Original Article

Factors Affecting Home Ranges of Red Foxes in Ikh Nart Nature Reserve, Mongolia

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Abstract

Changes in red fox home range size in relation to environmental and intrinsic factors were studied using radio-telemetry during 2006–2008 in Ikh Nart Nature Reserve, southeastern Mongolia. We captured a total of 12 red foxes (8 females and 4 males) and fitted them with VHF radio-collars. Marked animals were tracked up to five times a week to estimate home ranges. We also trapped small mammal and insects in different biotopes for 3 years to estimate relative abundance of prey. Our results showed that mean individual home range sizes varied widely and differed among years. There was variation in home ranges between adults versus juveniles, but no significant difference was found between males versus females. In addition, mean home range size did not differ seasonally for pooled years. Variation in home ranges was best explained by a model that included covariates of year and age. We suggest that spatiotemporal changes in resource availability across years influenced home range dynamics of red foxes in our study.

Introduction

The red fox (*Vulpes vulpes*) is a common meso-carnivore that ranges widely across the grassland, semi-desert, and desert steppe environments of northern and central Asia (Ognev, 1935; Heptner *et al.,* 1967; Clark *et al.,* 2009). In Mongolia, the species occurs in nearly every major ecosystem in the country, including desert, grassland, and forest (Heptner *et al.,* 1967; Clark *et al.,* 2006; Clark *et al., 2009,* Murdoch *et al.,* 2009*)*. The red fox historically occurred in relatively high densities throughout species range in Mongolia and has been prized

as a game species for its pelt (Heptner *et al.,* 1967). However, after transitioned into a free-market economy since the early 1990s, red fox populations in Mongolia have declined due to overharvesting triggered by high demand for furs from markets in China and Russia (Wingard & Zahler, 2006). Red foxes are now regionally categorized as Near Threatened by the International Union for Conservation of Nature (Clark *et al.,* 2006). While many aspects of red fox ecology in Mongolia, such as survival and food habits, are relatively well understood (Murdoch *et al.,* 2010a, b), but little information exists about seasonal variation in home range size and location relative to environmental and demographic factors.

Several factors shown to influence the home range of foxes. Red fox home range size varies with habitat conditions and food availability (Macdonald, 1983), and low food abundance tends to result in larger home range sizes (Heptner *et al.,* 1967*)*. Home range size of carnivores also linearly increases as a function of body mass (Harestad & Bunnel, 1979) due to increased metabolic needs (Gittleman & Harvey, 1982). Female reproductive status reportedly affects seasonal home range size of red foxes (Henry *et al.,* 2005). In carnivores that hunt communally for large ungulates, home range size may be correlated with group size (Macdonald, 1983). The home range size of red fox appears to correlate with the distribution of key resources (Macdonald, 1981). For example, shelter availability tended to influence variation in the home range size in a Mediterranean population (Lucherini *et al.,* 1995).

This paper presents analyses of home range size in red fox based on radio-telemetry data. The overall goals of our study were to: 1) estimate home range sizes, and 2) examine how changes in home range sizes may be affected by environmental and demographic factors in southeastern Mongolia. The highly variable climate in this region governs distributions of available forage plants (Yu et al., 2004), and we expected such variation would influence home ranges of foxes by affecting prey abundances. Specifically, we expected larger home ranges for red fox during years with low food availability (Macdonald, 1983). Further, we expected home ranges to vary among seasons. In general, the home range size of carnivores increases with

body size because of greater metabolic needs (Gittleman & Harvey, 1982). Thus, we expected that adult red foxes would use larger ranges than juveniles, and that males would use larger home ranges than females. Understanding the factors affecting changes in the home range sizes of red foxes has conservation implications in Mongolia.

