Arctic fox den use in relation to altitude and human infrastructure

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Abstract

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 sub-alpine region. The steady increase in number of vacation cabins and roads, and thus also in human garbage and road-killed animals, may subsidize 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 logistic regression model, there was also a statistical negative effect of number of cabins within 7x7 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 benefit red foxes. A successful conservation strategy for the arctic fox will probably require a reduction of the driving forces behind red fox expansion in the alpine areas.

Introduction

From 1850 to the 1930's the arctic fox *Vulpes lagopus* population in Fennoscandia (Norway, Sweden and Finland) decreased dramatically, and has since remained small (Lönnberg 1927, Linnell et al. 1999), recently estimated to less than 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 nutrition needs 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 2003a, Tannerfeldt et al. 2002a). Based on the hypothesis that human-induced increases in food availability favour 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

The study area is Børgefjell/Byrkije National Park in Norway (1447 km^2, 65º4'N, 13º49'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 1699 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 7x7 and 15x15 km squares around each arctic fox den (N = 27, see below) ranged 0-12 (mean

1.4) and 1-63 (mean 11.0), respectively. During 1998-2007, the number of vacation cabins within the four municipalities where the national park is situated increased by 26%, and during our study period 2001-2005 by 10% (Central Bureau of Statistics of Norway; 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 from 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 the 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 (2003a) 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 (2003a) 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 the 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, namely 7x7 km and 15x15 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 7x7 km (49 km^2) quantified most infrastructure within an arctic fox's home-range, which in Fennoscandia varies from 17-

62 km^2 (Angerbjörn et al. 1997, Landa et al. 1998). The larger 15 x 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 in 2001-2005, and two in 1985. Infrastructure outside the national park was possibly underestimated at the 15 x 15 km scale for one den in use, whereas two dens not in use were affected, and then also at the 7x7 km scale.

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 (AICc; Akaike 1973). We ranked models according to ΔAICc, the difference in AICc (between each candidate model and the model with the lowest AICc. Statistical analyses were carried out in R, version 2.6.1 (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 litters and dens without litters (Table 2). Within 7x7 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. Within15x15 km squares, the mean length of roads and number of cabins was lower for dens in use than for dens not in use (Fig. 1, Table 1), and a similar difference was found between dens with and without litters (Table 2). Also the mean length of trails tended to be lower within the 15x15 m squares for dens in use than for dens not in use (Fig. 1).

For dens used/not used, the best (lowest AICc) model included den altitude and number of cabins within 7x7 km squares, whereas the second best model included altitude and length of roads within 7x7 km (Table 1). For dens with and without litters, the best model included altitude and length of roads within the 15x15 km squares, and the second best altitude and number of cabins within the same scale (Table 2).

Discussion

As predicted, arctic fox den use in Børgefjell during 2001-2005 was related not only to altitude, as previously reported (Frafjord 2003a), but also to human infrastructure, such as number of cabins and kilometres of roads. For dens used, the best model included fewer cabins within 7x7 km squares, whereas dens with litters were best explained by less roads within 15x15 km squares. One possible interpretation is that a low degree of infrastructure within the 7x7 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 15x15 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 2003b).

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 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 because the two potential predators of arctic fox cubs in Børgefjell, golden eagle *Aquila chrysaetos* and 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 in the study period (Brøseth & Andersen 2007).

Børgefjell currently supports the most successful population of arctic fox in Fennoscandia, 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 it has historically had a relatively low natural abundance of red fox compared to other alpine areas. This could 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.

220 Conservation efforts should hence also be focused to reduce the driving forces behind
221 red fox expansion.
222
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229

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Table 1. Likelihood ratio tests in logistic regression models with arctic fox dens used (N = 14) and not used (N = 13) during 2002–2005 as response variables. The predictors are kilometres of trails and roads and number of cabins within 7x7 and 15x15 km^2 with the den in centre. Signs after variable names denote the effect in the statistical model.

Model	Used – not used			
	χ^2	P	R^2	ΔAICc
Den altitude +	28.43	<0.001		
Cabins (7x7) –	12.84	<0.001	0.83	0.00
Den altitude +	27.23	<0.001		
Roads (7x7) –	10.62	0.001	0.77	2.21
Den altitude +	21.59	<0.001		
Roads (15x15) –	7.81	0.005	0.69	5.80
Den altitude +	21.47	<0.001		
Trails (15x15) –	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 (7x7) –	0.86	0.353	0.51	11.97
Cabins (15x15) –	14.18	<0.001	0.38	14.23
Roads (15x15) –	4.33	0.038	0.12	24.08
Den altitude + Cabins (15x15) –	Unstable parameter estimates			

Table 2. Likelihood ratio tests in logistic regression models with arctic fox dens with (N = 9) and without recorded litters (N = 18) during 2002–2005 as response variables. Explanations as in Fig. 1.

Model	B) Litters – no litters			
	χ^2	P	R^2	ΔAICc
Den altitude +	6.17	0.013		
Roads (15x15) –	6.09	0.014	0.39	0.00
Den altitude +	5.00	0.025		
Cabins (15x15) –	3.80	0.051	0.32	2.29
Den altitude +	8.16	0.004		
Trails (7x7) –	3.48	0.062	0.31	2.61
Den altitude +	7.29	0.007	0.21	3.55
Roads (15x15) –	7.21	0.007	0.21	3.62
Den altitude +	8.66	0.003		
Roads (7x7) –	2.20	0.138	0.28	3.89

Den altitude +	8.24	0.004		
Cabins (7x7) –	1.52	0.218	0.26	4.57
Cabins (15x15) –	6.09	0.014	0.18	4.75
Den altitude +	6.83	0.009		
Trails (15x15) –	1.07	0.301	0.24	5.02

411 Legend to figure:

412

413 Figure 1. Box plots, showing median, lower and upper quantiles (box), 10 and 90%
414 quartiles (intervals) and sample min and max, for the relationship between arctic fox
415 den use in Børgefjell and A) den altitude (m a.s.l.), B) kilometres of trails, C) kilometres
416 of roads and D) number of cabins. The three infrastructure variables were measured
417 within squares of 15x15 km with den in centre. For each predictor the box to the left
418 gives the values for dens used (N = 14) while the box to the right gives the values for
419 dens not used (N = 13) during 2001-2005.

420