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Short communication

Arctic fox *Vulpes lagopus* den use in relation to altitude and human infrastructure

Vidar Selås, Børge Steinmo Johnsen & Nina E. Eide

One obvious threat to the endangered arctic fox *Vulpes lagopus* population in Fennoscandia is competition with the larger red fox *Vulpes vulpes*, which may have expanded its range towards the alpine tundra because of increased food availability in the low-alpine and subalpine region. The steady increase in the number of vacation cabins and roads, and thus also in human garbage and road-killed animals, may subsidise easily available food resources and improve red fox survival in these otherwise marginal areas. In Børgefjell National Park, Norway, 14 of 27 known arctic fox dens were used by arctic fox during 2001-2005. The dens that were used were situated at higher altitudes, farther from natural red fox habitats, than unused dens. In the best of our logistic regression models, there was also a statistical negative effect of the number of cabins within 7 × 7 km squares around the den sites. Hence, our results support the prediction that the arctic fox is less likely to use areas where human activity might be benefiting red foxes. A successful conservation strategy for the arctic fox will probably require a reduction of the driving forces behind the red fox expansion in the alpine areas.

Key words: Arctic fox, competition, disturbance, ecosystem change, infrastructure, red fox, Vulpes lagopus, Vulpes vulpes

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The arctic fox *Vulpes lagopus* population in Fennoscandia (Norway, Sweden and Finland) decreased dramatically from 1850 to the 1930s, has since remained small (Lönnberg 1927, Linnell et al. 1999), and was recently estimated to < 120 adult individuals (Elmhagen et al. 2004, Linnell et al. 2004). Competition and predation from the larger red fox *Vulpes vulpes* is probably the major threat to the endangered arctic fox (Østbye et al. 1978, Frafjord et al. 1989, Angerbjörn et al. 2002, Tannerfeldt et al. 2002a, Elmhagen 2003, Selås & Vik 2007). In fact, sterilised red foxes have successfully been used to eradicate arctic foxes on islands in Alaska (Bailey 1992). The altitudinal segregation between the two fox species is probably caused by the higher nutritional need of the red fox (Hersteinsson & Macdonald 1992, Tannerfeldt et al. 2002b), preventing it from occupying the high-alpine areas, where the amount of prey is generally low and more unstable in availability (Oksanen et al. 1999).

Improved availability of winter food, i.e. ungulate carcasses and human garbage, has been suggested as the main cause for the rapid expansion of red fox populations during the 20th century (Hjeljord 1980, Selås & Vik 2006). Human infrastructure such as roads and power lines has also increased the availability of accidentally killed animals (Forman & Alexander 1998, Bevanger & Brøseth 2004). In both Norway and Sweden, garbage, domestic animals and carcasses can constitute a significant part of the red fox winter diet (Lund 1962, Lindström 1982). Back-tracking of red foxes in low-alpine habitats has revealed that red foxes use areas close to cabins more than other areas in search of food (Røhnebæk 2004).

In Norway and Sweden, arctic fox dens with recorded breeding after 1980 were situated at higher altitudes and farther from red fox dens located above the tree line than those without breeding (Linnell et al. 1999, Dalerum et al. 2002, Frafjord 2003b, Tannerfeldt et al. 2002a). Based on the hypothesis that human-induced increase in food availability favours red fox populations, we predict that arctic fox den use depends on altitude and on the degree of human activities in the surrounding landscape. We tested this prediction by analysing arctic fox den use in Børgefjell National Park, Norway, during 2001-2005, in relation to both altitude and human infrastructure.