Materials and Methods

Study area. We conducted the study in Ikh Nart Nature Reserve, southeastern Mongolia (N45.72°; E108.65°). Ikh Nart was established in 1996 to protect 666 km² area of rocky outcrops and open plains (Myagmarsuren, 2000; Reading *et al.*, 2011). The reserve lies on the border of two major vegetation zones in Mongolia, the steppe and semi-desert zones (Murzaev, 1948; Mallon, 1985). Gently rolling plains dominated by grasses, semi-shrubs, and shrubs characterize the steppe zone. The semi-desert zone is more rugged, consisting of rocky outcrops and steep drainages, separated by shrub lands and open forbs-dominated plains. The climate in the area is continental and highly variable. Winter months are often cold, dry, and windy with temperatures that can reach below -40°C. Summer months are hot and dry with temperatures often between 30 and 40°C. Average temperature in the reserve is 5°C and precipitation is rare, falling mainly as rain. Most precipitation occurs during July and August. The reserve harbors a diverse fauna consisting of a mixture of grassland and semi-desert species (Murdoch *et al.*, 2009; Reading *et al.*, 2011). At least 39 mammal species occur in the study area, including carnivores such as corsac fox (*Vulpes corsac*), Pallas' cat (*Otocolobus manul*), badger (*Meles leucurus*), wolf (*Canis lupus*) and lynx (*Lynx lynx*), and ungulates such as argali sheep (*Ovis ammon*), Asiatic ibex (*Capra sibirica*) and Mongolian gazelle (*Procapra gutturosa*), along with at least 190 bird, 7 reptile, and dozens of insect species (Reading *et al.*, 2013 in press).

Materials. During 2006–2008, we live-trapped 12 red foxes (8 females and 4 males) using padded soft-catch leg hold traps (Victor Soft Catch 1.5, Wood stream Corporation, Lititz, Pennsylvania, USA).

Methods. The traps were baited with commercial hunting lures and we modified traps by increasing the jaw offset to minimize

the potential for injury. Captured red foxes were handheld in cloth bags without chemical restraint. We outfitted each captured red fox with an ear tag (Conservation tags, National Band and Tag Company, Newport, Kentucky, USA) and VHF radio transmitters weighing ~60 g (model 1950, Advanced Telemetry Systems, Isanti, Minnesota, USA), which comprised <5% of body weight. We collected individual covariates, including sex and age, for all foxes radio-collared to investigate their effects on home range sizes. Protocols for animals capture and handling were approved by the Animal Care and Use Committee of the Denver Zoological Foundation, USA. All red foxes were released at their capture sites.

We located marked foxes using handheld and null peak antennas up to 5 times a week. Inter-bearing angles were maintained between 20° and 160°. And triangulated fox locations using the bearing data in LOAS. 3.0 Software (Ecological Software Solutions, Hegymagas, Hungary). To minimize triangulation error, we censored bearings that intersected at ≤20° or ≥160° from analyses (Gese *et al.,* 1988). We successfully retrieved 2,673 locations data for marked animals during 2006–2008. To calculate home range size we used ArcView 3.2 (Environmental Systems Research Institute, Redlands, California, USA) software with the Kernel Home Range estimator tool. We estimated home ranges using 90% fixed kernels (Worton, 1989). To account for seasonal variation in home range size, we divided the study period into three seasons on the basis of energetic demands and behavioral characteristics (Murdoch *et al., 2010b):* pup-rearing season (April 15 to August 14), dispersal season (August 15 to December 14), and breeding/gestation season (December 15 to April 14).

To understand the inter-annual variation in resource abundances, we used three indices of NDVI (Normalized Difference Vegetation index; Pettorelli *et al.,* 2005) and relative abundance of the two most consumed prey groups in red fox diet; rodents and insects (Murdoch *et al.,* 2010a). First, to assess vegetation productivity (indexed as NDVI), we used NDVI data acquired by theme the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the TERRA. We obtained a 16-day NDVI composite in 250-m resolution for the periods of peak vegetation growth (e.g. August) during 2006–2008, from NASA's Earth Observing System Gateway (http://reveb.echo.nasa.edu). Given that radio-collared animals traversed beyond the reserve, we created a 10 km buffer around the reserve boundary in Arc-Map 9.3 (Environmental Systems Research Institute, Redlands, California, USA) software and extracted NDVI values within the buffered area in each year. Second, we live-captured rodents using box traps (XLK folding traps, H.B. Sherman Traps, Tallahassee, Florida, USA). The traps were baited with millet seed and peanut butter and we placed nesting material (i.e. wool, paper towels, etc.) in traps to minimize heat loss during capture. As some species in the reserve possess long tails, we modified trap doors to prevent tail catches and injuries. We set one randomly located 1-hectare grid in each of the six distinct habitat types that occur in the region, including low-density shrub, high-density shrub, semi-shrub, forbs-grass, tall vegetation, and dense rock (Jackson *et al.,* 2006). A trap grid consisted of a 10 x 10 matrix of 100 live traps spaced 10 m apart. We opened traps one hour after sunset and checked and closed them one hour before sunrise for five consecutive nights each month. Third, to calculate insect abundance, we set dry pitfall traps along five randomly located transects consisting of 25 traps in each of the previously defined 6 habitat types. We set traps in the evening and checked them the next morning. To determine a relationship between prey abundance and yearly vegetation productivity, we pooled the number of rodents and insects trapped during the dispersal season (August – December) across all habitat types to estimate a relative abundance (total number of individuals trapped for each group) in each year.

