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# Modeling Siberian ibex (*Capra sibirica*) occupancy in Ikh Nart Nature Reserve, Mongolia

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**Modeling Siberian ibex (*Capra sibirica*) occupancy in Ikh Nart**

**Nature Reserve, Mongolia**

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## ABSTRACT

As the world becomes increasingly populated, humans continue to modify habitats to suit their needs. Mongolia is one of many Asian countries currently undergoing human-induced landscape change, namely in the form of increased grazing pressure on the land by domesticated animals. There is uncertainty as to how wildlife will be impacted by this change. The Siberian ibex (*Capra sibirica*) is an ungulate classified as IUCN Near Threatened in Mongolia and an important species for tourism. I developed an occupancy model for the species based on radio-telemetry locations ( $n = 920$ ) collected in Ikh Nart Nature Reserve, then estimated the effect of habitat reductions as expected under increasing levels of grazing. I developed 13 candidate models that include combinations of habitat and human variables, and used model selection techniques to evaluate the best-supported model in the set. The model with the most support indicated that rocky outcrop, open plain, and their interaction best described ibex occupancy. Average occupancy was 5.7% across the northern Ikh Nart landscape, 7.4% within the borders of the reserve, and 17.4% within the reserve's core protected area. Simulations showed that in the absence of open plain habitat, average occupancy declined to 1.9%, 2.1%, and 5.0% respectively in these areas. The results provide a description of how landscape factors shape the distribution of the species. Because livestock grazing is concentrated in open plain habitats, these results may be used to inform decision-making about ibex conservation in the region.

**Keywords:** *Capra sibirica*, Gobi desert, landscape change, livestock, Mongolia, occupancy modeling, pastoralism, Siberian ibex, steppe

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## INTRODUCTION

As the world becomes increasingly populated, humans continue to modify habitats to suit their needs. Globally, 21.8% of land area has been converted to human use, but this figure does not include land uses that degrade habitat quality, such as livestock grazing (Hoekstra et al. 2005). With landscape change comes a risk of biodiversity loss, as the natural states of habitats are altered and connectivity between remaining areas of habitat are lost (Hoekstra et al. 2005). Habitat protection can slow these impacts, provided the areas protected support diverse and important ecosystems (Hoekstra et al. 2005).

Mongolia is one of many countries experiencing large-scale landscape change. Following the breakup of the Soviet Union in 1990, Mongolia experienced an economic crisis that led to accelerated exploitation of its natural resources (Clark et al. 2006; Mallon and Jiang 2009). This resource exploitation has included a dramatic increase in number of livestock on grazing steppe vegetation (e.g. 25.2 million head in 1993 to over 33.5 million head in 1999) (Reading et al. 2006; Mallon and Jiang 2009) and an increase in economic focus on mining and construction of roads and railways for transportation (Ito et al. 2013). While Mongolia has also increased its number of protected areas and many pastoralists realize that their grazing practices may impact sensitive native species, the country still experiences conflicts as pastoralism reduces the amount of steppe vegetation and increases the risk of desertification (Maroney 2005; Lin et al. 2010). About 90% of Mongolia's land area is at risk of desertification due to a variety of factors (Wit et al. 1997). Currently, 30% of the country is moderately affected by degradation, and most areas with a high percentage of pastureland have undergone moderate and high degradation (Wit et al. 1997)

An important question in systems undergoing landscape change is how wildlife species will respond. Occupancy modeling is one approach for estimating how landscape characteristics influence where a species occurs (MacKenzie et al. 2002). Occupancy models are built from detection/non-detection data obtained from surveys, and use maximum likelihood methods to estimate the impact of covariates such as habitats on species presence (MacKenzie et al. 2002; MacKenzie et al. 2006). Despite the feasibility of this approach for some species, it is often difficult to conduct extensive detection/non-detection surveys especially for species that occur at low densities, have low detection probabilities, or are rare (MacKenzie et al. 2006). In these cases, presence-only data, such as radio-telemetry locations or observations, are more practical to obtain. Commonly used presence-only methods of occupancy modeling include maximum entropy and maximum likelihood (Royle et al. 2012; Fitzpatrick et al. 2013). These methods assume that detection probability is constant (Royle et al. 2012).

Siberian ibex (*Capra sibirica*) is the largest member of the *Capra* genus, with adult males reaching 171 cm in length and 130 kg in weight (Fedosenko and Blank 2001). The species occurs throughout the mountainous regions of central and middle Asia, southern Siberia, and the northwest Himalayas (Fedosenko and Blank 2001). Although the Siberian ibex often lives alongside argali sheep (*Ovis ammon*), the ibex generally shows a stronger association with rugged terrain and cliff faces than argali (Dzieciolowski et al. 1980; Fedosenko and Blank 2001). Ibex are gregarious, occupying both single sex and mixed groups seasonally, with 80-96% of ibex in mixed sex herds during autumn for the rutting period (Fedosenko and Blank 2001). In Mongolia, the average herd size is 19.7 individuals for all-female groups, 6.5 individuals for male groups, and 60 individuals for mixed sex groups (Fedosenko and Blank 2001). Average 95% kernel home range size for individual ibex in Ikh Nart Nature Reserve, Mongolia is about



1500 ha, and individual home ranges tend to overlap more than 89% with other individuals of the same herd (Reading et al. 2007). Home range size has not been found to differ significantly between sexes and age cohorts (Reading et al. 2007).

Along with argali sheep and other wild ungulates, Siberian ibex maintain steppe vegetation, such as *Allium* spp. and other forbs and short grasses, through their grazing (Fedosenko and Blank 2001). They also serve as an important prey species for many large carnivores, including snow leopard (*Panthera uncia*) (Fedosenko and Blank 2001). Much like argali sheep, Siberian ibex are economically important as a draw for tourists due to their impressive and iconic stature (Clark et al. 2006). Ibex are considered a prized trophy animal among big game hunters and a limited number of hunting licenses are granted in Mongolia every year, which helps fund conservation efforts (Clark et al. 2006).

The Siberian ibex is listed as IUCN Least Concern globally, but IUCN Near Threatened in Mongolia (Clark et al. 2006). Although Siberian ibex has been studied in the Himalaya Mountains of India (Fox et al. 1992; Bhatnagar 1997; Bagchi et al. 2004) and the Tianshan Mountains of China and Kyrgyzstan (Fedosenko and Blank 1982; McCarthy et al. 2010; Li et al. 2015), few studies have been undertaken in Mongolia (Dzieciolowski et al. 1980; Reading et al. 2007; Singh et al. 2010; Ito et al. 2013) and large gaps in knowledge exist in the species' ecology (Mallon et al. 1997).

