зэрлэг амьтлын өөрчлөлт орчны нэгэн чухал сэдэв юм. Монгол оронд зэрлэг амьтлын амьдрал бүтэц болон уул урхай, мал аж ахуй, дэд бүтэц болон уур амьсгалын өөрчлөлтүүд зэрэг хүчнээс буй амьдрал багтаж байна. Гэвч харамсалтай нь онгоогийн байдал бүр Монгол оронд зэрлэг амьтлын өөрчлөлт орчны нэгэн чухал сэдэв юм. Монгол оронд зэрлэг амьтлын амьдрал бүтэц болон уул урхай, мал аж ахуй, дэд бүтэц болон уур амьсгалын өөрчлөлтүүд зэрэг хүчнээс буй амьдрал багтаж байна.
3.2. Introduction

Landscape change affects the distribution of wildlife and represents a conservation concern, especially for habitat-sensitive species and those that are threatened or declining (Lindenmayer and Fischer 2006). Throughout Asia, many countries are experiencing rapid economic growth, which has led to widespread changes in natural communities (UNEP 2002). Changes include the loss and conversion of habitat due to a variety of reasons including infrastructure development (e.g., houses, roads, railroads), resource extraction (e.g., mining and livestock production), and climate change (Reading et al. 2010). Mongolia has undergone rapid economic and social change since the collapse of the Soviet Union in 1990 (Pratt et al. 2004). Consequences of this change include increased development and demand for natural resources for local and international markets (World Bank 2006). Although wildlife conservation represents a national priority, the impacts of landscape change on species remain poorly studied (Clark et al. 2006b).

Changes that affect the amount and distribution of habitats can affect species in several ways. Some species benefit from changes. For example, foxes (Vulpes spp.) successfully occupy highly developed urban centers due to the abundance of food and lack of larger predators and competitors (Macdonald and Reynolds 2004). Red foxes (V. vulpes) occur at saturation density in cities such as Oxford and Bristol in the United Kingdom (Doncaster and Macdonald 1991, Baker and Harris 2004). Similarly, one of the largest remaining populations of endangered San Joaquin kit foxes (V. macrotis mutica) occurs in the city of Bakersfield, California, USA (Cypher 2010). However, change may also negatively impact species. For example, the construction of roads in Florida, USA
led to increased rates of mortality among black bears (*Ursus americanus*) and effectively isolated populations (Dixon et al. 2007).

Understanding the impacts of landscape change on a species requires information on how the aspects of the landscape, such as habitat distribution, affect a species. A common approach involves modeling the effects of landscape characteristics on distribution, then applying the model to various scenarios of change to predict impacts (Boyce and McDonald 1999). Occupancy modeling represents one approach to species distribution modeling (MacKenzie et al. 2002). An occupancy model is often based on detection/non-detection data (i.e., from surveys) and uses maximum likelihood methods to estimate parameters that describe the impact of covariates, such as habitats (MacKenzie et al. 2002, MacKenzie et al. 2006). Occupancy modeling has been applied to several species in Mongolia, including red foxes and agamas in Mongolia (Murdoch et al. 2013, Murdoch et al. 2015). However, obtaining sufficient detection/non-detection data is often challenging and impractical for some species, including those that are rare, occur at low densities, and are difficult to detect (MacKenzie et al. 2006). Occupancy models can be built from presence-only data such as animal location and several approaches may be used such maximum entropy methods (e.g., MaxEnt program) and maximum likelihood methods (e.g., MaxLike package for R) (Royle et al. 2012, Fitzpatrick et al. 2013). Presence-only methods generally assume that detection probability is constant across variables of interest (Royle et al. 2012).

The corsac fox (*V. corsac*) is a small, arid-adapted fox species that occurs throughout northern and central Asia (Heptner and Naumov 1998, Murdoch 2014). The species occupies mainly grassland and shrubland steppe and semi-desert regions, and
represents one of the least studied canids (Heptner and Naumov 1998, Poyarkov and Ovseenikov 2004, Clark et al. 2009). Corsacs are generally nocturnal and secretive in nature, have a variable diet that often consists of rodents and insects, and occupy home ranges that appear to vary according to the distribution of habitats (Heptner and Naumov 1998, Clark et al. 2009, Murdoch 2009, Murdoch et al. 2010a). In Mongolia, corsacs were once widespread and considered a common and abundant species (Heptner and Naumov 1998, Clark et al. 2006b). However, notable declines have occurred, which led the government to classify the species as IUCN Near Threatened in the country (Clark et al. 2006b). The decline of corsac foxes is a concern given the economic importance of the species as a furbearer, their perceived role in controlling rodent populations (that compete with livestock), their value to tourism, and cultural importance (Clark et al. 2006b).

