The conservation of Fennoscandian arctic foxes: the effects of supplemental feeding and red fox hunting.

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ABSTRACT

The SEFALO+ project has focused on conservation actions to increase the viability of the threatened Fennoscandian arctic fox. But one of the tasks has also been to evaluate the effect of supplementary feeding and red fox culling for future management of the arctic fox population. Supplementary feeding has been shown to have a positive effect on the number of litters and an increase in juvenile survival. In addition to this we have also found an increase in the litter sizes. However, supplementary feeding can also have an attracting effect on the red fox and thereby have a negative effect on the arctic fox. Red foxes are known to kill both adult and juvenile arctic foxes. When conducting both feeding and red fox culling there was a strong effect with an increase of litters. However, when we performed red fox culling alone, no effect was found on the number of litters. In areas with intensive feeding and red fox culling a doubling of the number of litters between each rodent peak (every 3-4 year) were recorded. In areas with no or a low intensity of actions, the number of litters have had a slightly negative trend or been stable. We therefore recommend the combination of supplementary feeding and red fox culling for the future management of the Fennoscandian arctic fox.

INTRODUCTION

The arctic fox (*Alopex lagopus*) in Fennoscandia is threatened to go extinct and is considered a priority species according to the EC Habitat directive. The Fennoscandian arctic fox mainly relies on voles and lemmings as a food resource (Elmhagen, Tannerfeldt & Angerbjörn, 2002) and its population dynamics is therefore highly correlated to the rodent population cycles (Figure 1.). During the mid-19th century, the Swedish population size approximated 4700 individuals during lemming peak years(Tannerfeldt, 1997). However, as trading with arctic fox fur became profitable in the end of the 19th century, human hunting pressure was intensified and the population drastically declined to a few hundred individuals (Zetterberg, 1945). The arctic fox has been protected by law since 1928 in Sweden, 1940 in Finland and 1930 in Norway, but their numbers has still not increased and the situation deteriorated during the 1980s and 1990s due to absence of lemming peaks (Gärdenfors, 2005; Hersteinsson *et al.*, 1989; Kålås, Viken & Bakken, 2006). Today, there are approximately 120 adult arctic foxes in Fennoscandia, of which approximately 50 are found in Sweden, 50 in Norway, and less than 10 in Finland (Angerbjörn, Hersteinsson & Tannerfeldt, 2004; Kaikusalo, 2000; Linnell, 1999b). Due to the species capacity for extensive migrations, the arctic fox in Sweden, Finland and Norway was previously regarded as a single population (Hersteinsson *et al.*, 1989). However, according to genetic analyses, these are fragmented into four isolated areas with no gene flow in between (Dalén *et al.*, 2006). Each of these areas is inhabited of about 10-50 individuals each and, accordingly, the risk of negative effects directly or indirectly related to the low population size is substantial (Dalén *et al.*, 2006).

There are several factors influencing the non-recovery of the Fennoscandian arctic fox, of which the small population size constrained by low food availability in combination with inter-specific interactions with red foxes (*Vulpes vulpes*) is considered the most prominent ones (Angerbjörn *et al.*, 2004). Due to the high degree of specialization in utilizing rodents as food resource, the number of arctic foxes is dependent on the density phase of the rodent cycle and the population numbers can differ drastically between good and bad rodent years (Angerbjörn *et al.*, 1995). The species has the largest litter size of all carnivores, with capacity of raising as much as 19 cubs during years with high food availability (Angerbjörn *et al.*, 2004). When rodent availability is high, the population size increases rapidly, but is typically followed by a crash one or two years later due to decreasing rodent density (Tannerfeldt & Angerbjörn, 1998). In Fennoscandia, these population cycles are in general repeated with a four years interval and, thus, each time the rodent cycle crashes, the arctic fox population collapses to extremely low numbers. On a yearly basis, juvenile mortality rate due to starvation and predation can reach 90% whereas the adult mortality rate is about 50% (Tannerfeldt, Angerbjorn & Arvidson, 1994). The arctic fox also depends on remains of carrion left by larger predators such as the wolf and the wolverine(Elmhagen & Rushton, 2007; Hersteinsson *et al.*, 1989; Tannerfeldt, Elmhagen & Angerbjörn, 2002). Present low numbers of these predators may have reduced the amount of available winter food for arctic fox. Global warming is also assumed to affect the climate in northern Fennoscandia through decreased snow cover, increased growing season and increased primary productivity (Moen *et al.*, 2004).