Preliminary research into Siberian ibex in Mongolia suggested that the species strongly associated with rocky, rugged terrain as in other parts of its range (Reading et al. 2007). Ibex also often live in close contact with grazing livestock in many parts of their range (Reading et al. 2006; Reading et al. 2007). The relationship between ibex and grazing livestock has been investigated elsewhere (Dzieciolowski et al. 1980; Bagchi et al. 2004). For example in India's

Pin Valley National Park, Siberian ibex experience resource limitation due to migratory grazing of domestic goats and sheep, which presumably reduces population size (Bagchi et al. 2004). One of the current management needs for Siberian ibex is to examine the effects of livestock grazing on the species (Mallon et al. 1997; Clark et al. 2006). This is especially important since many protected areas in Mongolia allow a variety of consumptive uses, including livestock grazing (Reading et al. 2006).

As changes in landscape use occur in Mongolia, it is important to determine how these changes affect habitat-sensitive species such as Siberian ibex in order to develop effective management practices that balance the needs of wildlife and people. I modeled how landscape characteristics including habitat distributions and human variables affect Siberian ibex occupancy. I then examined how the loss of key habitat types affected the occupancy probability for the species at various spatial scales.

## METHODS

*Study area.*—The study was conducted in and around Ikh Nart Nature Reserve, Dornogobi Aimag (province), Mongolia (Fig. 1). The reserve was established in 1996 to protect one of the largest populations of argali sheep in Mongolia and encompasses approximately 666 km<sup>2</sup> (Myagmarsuren 2000; Reading et al. 2005). Ikh Nart covers two soums (counties), Dalanjargal and Airag, which jointly manage the reserve with some oversight from the national government (Jackson et al. 2006). The 71 km<sup>2</sup> core protected area within the reserve, which serves as a center for biodiversity, receives a higher level of protection than other parts of the reserve (Murdoch et al. 2014). The reserve is generally considered part of the ‘Gobi-steppe ecosystem’, as it lies at the border of steppe and semi-desert zones along the northeastern side of

the Gobi Desert (Reading et al. 2006; Reading et al. 2011). Steppe habitats within the reserve include shrublands, open plains, and tall grasslands (Fig. 1). Semi-desert habitats include rocky, rugged outcrops that are sparsely vegetated (Fig. 1). Average elevation in the reserve is ~1,200 m. Temperatures range from -40°C to +40°C throughout the year, and the region is arid with average annual precipitation of < 200 mm (Murdoch et al. 2006). Approximately 110 families live in ger/yurt camps in and around Ikh Nart and raise livestock for subsistence (Davie et al. 2014b). All herding families in Ikh Nart raise sheep and goats, with two thirds managing herds larger than 350 animals (Davie et al. 2014b). A system of dirt roads connects herder camps with soum centers (Davie et al. 2014b). Ikh Nart supports a diverse fauna and flora, including at least 33 species of mammals, 125 species of birds, 6 species of reptiles, and more than 220 species of plants (Murdoch et al. 2006).

*Data collection.*—I used Siberian ibex locations from radio-telemetry locations ( $n = 920$ ) collected from 42 radio-collared adult (> 1 year old) ibex (22 females, 20 males) to build the model (Fig. 1). Ibex were collared as part of a long-term research project conducted by the Denver Zoological Foundation and Mongolian Academy of Sciences (Reading et al. 2011). Procedures for capturing and collaring ibex followed those developed for argali sheep (Kenny et al. 2008). Ibex were driven into nets and hooded, then morphometric measurements were taken and the animals were collared (Kenny et al. 2008). Capture, handling, and radio-collaring followed the guidelines of the American Society of Mammalogists (Sikes and Gannon 2011). Capturing aimed to minimize collaring from the same social groups, however this was not always possible. The goal was to obtain at least one telemetry location per individual per week. Mean number of telemetry locations taken for each individual in the study was 42.11 (SE =

8.47). Repeat locations were removed for model building. All location data were collected from January 2009 to December 2011.

*Modeling approach.*—I developed an *a priori* set of models to explain patterns of Siberian ibex occupancy based on three habitats and two anthropogenic factors. Habitats included rocky outcrop, shrubland, and open plain. I used habitat raster maps ( $30 \times 30$  m pixels) developed by Lkhagvasuren et al. (2016) based on a superficial classification of a Landsat 7ETM+ satellite imagery (Jackson et al. 2006). Each pixel in a given raster was given an attribute that included the proportion of that habitat within a 250 m radius. The two anthropogenic factors included the distance to nearest ger camp and road (Davie et al. 2014a).

The model set included 13 models that predicted occupancy probability ( $\psi$ ) as a function of different additive combinations of covariates and interactions between the covariates (Table 2). Previous research indicated that Siberian ibex in other regions were influenced by all three of the habitat covariates, so I included all subsets of these covariates as well as interactions between them (Fedosenko and Blank 2001). I hypothesized that rocky outcrops would positively influence ibex occupancy based on known habitat preferences (Fox et al. 1992; Fedosenko and Blank 2001; Reading et al. 2007; McCarthy et al. 2010). Likewise, I predicted a positive influence of open plain habitat due to possible forage in these areas (Fedosenko and Blank 2001). Based on the literature, I predicted that shrubland habitat would negatively influence occupancy (Fedosenko and Blank 2001). I also included single and additive models of distance to ger camps and roads. Gers represent areas of concentrated human activity and livestock use, so I predicted that these would negatively influence ibex occupancy as the species probably avoids humans because they are occasionally poached (Dzieciolowski et al. 1980; Mallon et al. 1997;

Bagchi et al. 2004; Davie et al. 2014b). I also predicted that ibex would avoid dirt roads to avoid encountering humans.

I used the MaxLike package for R to build and compare occupancy models (Royle et al. 2012; R Core Team 2015). MaxLike uses maximum likelihood methods to estimate parameter values (i.e., betas) for an occupancy model given a set of presence-only locations (Royle et al. 2012). Before running the models, I randomly selected 30% of the ibex locations ( $n = 276$ ) from the data set and reserved them for use in evaluating model performance. I used the remaining 644 ibex locations to develop the models. Each model included a beta for the intercept and one for each covariate. I used Akaike's Information Criterion (AIC) to rank the relative support for each model and considered models with a  $\Delta\text{AIC} < 2$  to have strong empirical support (Burnham and Anderson 2002).