Material and methods

Study area

Our study area is Børgefjell/Byrkije National Park in Norway (1,447 km^2, 65°4' N, 13°49' E), which together with the adjacent Swedish Borgafjäll has the most vital arctic fox population in Fennoscandia (Eide et al. 2009). Most of the area is situated above the tree line (500-600 m a.s.l.). The landscape is characterised by deep valleys and high mountains (up to 1,699 m a.s.l.), with many rivers and lakes. The summer is short with snowmelt around June and first snowfall in September-October. The national park has a low degree of development for tourism, with few trails and only 10 rentable/open cabins. However, there are several vacation cabins, frequently used both in summer and winter, relatively close to the park. The mean number of cabins counted within 7×7 and 15×15 km squares around each arctic fox den (N = 27, see below) was 0-12 (mean: 1.4) and 1-63 (mean: 11.0), respectively. During 1998-2007, the number of vacation cabins within the four municipalities in which the national park is situated increased by 26%, and during our study period (2001-2005) by 10% (Central Bureau of Statistics of Norway; available at: http://www.ssb.no).

Den use (response variable)

We used national monitoring data from 27 known arctic fox dens in Børgefjell (see Andersen et al. 2005). All known arctic fox dens in Børgefjell were monitored for breeding activity during 2001-2005. None of the dens were used in 2003, when there was a decline in the population of small rodents, a food source that is important for arctic fox reproduction in this area (Frafjord et al. 1998).

During our study period litters were recorded in nine dens. In addition, there were five instances where adult(s) were observed at a den site in the breeding season, but we could not confirm litters. We assumed that these were dens with unsuccessful breeding attempts. The remaining dens showed no signs of use. The first two groups were combined into one group of dens in use (N = 14), and tested against dens not in use (N = 13). Because interference with red fox is a possible cause of unsuccessful breeding, we also tested dens used with litters (N = 9) against the combined latter two groups, i.e. dens with no recorded litters (N = 18).

Predictors

Frafjord (2003b) found that den altitude was a good predictor when testing for differences between arctic fox dens with and without litters in Børgefjell. We therefore used den altitude (m a.s.l.) as the main explanatory variable in our study. Because of the small sample size, we did not use additional predictors that were significantly correlated with altitude.

Frafjord (2003b) did not find any significant relationships between arctic fox den use and distances to different types of infrastructure, assumed to reflect human activities. However, in Børgefjell, with a few cabins situated within the National Park and several aggregated outside, we regarded the total load of infrastructure within a certain distance from the den to be a much better predictor for the presumed human influence on fox interactions than the distance to infrastructure. The predictors used in our analyses were 1) kilometres of trails, 2) kilometres of roads (public and private) and 3) number of cabins. We expected all three variables to be correlated with the availability of garbage. Furthermore, trails often contain remains from freshwater fishing, and roads the carcasses of road-killed animals.

Scales of analysis

We examined predictor variables at two different scales, 7×7 km and 15×15 km quadrates with dens at the centre. Arctic foxes are territorial and the fairly uniform distribution of dens suggested that most were located near the centre of arctic fox home ranges. Therefore, we expected that the scale 7 × 7 km (49 km^2) quantified most infrastructure within an arctic fox's home range, which in Fennoscandia varies from 17 to 62 km^2 (Angerbjörn et al. 1997, Landa et al. 1998). The larger 15 × 15 km scale was included because arctic foxes may not establish or use dens within 8 km or more from breeding dens of red foxes (Tannerfeldt et al. 2002a, Elmhagen 2003).

The different scales were measured on M711-maps (1:50,000) with an electronic telemeter (Model DM-138). Seven maps compose the study area, of which five were produced during 2001-2005 and two in 1985. Infrastructure outside the national park was possibly underestimated at the 15 × 15 km scale for one den in use, whereas two dens, which were not in use, were affected at the 7 × 7 km scale.