Moreover, the red fox is currently increasing its range above the tree line and threatens the arctic fox by competition for resources (Tannerfeldt *et al.*, 2002)and intra-guild predation (Hersteinsson *et al.*, 1989). Basically, the arctic fox and the red fox have the same fundamental food niche (Frafjord, 2000), although red fox is a generalist to a higher extent and can thus switch to alternative prey like birds when rodent density is low (Elmhagen *et al.*, 2002). Furthermore, the arctic fox and the red fox have similar habitat preferences and the dominant red fox can thus exclude arctic foxes from their breeding range by taking over dens. Regarding intra-guild predations, there are two possible effects of which the first conveys in a direct killing which causes a direct demographic effect. A possible effect of global warming is an increasing primary productivity and prey availability on the mountain tundra, which may benefit the red fox. This would cause an increased competition and predation of red fox on the arctic fox with a predicted decrease in juvenile and adult survival as well as a lowered number of breeding attempts would be expected. Alternatively, killing might take place but only relatively rarely and the effect will rather be that of fear that such killing could infer. For successful breeding, the arctic fox is dependent on specific large dens and studies have shown that arctic foxes avoid breeding in the vicinity of red foxes and are accordingly pushed into areas at higher altitudes with lower productivity (Elmhagen *et al.*, 2002). According to data from Finland, where red fox abundance was compared to arctic fox abundance (Figure 2.), the red fox had a clear effect on the arctic fox dynamics. When the red fox appeared at the traditional arctic fox dens in Finland, they first stayed only during the winters but after a few years they stayed all year around and also reproduced at these dens. We saw similar trends in the Swedish arctic fox areas (Angerbjörn *et al.*, 2002). However, whether the red fox has a direct effect on arctic foxes through intraguild predation or direct competition is had not yet been investigated. Alternatively the effect shown in the Finnish data set could be due to indirect exploitative competition or even a case with no competition at all.

Management actions aiming to preserve the Fennoscandian arctic fox were firstly implemented in the EU/LIFE project SEFALO (1998-2002) by Sweden and Finland and later on in SEFALO+ (2003-2008) by Sweden, Finland and Norway. The aims of the first phase of SEFALO was to halt the present declining population trend and enhance the chances for the species to increase in numbers, by supplementary feeding and red fox control (Angerbjörn *et al.*, 2002). In the lemming peak year 2001, recruitment to the population was good, especially in the areas where SEFALO had combined supplemental feeding with red fox culling. During the second project period, we have used a dynamic management approach to monitor and allocate conservation actions to support the species in the most efficient way. A supplementary feeding programme during both summer and winter has been used in order to increase reproductive output and juvenile survival and a red fox control programme to safeguard the best arctic fox territories. These actions were implemented within authorities to ensure continuation of monitoring and conservation actions after the proposed project. Supplemental feeding has earlier been shown to confer an increased cub survival (Tannerfeldt *et al.*, 1994) and an increased number of litters (Angerbjörn *et al.*, 1991). However, whether supplemental feeding also conveys in an increased litter size has not yet been investigated. Supplementary feeding of the arctic fox, however, involves a risk of attracting red foxes to arctic fox territories. Therefore, we consider a combined evaluation of both actions necessary since supplementary feeding of arctic foxes involves a risk of attracting red foxes to arctic fox territories. We expect red fox culling to leave more dens and territories suitable for establishment of arctic foxes, which implies more litters born and higher juvenile survival due to decreased predation from red foxes. Hence, in combination with feeding, we expect to increase the number of successful reproductions. In this report, we aim to evaluate the effect of supplemental feeding and red fox culling on the number and size of arctic fox litters on a local and regional scale. On a local scale, we also aim to separate the effects of supplemental feeding from those connected to red fox culling.

MATERIAL AND METHODS

Arctic foxes at inhabited dens were fed during winter with commercial dog food (Dogman Dinner), or in some cases remains from reindeer slaughter, by putting out a plastic container within 100 m from an active den. The containers were controlled for arctic or red fox activity at least once a month. Red foxes have been culled during winter in areas close to recent or previous arctic fox territories by rangers in the county administration with special permits for using snowmobiles. All hunting has taken the utmost caution as not to cause any disturbance to other wildlife. We have classified a territory as being hunted if one or several red foxes had been shot within 2.3 km from a specific den.

To evaluate the effect of supplemental feeding and red fox culling on the number and size of arctic fox litters on a regional scale, we have used den surveys to investigate presence and breeding success of the arctic fox in all areas. During the summer inventories, we surveyed all known dens in Helagsfjällen (SE), Borgafjäll (SE), Børgefjell (NO), Vindelfjällen (SE) and parts of Norrbotten (SE) for arctic fox activity between years 2001-2007. Management actions in Helagsfjällen (SE) and Borgafjäll (SE) have been intense and continual during the entire study period, whereas actions have been moderate in Vindelfjällen (SE) and Norrbotten (SE) (Table1). In Børgefjell (NO), no actions have been implemented. These areas differ in size, in number of natal dens (defined as having at least one arctic fox reproduction between 1981-2007 and number of reproducing arctic foxes (Table 1). However, since the areas are situated in discrete mountain areas and all of them contain high-quality arctic fox habitats, we consider that they have similar prerequisites for arctic fox activity and are thus valid for comparison. There are additional arctic fox habitats on the Finnish and Norwegian mountain tundra as well but there are no records of arctic fox presence in Finland since 1994 and in Norway, no management actions have been implemented. Thus, we consider a comparison with these areas uninformative.