I evaluated model performance for the top-ranking model using a Receiver-Operating-Characteristic (ROC) curve (Fielding and Bell 1997; Pearce and Ferrier 2000). The curve is a plot of the rate of true positive predictions versus the rate of false positive predictions of a model over a range of threshold values (Fielding and Bell 1997). I calculated rates of true positive and false positive predictions by applying the model to the reserved ibex locations and an equal number of random locations from the Ikh Nart landscape, which were assumed to represent absences. Four outcomes were possible when the model was applied to a location: true positive, true negative, false positive, and false negative. The outcome was dependent on a threshold value. For example at a threshold value of 0.50, if the model predicted a known ibex location had an occupancy probability of 0.75, this was counted as a true positive, because  $0.75 > 0.50$ . In this case, the model would have correctly predicted the occupancy probability of an ibex in that location (i.e., a true positive). The fraction of all sites that were true positive and false

positive for a range of thresholds from 0 to 1.0 were calculated and plotted to represent the ROC curve (Eng 2014). The Area Under the Curve (AUC) was estimated for the curve; an AUC value of 0.50 indicated that the model did not predict occupancy any better than random. I considered an AUC > 0.80 to indicate that the model adequately described occupancy and had good predictive ability.

*Mapping.*—I used the top-ranking model to build an occupancy map of Siberian ibex in the northern Ikh Nart region by applying the model to each 30 × 30 m pixel in the map of the region using ArcGIS (area enclosed by N45.838043° to N45.5245°; E108.489732° to E108.731806° [729.37 km<sup>2</sup>]). This entailed 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 show areas of high and low occupancy probability.

*Simulating habitat loss.*—Livestock grazing affects the amount of vegetation in the landscape. I simulated the reduction and eventual loss of habitats that influence ibex occupancy (i.e., habitat covariates in the top-ranking model, excluding rocky habitat which would not change). I reduced the proportion of habitat in each pixel in 10% increments, until no habitat remained. This resulted in 10 new raster maps, each representing progressive 10% losses in habitat amount. I then estimated average occupancy across the landscape for each map and made comparisons to the current conditions.

## RESULTS

Mean proportion of rock within 250 m across the landscape was 0.093, mean proportion of shrubland was 0.220, and mean proportion of open plain was 0.348. Average distance to ger

camps was 1611.8 m and average distance to roads was 667.8 m. The top-ranking model in the set was the interaction between rocky outcrops and open plain within 250 m of a given site (Table 2). No other model, including those with single covariates, additive combinations of covariates, or other interactions had strong empirical support. Parameter estimates for the top model indicated that the interaction of both covariates positively influenced occupancy probability in the landscape (Table 3, Fig. 2). Therefore, areas with high proportions of both rocky outcrops and open plains would have greater occupancy probability than areas with only one of these habitat types. Confidence intervals (95%) for all parameters did not include zero, indicating that the effects for the three covariates were meaningful (Table 2). The Receiver-Operating-Characteristic (ROC) curve for the top model indicated that the model predicted occupancy much better than random (Fig. 3). Area Under the Curve (AUC) for the model was 0.89 or 89% (Fig. 3).

The occupancy map had an average occupancy probability of 5.7% across all pixels (Fig. 4). Within the borders of Ikh Nart Nature Reserve, average occupancy probability was a slightly greater 7.4% (Fig. 4). The Ikh Nart core area had the greatest average occupancy probability, 17.4% (Fig. 4). Occupancy probability was greatest in areas with concentrated rocky outcrops and lowest in areas that consisted mainly of shrubland habitat (Figs. 1, 4). Simulations of open plain habitat reductions indicated decreasing occupancy probability in all three areas (Fig. 5). The most dramatic decrease in average occupancy probability occurred in the core area, which consists largely of open plain and rocky outcrop habitat (Fig. 5).

## DISCUSSION

Landscape change is occurring at a rapid rate throughout much of northern and central Asia, which presents a conservation concern for wildlife. As habitats change or are lost, management will become increasingly important, especially for species that are rare, occur in low density, have low fecundity, and have large spatial requirements (Hoekstra et al. 2005). I examined how factors in the arid landscapes of Mongolia shape the distribution of one such species, the Siberian ibex, then simulated how the loss of important habitat for the species affects landscape quality. Ibex occupancy was a function of the rocky outcrops, open plains, and their interaction, all of which exerted positive effects. Reductions in the amount of open plain habitat, which may result from increased livestock grazing caused occupancy to decline over 3.8% across the landscape and 12.4% within the core protected area.

The influence of rugged, rocky terrain on ibex is consistent with findings of studies conducted elsewhere in Asia (Fox et al. 1992; Fedosenko and Blank 2001; McCarthy et al. 2010). Rocky outcrops may provide ibex with greater opportunity for vigilance to detect possible predators, serve as a refuge from predators, or represent areas with lower competition from other sympatric ungulates such as argali sheep (Dzieciolowski et al. 1980; McCarthy et al. 2010). The influence of open plain habitat is also supported by the literature, which suggests these plains are important foraging habitats (Fedosenko and Blank 2001; Bagchi et al. 2004; Mallon et al. 1997). Previous research into Siberian ibex movement in the Himalaya Mountains of India found that ibex were rarely found more than 350 m from “escape terrain” (rugged, rocky terrain), which provides some support for the interaction term in the model (Fox et al. 1992). As Siberian ibex in Ikh Nart require foraging habitat in the form of open plains, they also require escape habitat to retreat from predators and other disturbances. Therefore the amount of both



open plain and rocky outcrops in a given area would influence occupancy probability. Although previous studies have looked at the influence of individual habitat covariates and additive combinations on ibex, interactions between habitats have not yet been examined in the literature.

Anthropogenic factors, such as roads and ger camps, were expected to have a negative effect on ibex occupancy; however models that included these variables had little empirical support. This is surprising since previous research suggested that ibex tend to avoid human activity to reduce competition with livestock and avoid poaching (Dzieciolowski et al. 1980; Fox et al. 1992). The lack of support for avoidance behavior of ibex in Ikh Nart could be due to acclimatization to the longtime practice of pastoralism in the area or the low risk of poaching (Clark et al. 2006). Additionally, vehicle traffic along Ikh Nart's dirt roads is fairly low, which could explain why roads had little influence on occupancy.

