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Original Article

Evaluating the Quality of Protected Areas for Species: A Case Study in Ikh Nart Nature Reserve, Mongolia

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Abstract

Key words: agama, distribution, habitat quality, Ikh Nart Nature Reserve, occupancy modeling, protected area, red fox

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Species' distributions reflect the quality of landscape conditions, and represent an important component of protected area management. However, distributions are difficult to estimate, and consequently, often determined through a combination of limited field data and expert opinion, which may lead to biases. We demonstrate the use of occupancy models to map distributions and estimate landscape quality. We used occupancy models for two species, the red fox and toad-headed agama, to map their distributions in Ikh Nart Nature Reserve located in southeastern Mongolia. We then used occupancy probability as a measure of quality and tested whether differences existed in quality between three areas: 1) inside the reserve, 2) inside the reserve's core protected area, and 3) outside the reserve, using 30 sample sites in each. Occupancy probability varied from 0.084 to 0.997 for red foxes and 0.022 to 0.949 for agamas in maps. Landscape quality was highest in the core area and lowest outside the reserve for red foxes, and highest outside the reserve and lowest in the core area for agamas. Our results provide visual depictions of distributions across the Ikh Nart landscape and a means of assessing the quality of the Ikh Nart protected area that may inform management activities.

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Introduction

Mongolia has an extensive protected area system that includes nearly 100 areas covering approximately 27 million hectares or 17% of the country, which reflects a national commitment to conservation. Protected areas in Mongolia have several goals, one of which is to protect individual species. Some protected areas have even been created primarily for this purpose. For example, the Ikh Nart Nature Reserve in Dornogobi *aimag* (province) was established in part to protect one of the largest remaining argali sheep (*Ovis ammon*) populations in the country (Myagmarsuren, 2000). Argali have been promoted as a flagship species for generating public support for the region and umbrella species for broader biodiversity conservation (Reading *et al.*, 2011). Other protected areas have used a similar approach (e.g. Hustai National Park and

Przewalski's horse, *Equus ferus przewalskii*, and Tost Mountains Local Protected Area and snow leopard, *Panthera uncia*).

One of the greatest challenges to managing these species and others is the lack of scientific information on their distributions in protected areas and across the broader landscape (Clark *et al.*, 2006). Most estimates of distribution have been based on a combination of some field observation data (if available) and expert opinion (Clark *et al.*, 2006). However, science-based representations of species distributions are few, which hinder the ability of managers to precisely depict distributions within protected areas and assess the relative quality of different parts of the landscape.

Several approaches exist to model species-habitat relationships, which can be used to estimate distributions across broad areas (Boyce & McDonald, 1999; Franklin, 2009). One approach is occupancy modeling (MacKenzie *et al.*, 2002). This approach involves using detection/non-detection data from surveys, such as point counts for birds or camera traps for carnivores, to develop a model that describes occupancy probability at any given site in a landscape. The approach estimates occupancy probability using the multinomial maximum likelihood function and offers several useful advantages to wildlife managers. First, it relies on survey data that generally requires little advanced training to collect. Second, it accounts for detection probability when estimating occupancy probability, which is especially important given that non-detected species may actually be present at a site. Lastly, it allows for managers to build and compare models (using model selection techniques) that include the effects of covariates on occupancy such as habitat types or other landscape characteristics.

Occupancy models can be applied at a landscape scale to map distribution, which provide visual tools that can aid in decision-making about species. However, occupancy models have been relatively underused in mapping distributions and evaluating species in Mongolia despite their advantages.

In this paper, we demonstrate the utility of occupancy models by using them to map distribution. We then propose an approach for assessing the quality of protected areas for particular species using an occupancy map. The approach involves sampling occupancy as a measure of quality inside and outside of protected areas. We present a case study that focuses on the red fox (*Vulpes vulpes*) and toad-headed agama (*Phrynocephalus versicolor*) – two species for which occupancy models exist, in Ikh Nart Nature Reserve. Our objectives were to map the distributions of these two species and test for differences in quality between three areas: 1) inside the reserve, 2) inside the reserve's core protected area, and 3) outside the reserve in the surrounding landscape.