Statistical analysis. We used a *t*-test to compare home ranges between males and females and between adults and juveniles. We further examined sex and age differences in home ranges using a one-way Analysis of Variance (ANOVA) across years. We also used a one-way ANOVA to compare differences in overall home ranges among seasons and vegetation productivity among years. We used Pearson's conduct-moment correlation to examine the relationships between resource variables - NDVI, rodent and insect abundance indices, during 2006-2008.

Generalized Linear Models (GLM) with a

Gaussian error structure were used to evaluate joint effects of year, season, age, and sex on seasonal variation in home range size. We used Akaike Information Criterion corrected for small sample sizes (AICc) and Akaike weights in program R for model selection (Burnham & Anderson, 2002). We considered the model with the smallest AICc value to be the best model to fit the data and any model within 2 AICc values from the top model (i.e., Δ AICc< 2) to have empirical support (Burnham & Anderson, 2002). We used Akaike weights to assess the strength of evidence of one model versus another. We evaluated the relative importance of variables affecting red fox home range hierarchical variance (R Development Core Team, 2008) with R library 'hier. part' (Walsh & MacNally, 2004). The hierarchical partitioning examines all model combinations jointly to identify average influences of predictive variables rather than just variables from the single best model (MacNally, 2002).

Results

Seasonal home range size of marked foxes averaged 13.88 ± 13.71 km^2 (range = 1.3–75.5 km^2) and differed among years ($df = 3$, $F = 4.45$, $p < 0.04$); fox home ranges in 2008 were larger (19.23 ± 5.75 km^2) than those of foxes tracked in 2007 (13.90 ± 2.15 km^2) and 2006 (8.04 ± 1.91 km^2). During the 3-year study period, female home ranges differed significantly by year ($df = 2$, $F = 5.07$, $p < 0.03$; Fig. 1a), but we found no significant variation in home range size of males among years ($df = 2$, $F = 0.09$, $p = 0.77$). Overall, home range size pooled for 3 years did not differ between female versus male ($df = 1$, $t = 0.33$, $p = 0.57$). Adult home ranges varied signficantly among years ($df = 2$, $F = 4.24$, $p = 0.04$; Fig. 1b), however, we found no significant difference in juvenile home range sizes during 2006–2008 ($df = 2$, $F = 4.69$, $p = 0.08$). For pooled data across years, adults used significantly large home ranges than juveniles ($df = 1$, $t = 4.23$, $p < 0.05$). Home range size of foxes differed significantly during the breeding season among years ($df = 2$, $F = 8.20$, $p < 0.01$; Fig. 1c), but we observed no significant inter-annual difference home range size during dispersal ($df = 2$, $F = 0.29$, $p = 0.50$), and pup-rearing seasons ($df = 2$, $F = 0.05$, $p = 0.82$). Overall, home range size of foxes pooled

for 3 years did not vary significantly among seasons ($d.f = 2$, $F = 1.26$, $p = 0.23$).