The model performed better than expected by chance based on the Receiver-Operating-Characteristic curve and demonstrated strong predictive ability. For this assessment I utilized a subset of the original radio-telemetry data as presence locations and randomly selected locations as absences. The absence locations used in this assessment may not actually represent true absences, which introduces some bias. If a location randomly chosen as an absence was actually a presence location, the model would have a higher rate of true positives, which would mean a greater AUC. This suggests that the model may have had a stronger predictive power than was indicated by the analysis.

In recent years, the number of livestock in Mongolia has increased, prompting the need for management to effectively protect and conserve wildlife species (Clark et al. 2006). As number of livestock—and therefore grazing pressure on the land—increases, rangeland habitat could be increasingly prone to desertification (Reading et al. 2006; Lin et al. 2010). Siberian

ibex and other rare wild ungulates may experience degradation and loss of suitable habitat. In Ikh Nart, grazing occurs mostly in open plain habitat and Reading et al. (2006) even witnessed starvation of Siberian ibex and argali sheep following overgrazing of these areas by livestock. Habitat simulations performed in this study demonstrate how ibex occupancy is expected to change as open plain habitat decreases. These simulations provide a guide that can be used to improve management of ibex and livestock grazing in the region.

Siberian ibex occupancy of Ikh Nart Nature Reserve is largely concentrated around areas with both rocky outcrops and open plain habitat (Figs. 1, 4). Therefore it may be wise to place some restrictions upon livestock grazing within reserve areas that support both of these habitat types. The core protected area of Ikh Nart was created to help conserve the argali sheep population. This 71 km<sup>2</sup> area receives a higher level of protection compared to other parts of the reserve (Murdoch et al. 2014). Additionally, the core area represents the landscape scale that yielded both the greatest average occupancy probability for ibex and the most drastic decreases in occupancy probability with decreasing open plain habitat (Fig. 5). Although I did not include level of protection as a covariate in my model set, the high average occupancy probability within the core area indicates that there may be some management activities in the area that support differences in occupancy between the core area, reserve, and Ikh Nart landscape. Therefore focusing restriction of livestock grazing in the core area of Ikh Nart is warranted.

An adaptive process for managing livestock grazing within Ikh Nart could also be applied. In years with high rainfall, more grazing could be allowed since there would be more available forage and a lower risk of desertification. Likewise in drier years, grazing could be restricted or excluded altogether. This method would require monitoring open plain vegetation to determine how it is affected by different grazing regimes over time.

The variables examined in this study may not represent all possible variables that influence ibex occupancy. For example, several studies noted the importance of snow depth in determining areas utilized by ibex (Fox et al. 1992; Bhatnagar 1997; Fedosenko and Blank 2001). Since snowfall data for Ikh Nart were not available, I was unable to include this variable in my analysis. Presence of argali sheep could also influence ibex occupancy. Argali are often sympatric with ibex through much of their range, and competition with argali for food could negatively impact ibex (Dzieciolowski et al. 1980; McCarthy et al. 2010). Although data exist for argali sheep locations in Ikh Nart, modeling ibex and argali as a multi-species occupancy model would require large amounts of detection/non-detection data that were not available.

Occupancy probability may differ between sexes, among age cohorts, or in various seasons, due to a variety of factors. However, my intention was to obtain an aggregate model of ibex occupancy that produced a more generalized measure of how habitats and humans influence the species. Future studies could look more specifically at how these demographic and seasonal differences may impact ibex occupancy at a variety of spatial scales.

Several factors should be taken into account when determining best management practices for Siberian ibex in Ikh Nart. In addition to considering the ability of an area to support ibex based on its available habitat types, it is important to consider the implications of management plans in different regions. For example, an area where human use is already dense may not be an ideal location for grazing restrictions, since it would likely cause more conflicts with pastoralists than an area that is not presently considered important grazing land by herders. Restricting grazing for the benefit of a wild ungulate may breed negative feelings toward ibex among the people who depend upon the pastoral lifestyle, and ultimately result in increased persecution of ibex. The reserve's core area currently supports several ger camps, so it may be

easier to enact a management plan in an area that does not already experience concentrated human use in order to reduce conflicts with pastoralists while still supporting ibex occupancy in Ikh Nart.

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## LITERATURE CITED

- Bagchi, S., C. Mishra, and Y. Bhatnagar. 2004. Conflicts between traditional pastoralism and conservation of Himalayan ibex (*Capra sibirica*) in the Trans-Himalayan Mountains. *Animal Conservation* 7:121-128.
- Bhatnagar, Y. V. 1997. Ranging and habitat utilization by the Himalayan ibex (*Capra ibex sibirica*) in Pin Valley National Park. Ph.D. dissertation, Saurashtra University, Rajkot, India.
- Burnham, K., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. 2nd edition. Springer, New York, USA.
- Clark, E. L., T. Munkhbat, S. Dulamtseren, J. E. M. Baillie, N. Batsaikhan, R. Samiya, and M. Stubbe. 2006. Mongolian red list of mammals. Regional Red List Series, Zoological Society of London, London, UK.
- Davie, H., J. D. Murdoch, L. Ankhbayar, and R. P. Reading. 2014a. Measuring and mapping the influence of landscape factors on livestock predation by wolves in Mongolia. *Journal of Arid Environments* 103:85-91.
- Davie, H., P. A. Stokowski, L. Ankhbayar, and J. D. Murdoch. 2014b. Herders and wolves in post-Soviet society: an ethnographic study in Mongolia's Ikh Nart Nature Reserve. *Human Dimensions of Wildlife* 19:319-333.
- Dzieciolowski, R., J. Krupka, Bajandelger, and R. Dziedzic. 1980. Argali and Siberian ibex populations in the Khuhsyrh Reserve in Mongolian Alta. *Acta Theriologica* 25:213-219.
- Eng, J. 2014. ROC analysis: web-based calculator for ROC curves. Johns Hopkins University, Baltimore, Maryland, USA. [www.jrocfits.org](http://www.jrocfits.org). Accessed 30 March 2016.
- Fedosenko, A. K., and D. A. Blank. 1982. Behavior of the Siberian ibex (*Capra sibirica*) during