Materials and Methods

Study area

Ikh Nart Nature Reserve occurs in Dornogobi *aimag* and overlaps parts of two *soums* (districts), Dalanjargalan and Airag (Fig. 1; 45^{0}43´N–108^{0}39´E) (Reading *et al.*, 2011). The reserve covers 666 km^2 and was established in 1996 to protect a population of argali sheep and the unique landscape of the region. The reserve

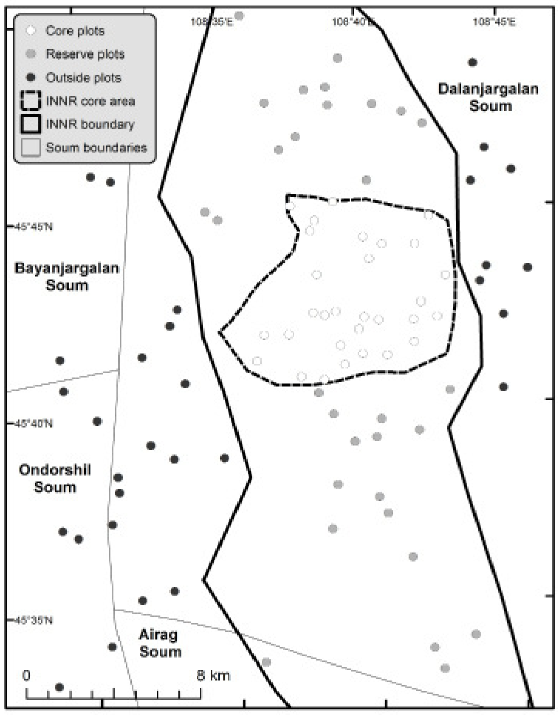

Figure 1. Map of the distribution of survey plots (N = 90) in Ikh Nart Nature Reserve (INNR), Mongolia. Plots were randomly selected in three areas: 1) inside INNR, 2) inside the INNR core protected area, and 3) outside INNR. At each survey plot, we estimated a measure of occupancy probability for two species (red fox, *Vulpes vulpes*, and toad-headed agama, *Phrynocephalus versicolor*) based on models developed by other projects.

is situated at the confluence of steppe and semi-desert ecozones (Murzaev, 1948), and includes gently rolling plains and rugged rocky areas separated by narrow valleys. Among the main habitat types include grasslands (dominated by needlegrass, *Achnatherum splendens*), shrublands (dominated by peashrub, *Caragana pygmaea*, and wild apricot, *Amygdalus penduculata*), open plains (dominated by various forbs and semi-shrubs), and sparsely vegetated rocky outcrops (Jackson *et al.*, 2006). Trees such as Siberian elm (*Ulmus pumila*) and willow (*Salix leucurus*) occur in some drainages, but represent a rare cover type. The area surrounding the reserve includes a similar mix of habitats, with the exception of rocky outcrops, which are confined mostly to the reserve. The region is arid, typically receiving <200 mm of precipitation per year, and temperatures are highly variable, often ranging from -40^0 C in winter to +40^0 C in summer (Jackson *et al.*, 2006). Wildlife in the region includes at least 33 mammal, 125 bird, and 6 reptile species (Murdoch *et al.*, 2006; Reading *et al.*, 2011).

Ikh Nart is designated as a 'nature reserve' and is managed primarily by the local *soum* governments with some oversight by the *aimag*. Management activities focus mainly on protecting argali sheep. Long-term monitoring of the argali population led to the development of a 'core protected area' that covers 71 km^2 within the Ikh Nart boundary (Fig. 1). This core area is thought to be important for the argali population and a center of biodiversity. It receives a higher level of protection from the reserve's ranger corp relative to other parts of the reserve.

Occupancy models

We demonstrate the utility of occupancy models using two species, the red fox and toad-headed agama. These two species occur widely throughout the Ikh Nart region and much of Mongolia and exhibit very different life history patterns (Heptner & Naumov, 1998; Clark *et al.*, 2006; Terbish *et al.*, 2006). Red foxes have been described to occur in all major ecozones in Mongolia (Mallon, 1985; Clark *et al.*, 2006). However, radio-telemetry and observation data suggest that red foxes select some habitats more frequently than expected suggesting that the species is not uniformally distributed across the country (Murdoch, 2009; Munkhzul *et al.*, 2012). In Ikh Nart, red foxes seem to favor more rugged, rocky terrain and the species is hunted intensively during the winter months (Murdoch *et al.*, 2007; Murdoch *et al.*, 2010a). Toad-headed agamas represent perhaps the most widely distributed reptile in Mongolia and can reach densities that exceed 100 individuals/ha (Rogovin *et al.*, 2001; Murdoch *et al.*, 2010b). Agamas tend to occur in more open, steppe terrain, and are a commonly encountered species in Ikh Nart.