As the natural landscapes of Mongolia continue to develop, corsac foxes may be at risk of further declines (Clark et al. 2006b). Tools are needed to better describe the influence of landscape characteristics on the species and predict the effects of change. In this study, I addressed two main questions: 1) how do common features of a landscape, such as habitats, topography, herder camps, and roads, shape the distribution of the species? and 2) how will changes in those features affect distribution in the future?

### 3.3. Materials and methods

#### 3.3.1. Study Area

I conducted the study in and around Ikhn Nart Nature Reserve in Dornogobi Aimag (province), Mongolia (45°43’N - 108°39’E) (Fig. 3.1) (Reading et al. 2011). Ikhn Nart is
approximately 666 km$^2$, and was established in 1996 to protect one of the largest remaining populations of argali sheep ($Ovis ammon$) in Mongolia (Myagmarsuren 2000, Reading et al. 2011). The reserve covers two soums (counties), including Dalanjargalan (northern 57% of the reserve) and Airag (remaining southern part of the reserve) and is administered locally with some oversight from the national government (Fig. 3.1) (Jackson et al. 2006). Ikh Nart includes a steppe and semi-desert habitats (Reading et al. 2011). Steppe habitats include shrublands (14.6%, dominated by peashrub, *Caragana pygmaea* and wild apricot, *Amygdalus pedunculata*), open plains (37.5%, dominated by turf semi-shrubs, short grasses, and forbs), and tall grasslands (5.6%, dominated by needlegrass, *Achnatherum splendens*). Semi-desert includes rocky outcrops (14.5%) with sparse vegetation. Steppe areas are typically gently rolling plains, whereas semi-desert areas tend to be more rugged and topographically variable terrain. This region is arid with annual precipitation of <200 mm, which falls mostly as rain from June to August. Temperature typically ranges from -40 to +40°C throughout the year and average elevation is approximately 1200 m. Approximately 110 families live in an around the immediate vicinity of the reserve and a network of dirt-track roads connects herder camps and the local soum centers (Davie et al. 2014b).

Ikh Nart has a diverse fauna including 33 species of mammals, 125 species of birds, 6 species of reptiles, and over 220 species of plants (Murdoch et al. 2006). Corsac foxes occur in most major habitats in the region, but favor steppe habitats such shrublands and grasslands (Murdoch et al. 2007). Red foxes also occur in the region and represent a competitor – red foxes caused 30% of mortality among a marked population of corsacs in the reserve (Murdoch et al. 2010b).
3.3.2. Occupancy model

To examine how common landscape characteristics shape corsac fox distribution, I developed an occupancy model based on presence-only data. I used corsac fox locations from three sources to build the model, including: 1) scat locations (n = 906) (Murdoch et al. 2007), opportunistic sightings (n = 32) (Murdoch et al. 2007), live-capture locations (n = 18) (Murdoch et al. 2007), and radio-telemetry locations (n = 1,009) collected from 18 marked foxes (9 females, 9 males) (Murdoch 2009). All data were collected from 2005-2009.

I overlaid the locations on maps of the study area using Geographic Information Systems (ArcGIS v. 10, ESRI, Redlands, California, USA), and extracted the following data for each location: 1) proportion of four habitats, including rocky outcrop (RO), shrubland (SH), open plains (OP), and tall vegetation (TV). Proportions were estimated from raster maps (30 x 30 m pixels) developed by Jackson et al. (2006) from a supervised classification of a Landsat ETM+7 satellite image. I estimated the proportion of each habitat at three spatial scales, 100 m, 250 m, and 1 km. However, Spearman’s rank correlation indicated that proportions per habitat were correlated across scales, so I arbitrarily chose 250 m values for the analysis; 2) average topographic ruggedness (within 250 m). I used a raster map of ruggedness index values developed by Bragin et al. (2013). This layer was based on the slope, aspect, and elevation characteristics of each pixel; and 3) distance to the nearest herder ger camp and road. Ger camp and road layers were based on maps developed by Davie et al. (2014a).
I then developed set of *apriori* models to explain patterns of occupancy. The model set included 19 total models that predicted occupancy probability (ψ) as function of different combinations of covariates (Table 3.1). They included all additive combinations of habitat variables. Previous research indicated that corsacs selected all four habitats, and included all subsets to examine all possible combinations of variables (Murdoch 2009). I predicted that steppe habitats including shrublands, open plains, and tall vegetation would positively influence occupancy given patterns of used described previously (Heptner and Naumov 1998, Murdoch 2009). I also predicted that rocky habitat would negatively influence occupancy because red foxes mainly occupy this habitat. Red foxes have been documented to kill corsacs during encounters and I reasoned that corsacs would avoid rocky habitats (Murdoch et al. 2010b). I included ruggedness and predicted that corsacs would favor less rugged conditions given descriptions of the species distribution (Heptner and Naumov 1998). Lastly, I included single and additive models of gers and roads. Gers represents centers of human activity and intensive livestock use and I predicted that corsacs would avoid these areas due to their risk of encountering humans and dogs that kill foxes (Davie et al. 2014a). Dirt track roads receive low traffic and corsacs probably also avoid them.