We found lower NDVI values in 2008 (0.27 ± 0.01) than in 2007 (0.32 ± 0.02) and 2006 (0.37 ± 0.03); significant difference among years ($d.f = 1$, $F = 286.79$, $p < 0.01$). There was a weak correlation between NDVI versus insect abundance ($r = 0.33$, $p = 0.51$), and small mammal versus insect abundances ($r = 0.06$, $p = 0.93$). However, we found a strong positive correlation between NDVI and small mammal abundance ($r = 0.96$, $p < 0.01$).
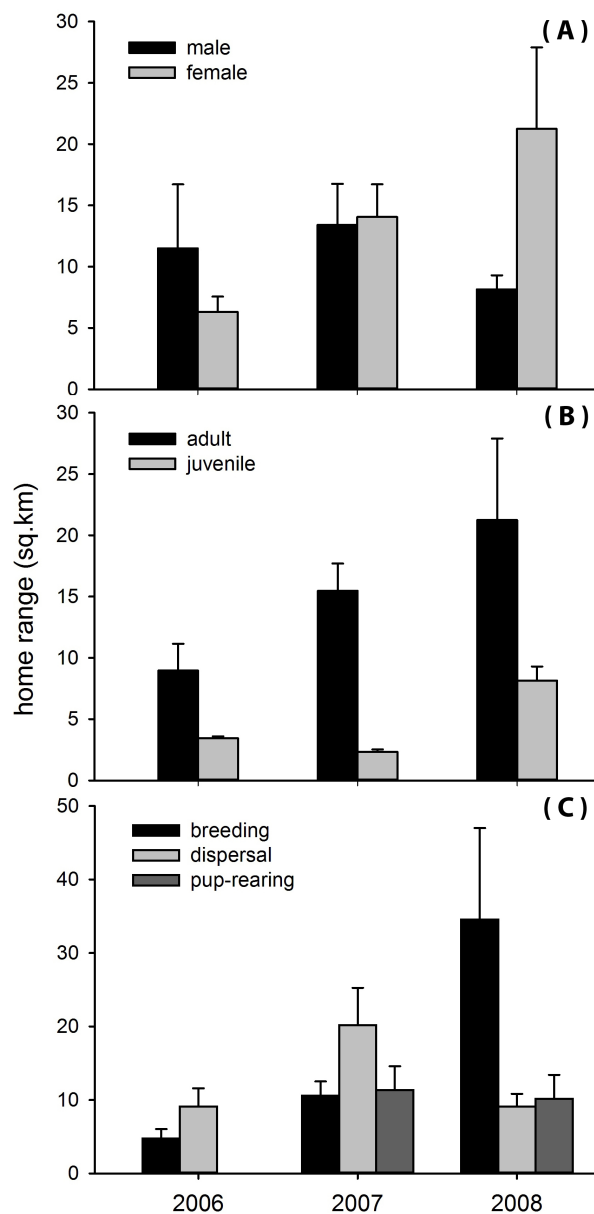

Figure 1. Comparison of average home range sizes of red foxes ($n = 12$) by sex, age (B), and season (C) during 2006–2008 in Ikh Nart Nature Reserve. Means are presented with ±1 standard error.

Table 1. Effects of sex, season, year and age on changes in home range sizes of red foxes (n = 12) in Ikh Nart Nature Reserve. AICc = Akaike Information Criterion corrected for small sample size.

Model structure	AICc	Δ AICc	AICc weights
Year+age	401.235	0.000	0.379
Year+age+season	402.281	1.046	0.265
Year	404.485	2.250	0.090
Sex+age+season	404.456	2.321	0.087
Age	404.696	2.461	0.081
Season+year	404.884	2.649	0.074
Sex+season+year+age	405.741	3.506	0.048
Season+age	406.121	3.886	0.040
Sex+year	406.666	4.431	0.030
Sex+age	406.694	4.459	0.030
Sex+season+year	407.219	4.984	0.023
Season	407.623	5.388	0.019
Sex+season+age	408.277	6.042	0.014
Sex	408.575	6.340	0.012
Sex+season	409.633	7.398	0.007

On the basis of minimum AICc, the model for red fox home range size that best fit our data contained parameters for year and age (Table 1). This model accounted for 38% of the AICc weight among the 15 subset models we considered (Table 1). The inclusion of season to the best model produced the second ranked model, that competed well with the best model (AICc weight = 27%; Table 1). In top model, seasonal home range size of red foxes associated positively with year (β = 5.53, SE = 2.56, p = 0.03) and age (β = 10.99, SE = 5.22, p = 0.04). The relative importance of year (46%), age (30%), and season (22%) was greater than sex (2%) in explaining seasonal changes in the home range size of foxes.