- the period of reproduction in North Tian-Shan. *Zoologicheskyy Zhurnal* 61:428-435.
- Fedosenko, A. K., and D. A. Blank. 2001. *Capra sibirica*. *Mammalian Species* 675:1-13.
- Fielding, A. H., and J. F. Bell. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environmental Conservation* 24:38-49.
- Fitzpatrick, M. C., N. J. Gotelli, and A. M. Ellison. 2013. MaxEnt versus MaxLike: empirical comparisons with ant species distributions. *Ecosphere* 4:1-15.
- Fox, J. L., S. P. Sinha, and R. S. Chundawat. 1992. Activity patterns and habitat use of ibex in the Himalaya Mountains of India. *Journal of Mammalogy* 73:527-534.
- Hoekstra, J. M., T. M. Boucher, T. H. Ricketts, and C. Roberts. 2005. Confronting a biome crisis: global disparities of habitat loss and protection. *Ecology Letters* 8:23-29.
- Ito, T. Y., B. Lhagvasuren, A. Tsunekawa, M. Shinoda, S. Takatsuki, B. Buuveibaatar, and B. Chimeddorj. 2013. Fragmentation of the habitat of wild ungulates by anthropogenic barriers in Mongolia. *PloS one* 8:e56995.
- 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 Dornogobi and Dundgobi Aimags, Mongolia. *Mongolian Journal of Biological Sciences* 4:33-40.
- Kenny, D., A. DeNicola, S. Amgalanbaatar, Z. Namshir, G. Wingard, and R. P. Reading. 2008. Successful field capture techniques for free-ranging argali sheep (*Ovis ammon*) in Mongolia. *Zoo Biology* 27:137-144.
- Li, Y., Y.-Q. Yu, and L. Shi. 2015. Foraging and bedding site selection by Asiatic ibex (*Capra sibirica*) during summer in Central Tianshan Mountains. *Pakistan Journal of Zoology* 47:1-6.
- Lin, Y., G. Han, M. Zhao, and S. X. Chang. 2010. Spatial vegetation patterns as early signs of

- desertification: a case study of a desert steppe in Inner Mongolia, China. *Landscape Ecology* 25:1519-1527.
- 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* doi:10.1093/jmammal/gyw067.
- MacKenzie, D. I., J. D. Nichols, G. B. Lachman, S. Droege, J. A. Royle, and C. A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. *Ecology* 82:2248-2255.
- MacKenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollock, L. L. Bailey, and J. E. Hines. 2006. Occupancy estimation and modeling inferring patterns and dynamics of species occurrence. Academic Press, Burlington, Massachusetts, USA.
- Mallon, D. P., S. Dulamtseren, A. Bold, R. P. Reading, and S. Amgalanbaatar. 1997. Mongolia. Pages 193-201 in D. M. Shackleton, and the IUCN/SSC Caprinae Specialist Group, Eds. Wild sheep and goats and their relatives: status survey and conservation action plan for Caprinae. IUCN/SSC Caprinae Specialist Group, Gland, Switzerland.
- Mallon, D. P., and Z.-G. Jiang. 2009. Grazers on the plains: challenges and prospects for large herbivores in Central Asia. *Journal of Applied Ecology* 46:516-519.
- Maroney, R. L. 2005. Conservation of argali *Ovis ammon* in western Mongolia and the Altai-Sayan. *Biological Conservation* 121:231-241.
- McCarthy, J. L., K. P. McCarthy, T. K. Fuller, and T. M. McCarthy. 2010. Assessing variation in wildlife biodiversity in the Tien Shan Mountains of Kyrgyzstan using ancillary camera-trap photos. *Mountain Research and Development* 30:295-301.
- Murdoch, J. D., H. Davie, M. Lkhagvasuren, and T. Munkhzul. 2014. Evaluating the quality of

- protected areas for species: a case study in Ikh Nart Nature Reserve, Mongolia. Mongolian Journal of Biological Sciences 12:45-51.
- 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 5:7-12.
- Myagmarsuren, D. 2000. Special protected areas of Mongolia. Mongolian Environmental Protection Agency and GTZ (German Technical Advisory Agency), Ulaanbaatar, Mongolia.
- Pearce, J., and S. Ferrier. 2000. Evaluating the predictive performance of habitat models developed using logistic regression. Ecological Modelling 133:225-245.
- R Core Team. 2015. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. [www.R-project.org](http://www.R-project.org). Accessed 15 March 2016.
- Reading, R. P., S. Amgalanbaatar, D. Kenny, A. DeNicola, and E. Tuguldur. 2007. Siberian ibex (*Capra sibirica*) home ranges in Ikh Nart Nature Reserve, Mongolia: preliminary findings. Mongolian Journal of Biological Sciences 5:29-37.
- Reading, R. P., S. Amgalanbaatar, G. Wingard, D. Kenny, and A. DeNicola. 2005. Ecology of argali in Ikh Nartiin Chuluu, Dornogobi Aimag. Erforschung Biologischer Ressourcen der Mongolei (Halle/Saale) 9:77-89.
- Reading, R. P., D. J. Bedunah, and S. Amgalanbaatar. 2006. Conserving biodiversity on Mongolian rangelands: implications for protected area development and pastoral uses. USDA Forest Service Proceedings RMRS-P-39.
- Reading, R. P., D. Kenny, and B. Steinhauer-Burkart. 2011. Ikh Nart Nature Reserve. 2nd edition. ECO Nature Edition Steinhauer-Burkart OHG, Oberaula, Germany.
- Royle, J. A., R. B. Chandler, C. Yackulic, and J. D. Nichols. 2012. Likelihood analysis of



species occurrence probability from presence-only data for modelling species distributions. *Methods in Ecology and Evolution* 3:545-554.

Sikes, R. S., and W. L. Gannon. 2011. Guidelines of the American Society of Mammalogists for the use of wild mammals in research. *Journal of Mammalogy* 92:235-253.

Singh, N. J., S. Amgalanbaatar, and R. P. Reading. 2010. Temporal dynamics of group size and sexual segregation in ibex. *Erforschung Biologischer Ressourcen der Mongolei* 11:315-322.

Wit, P., T. Adyasuren, N. Sarantuya, D. Namkhai, D. Purevtseren, D. Dash, and K. Jalbaa. 1997. National plan of action to combat desertification in Mongolia. United Nations Convention to Combat Desertification, Ulaanbaatar, Mongolia.

**Table 1.** Descriptions of covariates used in models to describe Siberian ibex (*Capra sibirica*) occupancy in Ikh Nart Nature Reserve, Mongolia.