I used the MaxLike package for R (Royle et al. 2012). MaxLike used maximum likelihood methods to estimate parameter values (i.e., beta or β values) for a specified occupancy model given a set of presence-only locations (Royle et al. 2012). Each model included a beta for the intercept and each covariate. I used Akaike’s Information Criterion (AIC) to rank the relative support of each model and considered models with a ΔAIC of <2 to have strong empirical support (Burnham and Anderson 2002).
3.3.3 Model performance

I evaluated the performance of the top ranking model using a Receiver-Operator-Characteristic (ROC) curve (Fielding and Bell 1997, Pearce and Ferrier 2000). The ROC curve represents a plot of the rate true positive (called sensitivity) predictions against the rate of false positive predictions (1 – specificity) of a model over a range of threshold values (Fielding and Bell 1997). I calculated rates of true positive and true negative by applying the model to all known ‘true’ locations (n = 1,965) and the same number of random locations in the landscape that I assumed to represent absences. There were four possible outcomes when the model was applied to a location: true positive, false positive, true negative, and false negative. The outcome was based on a threshold value. For example, for a known ‘true’ site where a corsac occurred, the model predicted an occupancy probability of 0.81 or 81%. At threshold value of 0.50, this site would then be classified as a true positive – it successfully predicted a positive – because 0.81 > 0.50. The fraction of all sites that were true positive and false positive under a range of thresholds from 0 to 1.0 were calculated and plotted to represent the ROC curve. The Area Under the Curve (AUC) was estimated. An AUC value of 0.50 indicated that the model predicted occupancy no better than random. Greater values indicated that model more frequently correctly predicted occupancy than falsely predicted occupancy.

3.3.4 Mapping distribution

I used my top ranking model to build an occupancy map of corsac foxes in Ikh Nart. I applied the model to each pixel (30 m x 30 m) in the map of the region using
ArcGIS (area enclosed by N45.838943° to N45.5245°; E108.489732° to E108.731806°, 729.37 km²). This involved applying the model parameters to the landscape conditions at each pixel and using the logit link function to estimate occupancy probability (MacKenzie et al. 2006). I then color ramped the final occupancy map to distinguish areas of high and low occupancy and to show distribution probability.

3.3.5 Simulating landscape change

Landscape change, whether through development, resource extraction, or climate change, will reduce the relative amount of habitats in the Ikh Nart region. I created seven simulations to explore how systematic reductions in each habitat (excluding rocky outcrop) affect corsac fox occupancy. I simulated 10% reductions in each habitat individually while holding other habitats constant (simulations a – c), 10% reductions in two habitats simultaneously while holding the other habitat constant (simulations d – f), and finally 10% reductions in all three habitats at the same time (simulation g). Reductions started at current conditions, then progressively declined until none of that habitat remained. I created simulations by randomly changing the classification of pixels in habitat maps. Selected pixels were changed to ‘non-habitat’ simulating the complete change of a habitat to bare ground – I assumed that the habitat at a given pixel would not convert to another, which seemed reasonable given observations in the study area.

3.4. Results

The top ranking model was the additive combination of all four habitats: rocky outcrop, shrubland, open plains, and tall vegetation (Table 3.2). This model had the
highest likelihood of being the best model in the set and was the only model with a ΔAIC <2 (Table 3.2). Models that included other combinations of habitat covariates and those containing ruggedness, gers, and roads alone or in combination had little empirical support, even though these models all contained fewer parameters (Table 3.2). Parameter estimates for the top model indicated that all four habitats had positive effects on occupancy probability (Fig. 3.2, Table 3.3). Tall vegetation had the strongest effect, followed by shrubland, rocky outcrop, and open plains (Table 3.3). Confidence intervals (95%) around parameter estimates did not cross zero indicating the effects of covariates were meaningful (Table 3.3). A Receiver-Operator-Characteristic curve of model performance that the top model had an Area Under the Curve of 77%, indicating that the model predicted considerably better than random (Fig. 3.3).