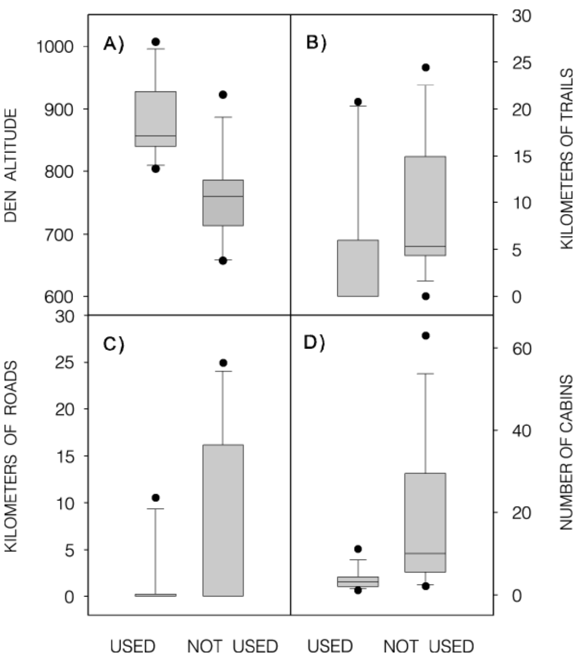

Figure 1. Box plots, showing median, lower and upper quartiles (box), 10 and 90% quartiles (intervals) and sample minimum and maximum, for the relationship between arctic fox den use in Børgefjell and A) den altitude (in m a.s.l.), B) kilometres of trails, C) kilometres of roads and D) number of cabins. The three infrastructure variables were measured within squares of 15 × 15 km with the den in the centre. For each predictor, the box to the left gives the values for dens used (N = 14) whereas the box to the right gives the values for dens not used (N = 13) during 2001-2005.

Statistical analyses

We used the likelihood ratio tests in logistic regression models to compare predictor variables associated with used and unused arctic fox dens, and dens with and without litters. Because of the limited number of dens, we used a maximum of two predictor variables in each model, i.e. altitude and one infrastructure variable. The selected models were tested for overdispersion. We compared models using Akaike's information criterion corrected for small sample sizes (AIC_c; Akaike 1973). We ranked models according to ΔAIC_c, i.e. the difference in AIC_c (between each candidate model and the model with the lowest AIC_c). Statistical analyses were carried out in R, version 2.6.1 (available at: http://www.r-project.org) and JMP, version 4 (© 1989-2000).

Results

Dens used by arctic foxes in Børgefjell during 2001-2005 were on average situated at higher altitudes than dens not used (Fig. 1, Table 1). A similar difference was found between dens with recorded

Table 1. Likelihood ratio tests in logistic regression models with the response variables arctic fox dens used (N = 14) and not used (N = 13) during 2002-2005. The predictors are kilometres of trails and roads and number of cabins within 7 × 7 and 15 × 15 km with the den in the centre. +/- signs after the variable names denote the effect in the statistical model.

	Used - not used			
Model	χ^2	P	R^2	ΔAIC_c
Den altitude +	28.43	< 0.001		
Cabins (7 × 7) -	12.84	< 0.001	0.83	0.00
Den altitude +	27.23	< 0.001		
Roads (7 × 7) -	10.62	0.001	0.77	2.21
Den altitude +	21.59	< 0.001		
Roads (15 × 15) -	7.81	0.005	0.69	5.80
Den altitude +	21.47	< 0.001		
Trails (15 × 15) -	6.77	0.009	0.67	6.06
Den altitude +	18.11	< 0.001	0.48	10.29
Den altitude +	18.95	< 0.001		
Trails (7 × 7) -	0.86	0.353	0.51	11.97
Cabins (15 × 15) -	14.18	< 0.001	0.38	14.23
Roads (15 × 15) -	4.33	0.038	0.12	24.08
Den altitude +	Unstable parameter estimates			
Cabins (15 × 15) -				

Table 2. Likelihood ratio tests in logistic regression models with the response variables arctic fox dens with (N = 9) and without recorded litters (N = 18) during 2002-2005. See legend to Table 1 for explanations.

	Litters - no litters			
Model	χ^2	P	R^2	ΔAIC_c
Den altitude +	6.17	0.013		
Roads (15 × 15) -	6.09	0.014	0.39	0.00
Den altitude +	5.00	0.025		
Cabins (15 × 15) -	3.80	0.051	0.32	2.29
Den altitude +	8.16	0.004		
Trails (7 × 7) -	3.48	0.062	0.31	2.61
Den altitude +	7.29	0.007	0.21	3.55
Roads (15 × 15) -	7.21	0.007	0.21	3.62
Den altitude +	8.66	0.003		
Roads (7 × 7) -	2.20	0.138	0.28	3.89
Den altitude +	8.24	0.004		
Cabins (7 × 7) -	1.52	0.218	0.26	4.57
Cabins (15 × 15) -	6.09	0.014	0.18	4.75
Den altitude +	6.83	0.009		
Trails (15 × 15) -	1.07	0.301	0.24	5.02