Variable	Description	Measure	Predicted effect on $\psi$	Source
Rocky outcrop	Sparsely vegetated exposed rock habitat within 250 meters of site.	Proportion	Positive	Jackson et al. 2006
Open plain	Areas of low ground cover including semi-shrubs (e.g. <i>Reaumuria soongorica</i> and <i>Salsola passerina</i> ), forbs (e.g. <i>Allium polyrrhizum</i> ), and short grasses (e.g. <i>Stipa gobica</i> ) within 250 meters of site.	Proportion	Positive	Jackson et al. 2006
Shrub	Areas of dense shrubs (e.g. <i>Caragana pygmaea</i> and <i>Amygdalus pedunculata</i> ) within 250 meters of site.	Proportion	Negative	Jackson et al. 2006
Road	Distance to nearest road.	Meters	Negative	Davie et al. 2014a
Ger	Distance to nearest ger/yurt herder camp.	Meters	Negative	Davie et al. 2014a

**Table 2.** Model selection results of Siberian ibex (*Capra sibirica*) probability of occupancy ( $\psi$ ) indicating the fit of 13 models to the observed data collected in Ikh Nart Nature Reserve, Mongolia from January 2009 to December 2011. Occupancy covariates included distance to nearest road (*road*) and distance to nearest herder ger camp (*ger*), and proportion of rocky outcrop (*ro*), open plain (*op*), and shrubland habitat (*sh*) within 250 meters of a given site.

Model	AIC	$\Delta$ AIC	No. of parameters	-2LogLike
$\psi(ro+op+ro*op)$	15864.26	0	4	16824.17
$\psi(ro+sh+op)$	15901.64	37.38	4	15893.64
$\psi(ro+op)$	15906.47	42.21	3	15900.47
$\psi(ro+sh+ro*sh)^*$	15949.02	84.76	4	15941.02
$\psi(ro+sh)$	15962.79	98.53	3	15956.79
$\psi(ro)$	15998.06	133.80	2	15994.06
$\psi(sh+op+sh*op)$	16832.17	967.91	4	16824.17
$\psi(sh+op)$	16832.44	968.18	3	16826.44
$\psi(sh)$	16839.39	975.13	2	16835.39
$\psi(op)$	17354.54	1490.28	2	17350.54
$\psi(ger+road)^*$	17355.90	1491.64	3	17349.90
$\psi(ger)$	17477.53	1613.27	2	17473.53
$\psi(road)$	17495.05	1630.79	2	17491.05

\*model did not converge

**Table 3.** Parameter estimates with standard errors (SE) and upper (UCI) and lower (LCI) 95% confidence intervals for the top-ranking model,  $\psi(ro+op+ro*op)$ , of Siberian ibex (*Capra sibirica*) occupancy data collected in Ikh Nart Nature Reserve, Mongolia from January 2009 to December 2011.

Parameter	$\beta$ estimate	SE	UCI	LCI
$\psi$ intercept	-5.32	0.226	-4.877	-5.763
Rocky outcrop	6.27	0.523	7.295	5.245
Open plain	1.11	0.356	1.808	0.412
Rocky outcrop * open plain	9.85	1.421	12.635	7.065

## FIGURE LEGENDS

**Figure 1.** Map showing the distribution of rocky outcrops, shrubland, open plains, ger camps, roads, and ibex telemetry locations in northern Ikh Nart Nature Reserve (INNR). Inset shows the location of INNR in Mongolia.

**Figure 2.** Siberian ibex (*Capra sibirica*) occupancy probability as a function of the interaction between proportion of open plain and proportion of rocky outcrop within 250 m of a given site. Occupancy probability estimated from a top-ranking model of ibex locations collected in Ikh Nart Nature Reserve, Mongolia.

**Figure 3.** Receiver-Operating-Characteristic (ROC) curve showing the performance of a top-ranking model predicting occupancy probability of Siberian ibex (*Capra sibirica*) in Ikh Nart Nature Reserve, Mongolia. Area Under the Curve (AUC) is 0.89 (or 89%).

**Figure 4.** Map showing occupancy probability of Siberian ibex (*Capra sibirica*) across the northern Ikh Nart Nature Reserve region, Mongolia. Occupancy probability estimated from a top-ranking model of ibex locations collected from January 2009 to December 2011.

**Figure 5.** Effect of a reduction in proportion of open plain habitat on average occupancy probability for Siberian ibex (*Capra sibirica*) across the northern Ikh Nart Nature Reserve region (Landscape), within Ikh Nart Nature Reserve (INNR), and within the reserve's core area.

Figure 1.