The top model was used to map occupancy probability in the landscape. The resulting map had an average occupancy probability of 22% across all pixels (Fig. 3.4). Occupancy was highest in steppe areas and lowest in semi-desert areas consisting mostly of rocky outcrops. Simulations indicated that incremental reductions of each habitat, while others habitat amounts remained constant, showed decreases in average occupancy in the landscape (Fig. 3.5). Reductions in shrubland habitat resulted in the greatest reduction in occupancy for single habitat declines (average occupancy declined to 7% in the absence of shrubland, Fig. 3.5). Reductions of habitat pairs resulted in greater declines (Fig. 3.5). The absence of shrubland and open plain together resulted in the largest decline among pairs and an average occupancy of 2% across the landscape (Fig. 3.5). When all habitats (except rocky outcrop) were removed, average occupancy
probability was 1% (Fig. 3.4, Fig. 3.5). The absence of these habitats resulted in concentrations of occupancy mainly in rocky outcrop habitat.

3.5. Discussion

Landscape change, such as loss or conversion of habitats, represents a conservation concern for wildlife and can result in changes in the distribution and even the extinction of a species (Fahrig 2003). Asian landscapes are experiencing widespread change due to the rapid economic growth of the region (Rigg 2004). In Mongolia, natural landscapes are changing mainly due to infrastructure development, livestock production, and climate change (Marin 2010, Reading et al. 2010). The impacts of change are largely unknown for many of the native species in the country. I developed an occupancy model for the corsac fox and examined the effects of landscape changes on the species, which ranges across the steppe and semi-desert regions of the country and has demonstrated notable population declines (Clark et al. 2006b, Murdoch 2014). Corsac occupancy was positively influenced by four habitats including tall vegetation, shrubland, open plains, and rocky outcrops, and reductions in the amount of these habitats (i.e., due to some form of landscape change) resulted in large decreases in distribution.

Corsac foxes occur in relatively low density in Ikh Nart and have been described to use all major habitats in the region (Murdoch 2009). However, corsacs tend to favor steppe areas characterized by gently rolling terrain with shrublands, grasslands, and forblands (Murdoch et al. 2007). My results examined models that included all subsets of habitat variables, including steppe and semi-desert habitats, and the results supported
previous observations. They also provided effect sizes for the impact of each habitat.

Tall vegetation, which included areas dominated by needlegrass, often occurred in sandy plains at the end of drainages. Long-term small mammal capture-mark-recapture studies and pitfall trap surveys indicate that rodent abundance and insect relative abundance is highest in this habitat (S. Buyandelger, personal communication). As corsac diet consists mainly of rodents and insects, the relative richness of food resources in tall grasslands may explain its large effect size (Murdoch et al. 2010a). Tall grasslands, along with shrubland, which also had the greatest effect size, provide cover that may allow corsacs to avoid detection by predators and competitors. In the Ikh Nart landscape, corsacs are occasionally killed by raptors, but more commonly by humans and domestic dogs (mainly during winter) (Murdoch et al. 2010b). They are also killed by red foxes, which appear to represent their main competitor (Murdoch et al. 2010b). Open plains, by contrast include little cover habitat and lower relative food amounts. However, they often include Siberian marmot (*Marmota sibirica*) colonies. The Siberian marmot is a large social rodent that lives in colonies that can cover >1 ha and include >100 burrow entrances (Townsend 2006). Corsacs use subterranean dens during the daytime hours, and frequently use marmot burrows (Ognev 1962, Heptner and Naumov 1998, Murdoch et al. 2009b). The positive effect of open plains on occupancy may reflect the relatively high number of available burrows. Surprisingly, rocky habitat also exhibited a positive effect on occupancy. Rocky habitats include few prey resources and are characterized by sparse vegetation, but do offer cover (Reading et al. 2011). Previous observations indicated that corsacs rarely occurred in rocky areas, but the scat data included several records in this habitat, and two radio-collared foxes consistently used dens in rock
crevices along the margin of open plains and shrublands (Murdoch 2009). It is possible that these observations inflated the effect size of rocky areas.