Occupancy models have been developed for both species (see: Murdoch *et al.*, 2013; Murdoch *et al.*, 2014). Each model estimates Ψ or occupancy probability as a function of covariates. Below are the models:

Red fox Ψ = βint + βrocky (% rocky outcrop in 250 m) + βshrub (% shrubland in 250 m)
where,
βint = -2.392
βrocky = 0.093
βshrub = 0.034

Toad-headed agama Ψ = βint + βrocky (proportion rocky outcrop in 250 m)
where,
βint = 2.927
βrocky = -7.679

The red fox model indicates that occupancy probability is a function of the percent of rocky outcrop and shrubland within 250 m of a given site in the landscape. If these two variables are estimated, then occupancy can be calculated. For example, if a site is surrounded by 20% rocky outcrop and 15% shrubland, then these two values would be multiplied by their respective coefficients or betas (βrocky = 0.093 and βshrub = 0.034) and added to the intercept value (βint = -2.932). The logit link function can then be used to estimate a probability from the model:

Logit link = exp(model)/(1+exp(model))

Red fox Ψ = exp(-2.392+0.093*20+0.034*15)/(1+exp(-2.392+0.093*20+0.034*15))

Red fox Ψ = 0.49, indicating that there is a 49% chance of red fox occurring at that given location in the landscape.

The agama model indicates that occupancy probability is a function of the proportion of rocky habitat within 250 m of a given site. Similarly, if the proportion of rocky outcrop at a site can be estimated, then this value would be entered into the occupancy model and the logit link function used to calculate occupancy probability.

Occupancy mapping

We used each model to develop an occupancy probability map for each species across the northern part of Ikh Nart Nature Reserve and surrounding area (Fig. 1). For each species, we applied the model to each pixel (30 m x 30 m) in a habitat map of the region (total map area = 702 km^2 enclosed by N45.838943°- N45.545245°; E108.489732°- E108.731806°). This habitat map was built from a supervised classification of a Landsat 7ETM+ satellite image (for classification details, see: Jackson *et al*., 2006; habitat maps are available from the authors). We used GIS software (ArcGIS, ESRI, Redlands, California, USA) to estimate the amount of each covariate (rocky and shrubland) with a 250 m buffer around each pixel, then entered each value into the occupancy model equation and calculated occupancy probability using the logit function for each pixel. We did this for each species, then color ramped the maps to visually depict occupancy across the landscape.

Evaluating quality

We evaluated the quality of the landscape for each species in three areas: 1) inside the reserve, 2) inside the reserve's core protected area, and 3) nearby areas outside of Ikh Nart reserve. We reasoned that occupancy would be a function of quality and thus used it as a measure of quality. We selected 30 random 250 m radius plots in each area type (N = 90 total plots). For each plot, we then summed the occupancy values of all pixels beneath that plot. To test for statistical differences between area types, we used a Kruskal-Wallis (non-parametric) Analysis of Variance on plot data. We evaluated the data for normality and considered tests significant when $P < 0.05$.

Results

We developed an occupancy probability map for each species (Fig. 2). Occupancy probability varied from 0.084 to 0.997 in the red fox map and 0.022 to 0.949 in the agama map (Fig. 2). Survey plot values in the red fox map varied from 0.19 to 0.89 in the reserve (mean = 0.47 ± 0.05 SE), 0.18 to 0.94 in the core area (mean = 0.61 ± 0.04 SE), and 0.11 to 0.98 in areas outside the reserve (mean = 0.45 ± 0.03 SE). Plot values differed significantly between area types, with occupancy highest in the core area and lowest outside the reserve (Kruskal-Wallis: $H = 4.52$, $DF = 2$, $P = 0.014$). Plot values in the agama map varied from 0.31 to 0.95 in the reserve (mean = 0.85 ± 0.04 SE), 0.31 to 0.95 in the core area (mean = 0.73 ± 0.04 SE), and 0.19 to 0.95 in areas outside the reserve (mean = 0.90 ± 0.02 SE). Plot values differed significantly between area types, with occupancy highest outside the reserve and lowest inside the core area (Kruskal-Wallis: $H = 25.33$, $DF = 2$, $P < 0.001$).