Discussion

This is the first attempt to quantify home range sizes of red foxes in Mongolia, and thus there is no comparable study for the species in Mongolia. We found generally larger mean home range sizes in Ikh Nart than those recorded elsewhere (Cavallini, 1996). Past studies found variable mean home range sizes depending on geographic location, and appear to relate to food resource availability. For example, red foxes living in resource-rich urban environments use ranges as small as < 1 km^2 (e.g., 0.4 km^2 for urban foxes in Oxford, UK), whereas those living in resource-poor environments, such as desert systems, occupy much larger home ranges (e.g., 50 km^2 for one fox in the desert of Oman) (Voigt & Macdonald, 1984). Further, we found high variability in home ranges sizes among individuals. We suspect that the quality and distribution of prey resources produced this variability, as predicted by the Resource Dispersion Hypothesis (Johnson *et al.,* 2002). This hypothesis suggests that territory size is a function of the richness (or fruitfulness) of food patches and the dispersion of those patches across the landscape. Red fox diet in Ikh Nart includes mainly small mammals and insects, which generally occur in discrete patches. For example, gerbils (*Meriones unguiculatus)* represent a main prey item and live in small colonies often separated by >500 m (Murdoch *et al.,* 2010a). Food resource patches, such as gerbil colonies, are generally low quality (i.e., in amount of available food) and highly dispersed relative to other areas. We believe that the unevenness in resource richness and dispersion influenced home range sizes among the foxes we studied.

Among the four predictor variables we modeled, year explaining the greatest percentage of variance in home range sizes of red foxes. As we predicted, red foxes used larger home ranges during years with low resource abundance (vegetation productivity and rodent abundance) during the 3 year study period. In other words, foxes ranged over larger areas to meet their energetic needs during the years with low resource availability, a pattern also observed for a red fox population in nearby Russia (Heptner *et al.,* 1967*)*.

In this study, juveniles used smaller home ranges than adults, as often observed among foxes elsewhere (Lariviere & Pasitschniak-Arts 1996). Juveniles in our study probably lived philopatrically with their parents, and occupied a smaller portion of their range. Differences in metabolic needs in relation to body mass (i.e. age) of foxes could be result in the differences in adult versus juvenile home range size we observed (Gittleman & Harvey, 1982).

With respect to the other factors, we found

no meaningful effect of season or sex on home range size. Seasonally, red foxes exhibit behaviors that affect home range size. For instance, red fox ranges usually contract during the pup-rearing season when mated pairs raise young and are constrained to areas around natal dens (Lariviere & Pasitschniak-Arts, 1996). Red foxes also typically disperse in search of mates in the autumn and early winter in the northern hemisphere (Lariviere & Pasitschniak-Arts, 1996). During dispersal, red foxes may venture into the home ranges of neighboring foxes or travel large distances, which would increase home range size estimates. Our results suggest that home ranges sizes were relatively stable among seasons. This may have resulted from for red foxes in Ikh Nart having to continually use all of their range because of low food availability, even during the pup-rearing period. We found a significant difference in home range size only for the breeding season (December–April). Heptner *et al.* (1967) found that snow limits red fox home range size, as it decreases activity and limits their movements. Spatiotemporal variation in snow cover and depth in the study area therefore, may have affected fox home ranges during this period by limiting access to resources. In contrary to our prediction, we identified sex as the least important factor influencing home range size, no significant sex-specific difference in home ranges. Males and females usually form monogamous pair bonds, especially in areas with low food availability, and share the same range (Macdonald, 1979). Our results appear to support this.

Two additional factors potentially influence fox home range sizes and are particularly worth considering for future research. First, variation in prey species composition may cause differences in nutritional quality even if overall abundance rates remain similar. Fine-scale information about prey species composition and spatiotemporal dynamics may thus aid efforts to explain changes in fox home ranges. Second, anthropogenic influences may significantly affect home ranges sizes of red foxes. Red fox populations in Mongolia have experienced declines due to overhunting (Wingard & Zahler, 2006). In fact, human hunting accounted for a majority (63%) of radio-collared fox mortality in the reserve (Murdoch *et al.,* 2010b); thus, red foxes may shift their home ranges in relation to density of households (e.g., hunters). Red foxes may also avoid free-ranging domestic dogs that commonly use the reserve (Reading *et al.,* 2006), as those dogs may kill foxes and compete with them for resources (Vanak & Gompper, 2009).

Acknowledgment

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