Topographic ruggedness and proximity to human structures including ger camps and roads had little meaningful effect on corsac occupancy. Ruggedness has been shown to negatively affect other fox species, such as kit foxes, which avoid these areas to reduce the chance of encounter larger coyotes (Warrick and Cypher 1998). Red fox occupancy is highest in more rugged, rocky terrain (Murdoch et al. 2015), but corsacs still used these areas, which may have diminished the effect of this covariate. Ger camps represent centers of human activity. Livestock are typically corralled at ger camps at night, which may provide some benefit to corsacs that occasionally consume goats and sheep (Davie et al. 2014b). However, gers also have 1-2 guard dogs, which have been observed killing corsacs and other wildlife including marmots and argali sheep (Young et al. 2011, Davie et al. 2014b). Herders also kill corsacs, especially during the winter period. Corsacs presumably avoid human areas despite their benefits to avoid encounters with humans and dogs. Similarly, roads are probably also avoided to some extent. However, road traffic is relatively low, which may explain the low importance of this covariate.

Landscape change in steppe and semi-desert environments is mainly driven by infrastructure development, including gers and roads, livestock production, and climate change. Corsac occupancy was not meaningfully influenced by gers and roads in the Ikh Nart landscape. However, other forms of landscape change is occurring in Ikh Nart. Livestock grazing occurs intensively throughout the reserve and reduces the amount of short grass and forbs characteristic of open plains, shrublands, and tall grasslands (Wingard et al. 2011b). Livestock density has intensified not only in Ikh Nart, but
throughout Mongolia, and presumably their presence will impact the relative distribution of open plains and tall grasslands through grazing, browsing, and trampling (Reading et al. 2006a). Simulations of declines of these three habitats resulted in substantial decreases in corsac fox distribution in the Ikh Nart landscape. My results may be used by wildlife managers to inform decision-making about livestock densities in the reserve.

Climate change represents a more challenging form of landscape change that will most likely affect the amount and distribution of steppe and semi-desert habitats. Mongolia has a continental climate and projections indicate the Mongolia will become hotter and drier under climate change (Dagvadorj et al. 2009). As a consequence, steppe and semi-desert regions are predicted to shift northward along with the expansion of the Gobi Desert (Marin 2010). Corsacs may be adaptable enough to shift in range. However, in Ikh Nart, my projection suggest that it will be unlikely that corsacs will persist. Ikh Nart is situated at the northeastern edge of the Gobi Desert and as climate becomes warmer and drier, the landscape will probably convert to the arid conditions typical of the Gobi and lose current vegetation communities especially shrublands and grasslands. The complete conversion of these habitats led to a 7% average occupancy probability for corsacs in the reserve, with occupancy concentrated almost exclusively in rocky areas. Given that red foxes occur mainly in these areas and represent major competitors, it is unlikely that corsacs will persist. Managing for climate change may involve protecting adequate areas that support sufficient occupancy to allow corsacs to gradually shift northward.

My study examined the influence of several factors to explain corsac fox occupancy. These factors represented common landscape characteristics. However,
other factors may certainly impact corsac occupancy. For example, red foxes probably influence the distribution of corsacs in the landscape. Multi-species occupancy models can be developed that examine the impacts of one species on another (Zipkin et al. 2010). These models generally require large amounts of data on both species that I was unable to obtain for this study. The location data used to develop the corsac model was presence-only data from multiple sources, including opportunistic scats locations and observations, live-capture sites, and radio-telemetry locations from marked individuals. Presence-only models perform best with randomly collected data (Royle et al. 2012), and the data sources in this study were not truly random. However, they were collected over several years and effort to capture foxes occurred systematically throughout the reserve (Murdoch 2009). I believe that any biases from the location data were minimal.

The simulations of landscape change I conducted represented a series of plausible changes to habitats. I made two assumptions that should be considered when interpreting the results. I assumed that the habitats would be reduced in a random pattern across the reserve. Reductions will most likely be caused by livestock and climate change, which may not affect the landscape evenly. I also assumed that a reduction in habitat equated to the loss of habitat and not its conversion. The model could be used to explore how corsac fox occupancy responds to the conversion, rather than the loss of habitat (e.g., shrubland to open plain).

The corsac model performed better than would be expected by random based on the Receiver-Operator-Characteristic curve (Fielding and Bell 1997). In this assessment I evaluated the model against known presence data, but also absences, which I represented as random locations in the landscape. These pseudo-absences may not truly be areas
without corsacs, which induces some bias in the assessment of model performance. However, this bias suggests that the model probably performed better estimated. Uncertainty exists in methods for adequately assessing presence-only models.