Discussion

Species management often relies on information about distribution patterns. However, distributions can be difficult to precisely define, especially across a large landscape, and are often estimated from a combination of field observations and expert opinion (Clark *et al.*, 2006; Terbish *et al.*, 2006). These two sources of information may induce a substantial amount of bias. For example, field observations are often not collected systematically and may exclude areas where a species occurs (Anderson, 2001). Observations also tend to represent 'presence-only' data and do not account for variation in detection probability in a landscape (MacKenzie *et al.*, 2002). Similarly, expert opinion is a function of the experience of 'experts' and their ability to reliably depict distribution, which may be affected by a range of subjective and psychological biases (Martin *et al.*, 2012). These biases and others can be overcome by developing a model that relates a species to the conditions of the landscape. Several modeling approaches exist, including occupancy modeling, which uses the multinomial maximum likelihood function to estimate the probability of a species occurring at a given site in the landscape (MacKenzie *et al.*, 2002).

In this study, we used occupancy models for two species, the red fox and toad-headed agama, to map occupancy across the Ikh Nart Nature Reserve and surrounding area in Dornogobi Aimag. We then used these maps to assess the quality of the protected area and its core zone relative to the surrounding landscape. Our approach offers a science-based means of mapping distribution

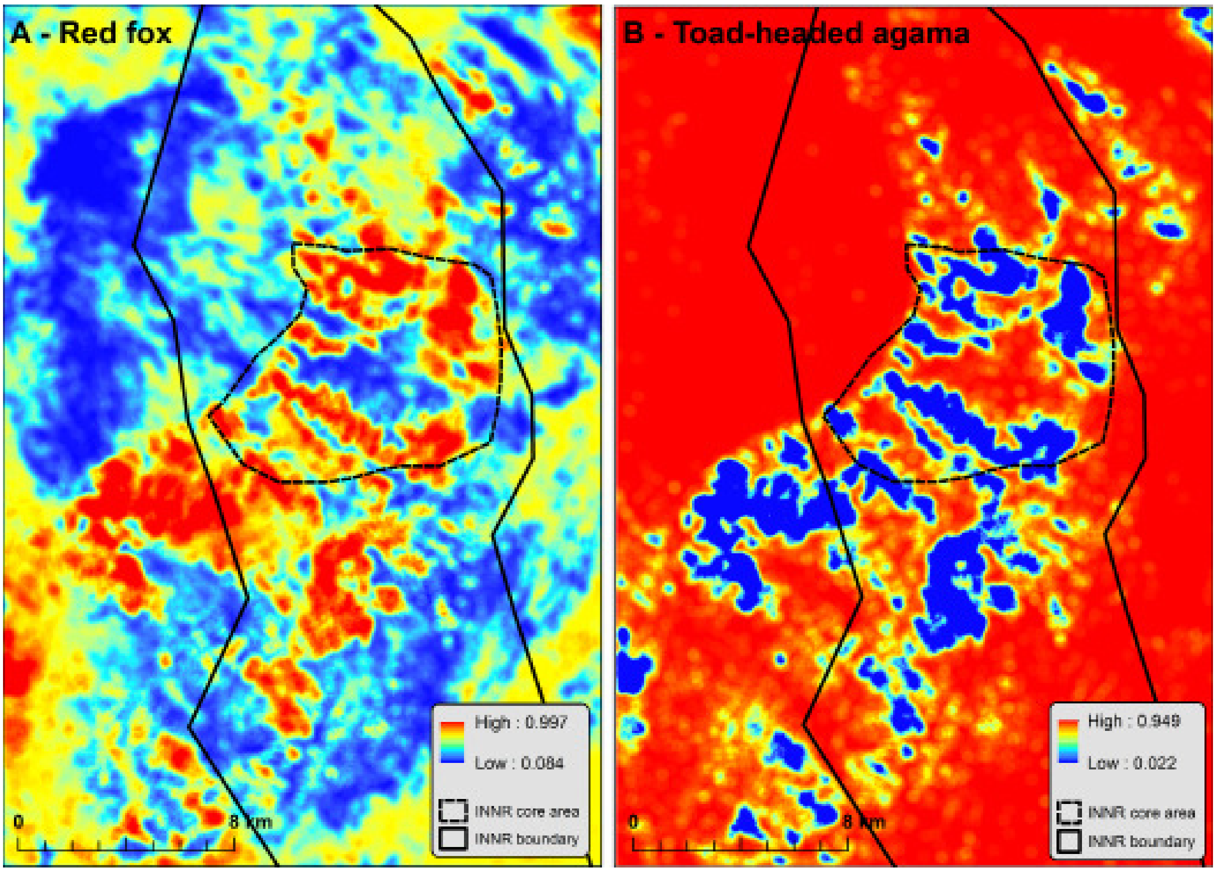

Figure 2. Map of (A) red fox (*Vulpes vulpes*) and (B) toad-headed agama (*Phrynocephalus versicolor*) probability of occurrence in Ikh Nart Nature Reserve (INNR), Mongolia and the surrounding area. We developed each map by applying an occupancy model for each species to each pixel (30 m x 30 m) of a habitat map. Probability values calculated using the logit link function and occupancy models are from Murdoch *et al.* (2013, 2014).

based on basic data collected from surveys and assessing the quality of different parts of the landscape.

We used two pre-existing occupancy models and applied them on a pixel by pixel basis to a landcover map using GIS (Murdoch *et al.*, 2013; Murdoch *et al.*, 2014). The results revealed very different patterns of distribution between the two focal species, which reflect the components (or β coefficients and covariates) of each model. Agamas occur widely throughout the region with the exception of rocky areas, which negatively influence occupancy (Murdoch *et al.*, 2013). Red foxes also range widely across the region and occupancy is positively influenced by the amount of habitats that provide cover including rocky areas and shrublands (Murdoch *et al.*, 2014).