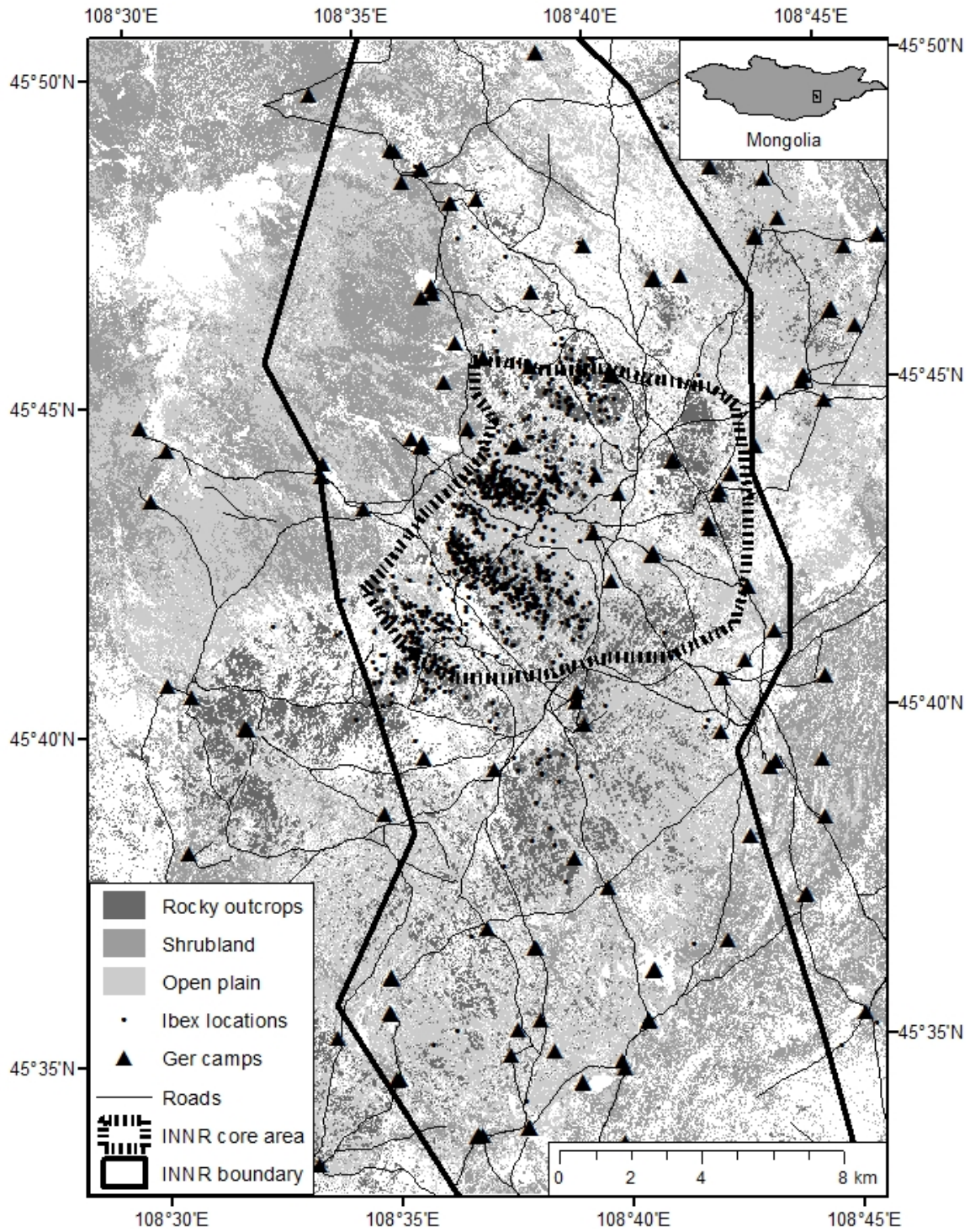


Figure 2.

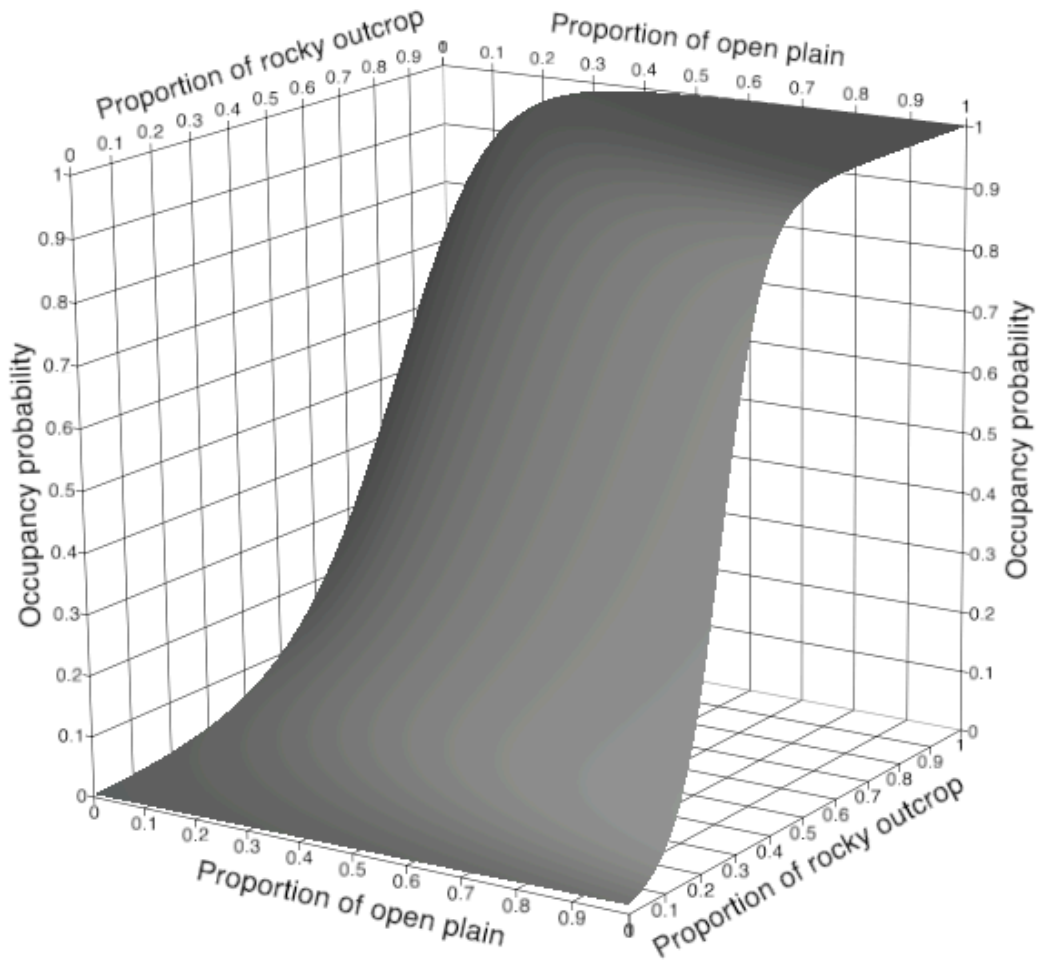


Figure 3.