The model could be improved by the addition of other sources of data. For example, expert opinion data on corsac distribution from local wildlife managers or herders in Ikh Nart could be used to update the model using a Bayesian framework. Expert opinion has been incorporated in distribution models elsewhere and may improve model performance (Murray et al. 2009). Variables used to develop the corsac model represent common characteristics of steppe and semi-desert region, so that the final model would be broadly applicable to other parts of Mongolia. The model represents the first quantitative, empirically based model of corsac occupancy and may be valuable for assessing patterns of distribution and impacts of change elsewhere in its range.

3.6. Acknowledgements

I thank the Denver Zoological Foundation for funding the project. I also received support from the Fulbright Scholarship program, Mongolian government, and University of Vermont. I am grateful to J. Murdoch, A. Strong, and L. Webb for their input on the study. T. Munkhzul, S. Buyandelger and G. Otgonabayar helped capture, radio-collar, and track corsac foxes. Hannah Davie provided ger and road. The project also received assistance from the Mammalian Laboratory, Institute of Biology and Earthwatch Institute, as well as B. Lkhagvasuren and R. Reading.
3.7. Literature cited


Jackson, D., J. D. Murdoch, and B. Mandakh. 2006. Habitat classification using Landsat 7ETM+ imagery of the Ikh Nart Nature Reserve and surrounding areas in


Myagmarsuren, D. 2000. Special Protected Areas of Mongolia. Mongolian Environmental Protection Agency and GTZ (German Technical Advisory Agency), Ulaanbaatar, Mongolia.


3.8. Figure legends

**Figure 3.1.** Map of Ikh Nart Nature Reserve, Mongolia showing reserve and core protected area boundaries.

**Figure 3.2.** Corsac fox (*Vulpes corsac*) occupancy probability ($\psi$) as a function of the proportion of rocky outcrop, shrubland, tall vegetation and open plain habitat within 250 m of a given location in Ikh Nart Nature Reserve, Mongolia. Estimates based on a top ranking occupancy model based on presence-only data.

**Figure 3.3.** Receiver Operator Characteristic (ROC) curve of model performance with an Area Under Curve (AUC) value of 77%. AUC=1 indicates that a model predicts perfect similarity between observed and predicted values, whereas an AUC=0.5 indicates that a model predicts no better than random. Curve estimated by plotting the rate of true positive and false positive classifications across a range of threshold values based on presence locations and pseudo-absences of corsac foxes (*Vulpes corsac*) in Ikh Nart Nature Reserve, Mongolia.

**Figure 3.4.** Map of corsac fox (*Vulpes corsac*) occupancy probability ($\psi$) in Ikh Nart Nature Reserve (INNR), Mongolia. A – corsac fox occupancy probability in the current landscape (mean $\psi = 22\%$), and B – corsac fox occupancy probability in the absence of shrubland, open plains, and tall vegetation habitats expected under climate change (mean $\psi = 7\%$).
Figure 3.5. Corsac fox (*Vulpes corsac*) occupancy probability ($\psi$) under 7 simulations of landscape change in Ikh Nart Nature Reserve, Mongolia. Occupancy probability estimated with a top ranking model based on presence-only data. The top ranking model included the additive combination of the following covariates: rocky outcrop (RO), open plains (OP), shrublands (SH), and tall vegetation within 250 m of a given location. Simulations involved reducing each covariate in 10% amounts across the landscape, and recording average occupancy. Simulations included: a – only TV reduced; b – only SH reduced; c – only OP reduced; d – only SH+OP reduced; e – SH+TV reduced; f – OP+TV reduced; and g – all variables reduced except RO.
### 3.9. Tables