We assumed that occupancy probability is related to habitat quality in the landscape. In other words, the higher the probability of occurrence for a species, the higher the quality of landscape conditions, and conversely, the lower the probability of occurrence for a species, the lower the quality of the landscape conditions. Assuming a functional relationship exists between occupancy and quality, our analysis indicated that Ikh Nart Nature Reserve provides higher quality conditions for red foxes than the surrounding areas outside of the reserve. Similarly, the core protected area in the reserve had higher quality than the marginal areas of reserve. This probably reflects the relatively high amount of rocky landcover in the reserve and particularly within the core area. For agamas, we found a different pattern. Areas outside of Ikh Nart had higher quality than areas within the reserve or core protected area due to the lower amount of rocky landcover.

Our results provide tools and information that may be helpful to wildlife managers in Ikh Nart. First, our maps provide visual depictions of distribution over a large landscape. These depictions are easy to interpret and may inform management activities. For example, red foxes are intensively hunted (illegally) in the reserve during the winter (Murdoch *et al.*, 2010a), and the distribution map shows areas where foxes are most likely to be found. Managers may then choose to focus their patrols on these areas during the hunting season. Second, they also provide a science-based measure of the quality of the protected area for each species, which may inform how habitats are managed. For example, red fox occupancy is partly a function of the amount of shrubland at a site. Managers could thus simulate changes in the amount of shrubland in the base map (perhaps through different regimes of grazing management), then assess how distribution changes in response. This may be particularly important as the species is thought to be declining in Mongolia and listed as an IUCN Near Threatened species at a country-level (Clark *et al.*, 2006). Similarly, other landscape changes such as those that may result from climate change could also be simulated to assess species' responses.

Few occupancy models have been developed for species in Mongolia, but we suggest that they are important tools for managing species and we recommend their development. Occupancy models generally rely on detection/non-detection data from multiple surveys of sites in a landscape (MacKenzie & Royle, 2005). Although survey data are often collected by monitoring projects, one challenge to developing occupancy models is that they often require a fairly large amount of survey sites and detections, which is not realistic for some species (e.g., those that are rare or difficult to reliably detect or that range over very large areas). However, occupancy models can be developed from 'presence-only' data. MaxLike is an R-package that will do just that given a set of presence data (like observations) and a base habitat map (Royle *et al.*, 2012). Occupancy models may also be extended to incorporate expert opinion (Low Choy *et al.*, 2009; Murray *et al.*, 2009). In this approach, opinion about the distribution of a species would be considered prior knowledge that would be used to update the probability values generated by a model using a Bayesian framework. In Ikh Nart, expert opinion could be solicited from managers, researchers, and herders, and potentially strengthen depictions of species distributions and inferences about landscape quality.

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