litters and dens without litters (Table 2). Within the 7 × 7 km squares, the mean length of trails or roads and the number of cabins did not differ significantly between dens used and dens not used, or between dens with and without litters. Within the 15 × 15 km squares, the mean length of roads and the number of cabins was lower for dens in use than for dens not in use (see Fig. 1 and Table 1), and a similar difference was found between dens with and without litters (see Table 2). Also the mean length of trails tended to be lower within the 15 × 15 m squares for dens in use than for dens not in use (see Fig. 1).

For dens used/not used, the best (lowest AIC_c) model included den altitude and number of cabins within 7 × 7 km squares, whereas the second best model included altitude and length of roads within 7 × 7 km (see Table 1). For dens with and without litters, the best model included altitude and length of roads within the 15 × 15 km squares, and the second best altitude and number of cabins within the same scale (see Table 2).

Discussion

As predicted, arctic fox den use in Børgefjell during 2001-2005 was related not only to altitude, as previously reported (Frafjord 2003b), but also to human infrastructure, i.e. number of cabins and kilometres of roads. For dens used, the best model included fewer cabins within 7 × 7 km squares, whereas dens with litters were best explained by less roads within 15 × 15 km squares. One possible interpretation is that a low degree of infrastructure within the 7 × 7 km scale is sufficient for the arctic fox to use a den, but not sufficient to allow successful breeding if there is a high load of infrastructure within the 15 × 15 km scale.

We find the most likely explanation for the negative relationship between arctic fox den use and infrastructure to be increased interference with red foxes that might have expanded their distribution following human activity and associated increases in garbage, remains from fishing and road-killed animals. Such food resources should be more stable in abundance compared to the very cyclic availability of small rodents, and may be especially important for the red fox in periods when natural food resources are scarce (Nielsen 1990, Lucherini & Crema 1994, Ferrari & Weber 1995). We suggest that increased food availability at the interface of the two fox species has affected the total red fox population positively, resulting in an influx of non-breeding red foxes to high-alpine areas, where the summer may be too short for the red fox to breed (Frafjord 2003a).

Alternative hypotheses for a negative relationship between arctic fox den use and infrastructure are that arctic foxes avoid breeding close to humans, or that populations of other arctic fox predators have responded positively to human infrastructure. We exclude the first alternative hypothesis because arctic foxes are usually not very shy; in fact, the Lappish name of the species means the fearless and foolhardy (Østbye & Pedersen 1990). We exclude the second alternative hypothesis because the two potential predators of arctic fox cubs in Børgefjell, the golden eagle *Aquila chrysaetos* and the wolverine *Gulo gulo* (Frafjord et al. 1989, Tannerfeldt & Angerbjörn 1996), avoid areas with human activity (May et al. 2006, Kaisanlahti-Jokimaki et al. 2008). Besides, the wolverine population in Børgefjell is low, with 0-2 recorded reproductions each year during our study period (Brøseth & Andersen 2007).

Børgefjell currently supports the most successful population of arctic fox in Fennoscandia, both with regard to numbers of breeding animals and reproductive performance. Winter feeding of arctic foxes and red fox control in Swedish Borgafjäll (Elmhagen et al. 2004) may be one contributing factor, but it may also be important that Børgefjell historically has had a relatively low natural abundance of red fox compared to other alpine areas. This might be because winters are severe, but also because Børgefjell has been less affected by human activities than most other alpine regions. Hence, recent increases in the number of vacation cabins around the park may have increased the negative impact on the arctic fox. As interference with the red fox appears to be a likely explanation for the observed patterns in arctic fox den use, further research should focus on factors that are of importance for the red fox expansion to the alpine habitats. Conservation efforts should hence also be focused on reducing the driving forces behind red fox expansion.

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