**Table 3.1.** Model variables used to examine corsac fox (*Vulpes corsac*) occupancy probability ($\Psi$) in Ikh Nart Nature Reserve, Mongolia.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Measure</th>
<th>Predicted influence on $\Psi$</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shrubland</td>
<td>Areas dominated by common shrubs including peashrub (<em>Caragana pygmaea</em>) and wild apricot (<em>Amydalus pedunculata</em>).</td>
<td>%</td>
<td>Positive</td>
<td>Jackson et al. (2006), Murdoch et al. (2007), Murdoch et al. (2009), Murdoch (2009).</td>
</tr>
<tr>
<td>Rocky outcrop</td>
<td>Area covered by exposed bare rock with sparse vegetation cover.</td>
<td>%</td>
<td>Negative</td>
<td>Jackson et al. (2006), Murdoch et al. (2007), Murdoch et al. (2009).</td>
</tr>
<tr>
<td>Open plain</td>
<td>Areas dominated by low ground cover including turfy semi-shrubs (e.g., <em>Reaumuria soongorica</em> and <em>Salsola passerina</em>) and forbs (e.g., <em>Allium polyrrhizum</em>), and short grasses (e.g., <em>Stipa gobica</em>).</td>
<td>%</td>
<td>Positive</td>
<td>Jackson et al. (2006), Murdoch et al. (2007), Murdoch et al. (2009).</td>
</tr>
<tr>
<td>Tall vegetation</td>
<td>Area covered by trees (<em>Ulmus pumila</em>, <em>Salix ledebouriana</em>) and tall grasses &gt;1m in height in late summer/autumn (<em>Achnatherum splendens</em>).</td>
<td>%</td>
<td>Positive</td>
<td>Jackson et al. (2006), Murdoch et al. (2007), Murdoch et al. (2009).</td>
</tr>
<tr>
<td>Ruggedness</td>
<td>Index of topographic ruggedness based on slope, aspect, and elevation.</td>
<td>1-9 scale</td>
<td>Positive</td>
<td>Bragin et al. (2013), Murdoch et al. (2007), Murdoch et al. (2009).</td>
</tr>
</tbody>
</table>
Table 3.2. Model selection results for corsac fox (*Vulpes corsac*) presence-only data collected in Ikh Nart Nature Reserve, Mongolia. Each model in the set included different combinations of the following covariates: rocky outcrop (rock), shrubland (sh), open plains (op), tall vegetation (tv), distance from nearest ger camp and road, and ruggedness. The top ranking model included the additive combination of rocky outcrop, shrubland, open plains and tall vegetation.

<table>
<thead>
<tr>
<th>Model name</th>
<th>AIC</th>
<th>ΔAIC</th>
<th>No. of parameters</th>
<th>Weight</th>
<th>loglike</th>
<th>-2loglike</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ψ(rock+shrub+op+tv)</td>
<td>51570.1</td>
<td>0</td>
<td>5</td>
<td>1.00</td>
<td>-25719.5</td>
<td>51438.9</td>
</tr>
<tr>
<td>Ψ(shrub+op+tv)</td>
<td>51693.2</td>
<td>123.1</td>
<td>4</td>
<td>0.00</td>
<td>-25842.6</td>
<td>51685.1</td>
</tr>
<tr>
<td>Ψ (rock+shrub+tv)</td>
<td>51848.3</td>
<td>278.2</td>
<td>4</td>
<td>0.00</td>
<td>-25920.2</td>
<td>51840.3</td>
</tr>
<tr>
<td>Ψ (shrub+tv)</td>
<td>51886.5</td>
<td>316.4</td>
<td>3</td>
<td>0.00</td>
<td>-25940.3</td>
<td>51880.5</td>
</tr>
<tr>
<td>Ψ (shrub+op)</td>
<td>52323.6</td>
<td>753.5</td>
<td>3</td>
<td>0.00</td>
<td>-26158.8</td>
<td>52317.5</td>
</tr>
<tr>
<td>Ψ (rock+shrub+op)</td>
<td>52330.0</td>
<td>759.9</td>
<td>4</td>
<td>0.00</td>
<td>-26161.0</td>
<td>52321.9</td>
</tr>
<tr>
<td>Ψ (rock+shrub)</td>
<td>52415.2</td>
<td>845.1</td>
<td>3</td>
<td>0.00</td>
<td>-26204.6</td>
<td>52409.2</td>
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<tr>
<td>Ψ (shrub)</td>
<td>52554.4</td>
<td>984.3</td>
<td>2</td>
<td>0.00</td>
<td>-26275.2</td>
<td>52550.4</td>
</tr>
<tr>
<td>Ψ (op+tv)</td>
<td>52742.9</td>
<td>1172.8</td>
<td>3</td>
<td>0.00</td>
<td>-26368.4</td>
<td>52736.8</td>
</tr>
<tr>
<td>Ψ (rock+op+tv)</td>
<td>52771.2</td>
<td>1201.1</td>
<td>4</td>
<td>0.00</td>
<td>-26381.6</td>
<td>52763.2</td>
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<tr>
<td>Ψ (rock+tv)</td>
<td>52776.4</td>
<td>1206.3</td>
<td>3</td>
<td>0.00</td>
<td>-26385.2</td>
<td>52770.3</td>
</tr>
<tr>
<td>Ψ (tv)</td>
<td>52859.9</td>
<td>1289.8</td>
<td>2</td>
<td>0.00</td>
<td>-26427.9</td>
<td>52855.8</td>
</tr>
<tr>
<td>Ψ (ger+road)</td>
<td>53026.6</td>
<td>1456.5</td>
<td>3</td>
<td>0.00</td>
<td>-26510.3</td>
<td>53020.5</td>
</tr>
<tr>
<td>Ψ (rock+op)</td>
<td>53194.9</td>
<td>1624.8</td>
<td>3</td>
<td>0.00</td>
<td>-26594.4</td>
<td>53188.8</td>
</tr>
<tr>
<td>Ψ (rock)</td>
<td>53205.6</td>
<td>1635.5</td>
<td>2</td>
<td>0.00</td>
<td>-26600.8</td>
<td>53201.6</td>
</tr>
<tr>
<td>Ψ (road)</td>
<td>53275.4</td>
<td>1705.3</td>
<td>2</td>
<td>0.00</td>
<td>-26635.7</td>
<td>53271.3</td>
</tr>
<tr>
<td>Ψ (op)</td>
<td>53425.3</td>
<td>1855.3</td>
<td>2</td>
<td>0.00</td>
<td>-26710.7</td>
<td>53421.3</td>
</tr>
<tr>
<td>Ψ (ruggedness)</td>
<td>53469.7</td>
<td>1899.7</td>
<td>2</td>
<td>0.00</td>
<td>-26732.9</td>
<td>53465.7</td>
</tr>
<tr>
<td>Ψ (ger)</td>
<td>53492.0</td>
<td>1921.9</td>
<td>2</td>
<td>0.00</td>
<td>-26744.0</td>
<td>53488.0</td>
</tr>
</tbody>
</table>
**Table 3.3.** Parameter estimates of the top tanking model of corsac fox (*Vulpus corsac*) occupancy probability ($\Psi$). Estimates include standard error and 95% upper (UCI) and lower (LCI) confidence intervals.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$\beta$ estimate</th>
<th>SE</th>
<th>UCI</th>
<th>LCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model – $\Psi$(rock+shrub+tv+op)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>-5.54</td>
<td>0.191</td>
<td>-5.166</td>
<td>-5.914</td>
</tr>
<tr>
<td>Rocky outcrop</td>
<td>3.95</td>
<td>0.371</td>
<td>4.677</td>
<td>3.223</td>
</tr>
<tr>
<td>Shrubland</td>
<td>6.83</td>
<td>0.316</td>
<td>7.449</td>
<td>6.211</td>
</tr>
<tr>
<td>Open plain</td>
<td>3.49</td>
<td>0.600</td>
<td>4.666</td>
<td>2.314</td>
</tr>
<tr>
<td>Tall vegetation</td>
<td>8.10</td>
<td>0.224</td>
<td>8.539</td>
<td>7.661</td>
</tr>
</tbody>
</table>
3.10. Figures