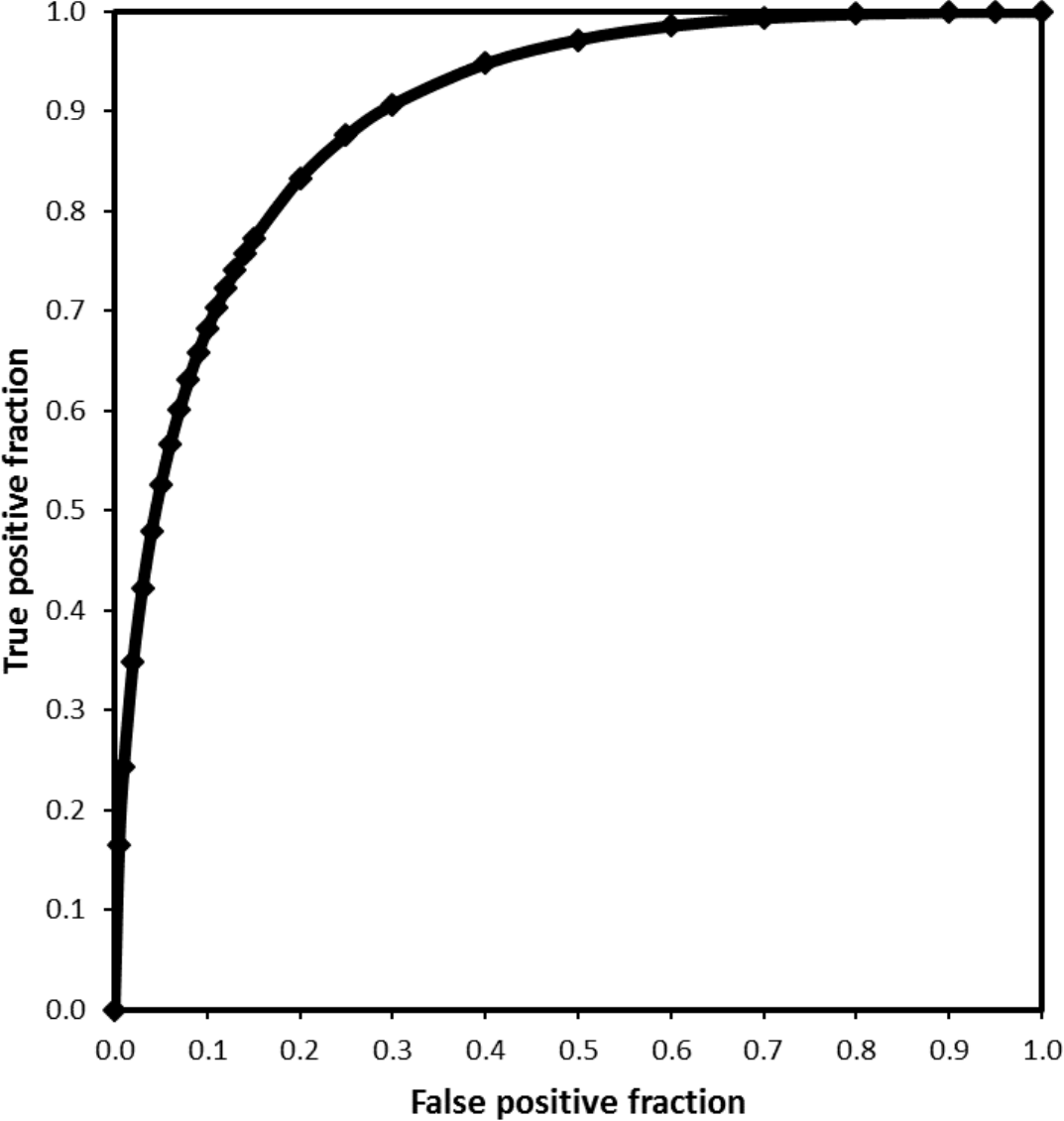




Figure 4.

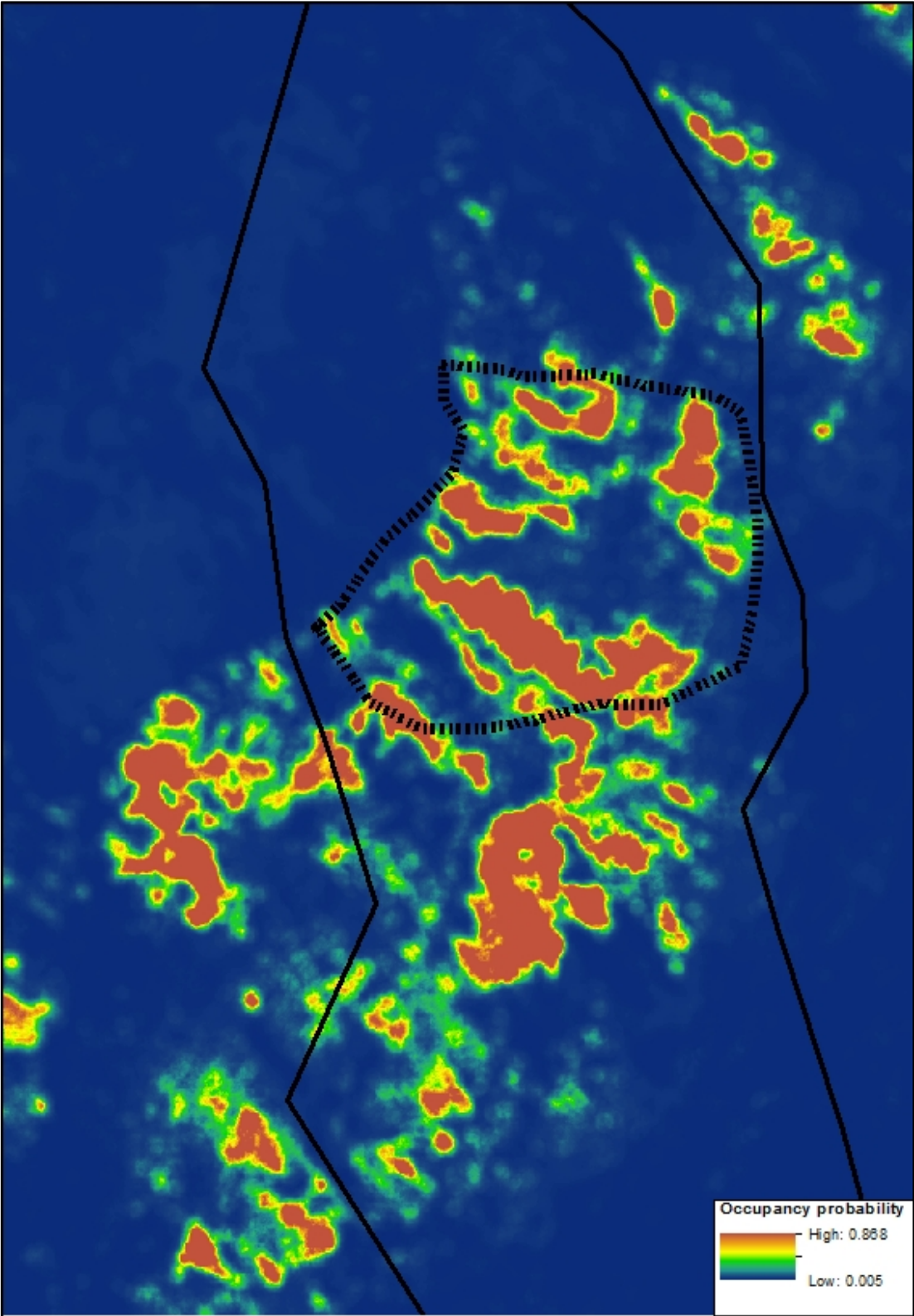


Figure 5.