Figure 3.1
Figure 3.2

The graph illustrates the probability of occupancy as a function of the proportion of habitat. The data are represented by different lines and markers for different categories: ro, sh, tv, and op. The probability of occupancy increases as the proportion of habitat increases.
Figure 3.3
Figure 3.4
Figure 3.5

(a) Proportion reduction of tall vegetation
(b) Proportion reduction of shrubland
(c) Proportion reduction of open plain
(d) Proportion reduction of shrubland and open plain
(e) Proportion reduction of shrubland and tall vegetation
(f) Proportion reduction of tall vegetation and open plain
(g) Proportion reduction of all habitats
CHAPTER 4: COMPREHENSIVE BIBLIOGRAPHY


Myagmarsuren, D. 2000. Special Protected Areas of Mongolia. Mongolian Environmental Protection Agency and GTZ (German Technical Advisory Agency), Ulaanbaatar, Mongolia.


Appendix I. Corsac fox (*Vulpes corsac*). Photo © Xavier Eichaker.
Appendix II. Steppe (top) and semi-desert (bottom) habitats in Ikh Nart Nature Reserve, Mongolia. Photos © James Murdoch.
Appendix III. Maps of the distribution of habitats (rocky outcrops, shrublands, open plains, tall vegetation), ruggedness, gers, and roads in Ikh Nart Nature Reserve, Mongolia (A – G). Habitat map values represent the proportion of habitat within a 250 m radius. Ruggedness values represent an index of ruggedness (1 = low, 9 = high) based on slope and elevation. Ger and road values represent the distance in meters to the nearest ger or road. Maps used as covariates in to develop an occupancy model for corsac fox (Vulpes corsac).
A - Rocky outcrops
B - Shrublands
C - Open plains
D – Tall vegetation
E – Ruggedness
F - Ger camps
G - Roads