Presence of arctic or red fox at dens has been determined by visual observation or DNA analysis of faeces collected during surveys. A den was considered as inhabited when arctic fox presence was documented by visual observations or faecal DNA analysis. When rodent abundance is increasing or high, most adult arctic foxes try to reproduce and are stationary at dens during summer. A den survey during a year of high or increasing rodent abundance will thus provide a good approximate of the number of adult arctic foxes. However, during a year with low food availability, fewer individuals try to reproduce and will therefore not be stationary at the dens which conveys in difficulties to approximate the number of individuals. Since visual observations during summer are mainly restricted to stationary and breeding adults, and the detection probability will thus be affected by the local rodent density. Tannerfeldt & Angerbjörn (1998) suggested that arctic fox reproduction mainly occurred during years with high rodent availability. Generally, both the male and the female participate in cub rearing and, during this period, they are rather stationary (Angerbjörn *et al.*, 2004). Therefore, during years with low rodent density, there is a risk to underestimating the number of individuals alive due to the low number of breeding adults. When rodent density is low, it is likely that there is a higher number of non-breeding adults that are not tied permanently to specific dens. We have therefore focused on the years of increasing rodent densities in some of our analyses (i.e. 2001, 2004 and 2007). Visual or audible observations of arctic fox cubs were used for recording presence of litters. The minimum litter size at weaning was determined by direct counts of the number of cubs observed at the den.

To evaluate the joint and separate effect of red fox culling and supplemental feeding, we studied the effect of supplemental feeding and red fox culling on the number and size of arctic fox litters in Helagsfjällen in Jämtland county (SE) between 2001-2007. Here, we aimed to investigate the joint and separate effect of supplemental feeding and red fox culling in relation to specific territories without any actions at all (Table 2). As can be seen in Table 2, the number of territories displayed to management actions differed between years.

Of the 25 natal dens in the Helags area, we supplied 20 with extra food for one or several years (all together n=82) (Table 2). The arctic foxes used these feeding stations in varying extent where at some places up to 20 kg of dog food could be consumed during 30 days but in other cases only a few kg was used. However, in the following analyses, we have only included data on whatever a den was fed during the winter or not. Furthermore, we have used data provided by the county board administration on red fox culling. Red foxes have been culled during the winters in areas close to recent or previous arctic fox territories by rangers in the county administration with special permits. All hunting has taken the utmost caution as not to cause any disturbance to other wildlife. In total, 245 red foxes have been shot in the area over all years (Table 1). In these analyses, we classified a territory as being hunted if one or several red foxes had been shot within 2.3 km from a specific den. A characteristic arctic fox territory is approximately 25 km^2 (Angerbjörn, Stroman & Becker, 1997), which gives a radius of 2.3 km around the den. In some territories more than one red fox was shot, however, we have in our statistical analyses only classified territories as being hunted or not hunted.

Table 1. Description of study areas included in the regional scale evaluation.

Area	County	Size (km^2)	Known dens	Natal dens 1990-2000	Natal dens 2000-2007	Natal dens 1980-2007
Helags (SE)	Z	1800	68	9	10	25
Borgafjäll (SE)	Z/AC	1676	45	-	14	16
Børgefjell (NO)	NO		27	-	-	-
Vindelfjällen (SE)	AC	2100	115	23	8	33
Padjelanta (SE)	BD	1984	48	3	3	13
Sitas (SE)	BD	1680	23	0	1	6
Rousto (SE)	BD	2448	49	0	1	10

Table 2. Number of litters in Helagsfjällen and intensity of management actions (2001-2007).

Year	Arctic fox	No. of dens			
	litters	hunted	fed	both	none
2001	2	7	1	4	13
2002	4	9	3	5	8
2003	1	6	3	3	13
2004	4	2	2	6	15
2005	6	10	0	9	6
2006	1	5	4	6	10
2007	9	4	7	3	11

RESULTS

Combined effects of hunting and feeding on a regional scale

Coincidence of red fox appearance and a decreased arctic fox population in the Finnish data set (Figure 2.), initiated red fox culling at traditional arctic fox dens in both Finland and Sweden (Appendix 1). The numbers of red foxes culled in each area have varied in relation to red fox abundance and due to different logistical problems. On a larger regional scale, we tested the effect of red fox culling (i.e. if a specific year was hunted vs. not hunted) on the number of occupied arctic fox dens in five areas in Sweden (Helags, Borgafjäll, Vindelfjällen, Sitas, Råstojaure) from 1999-2006. We found significantly more occupied dens in years where at least one red fox had been culled in the area (Figure 5.). The effect of red fox culling during winter was present both during winter and summer, although there were fewer dens occupied during the summer (between seasons: $F(1,76)=27.3$, $p<0.001$). Further, when we tested the quantitative effect of red fox hunting by using the number of culled red foxes each winter per area, we again got a positive effect on the number of reproducing arctic foxes (Table 3). However, the effect seems to level out at about 20 red foxes shot per year in a single area (Figure 6.). Surprisingly, the rodent abundance did not contribute to explain the variation in arctic fox reproduction in this data set (Table 3).

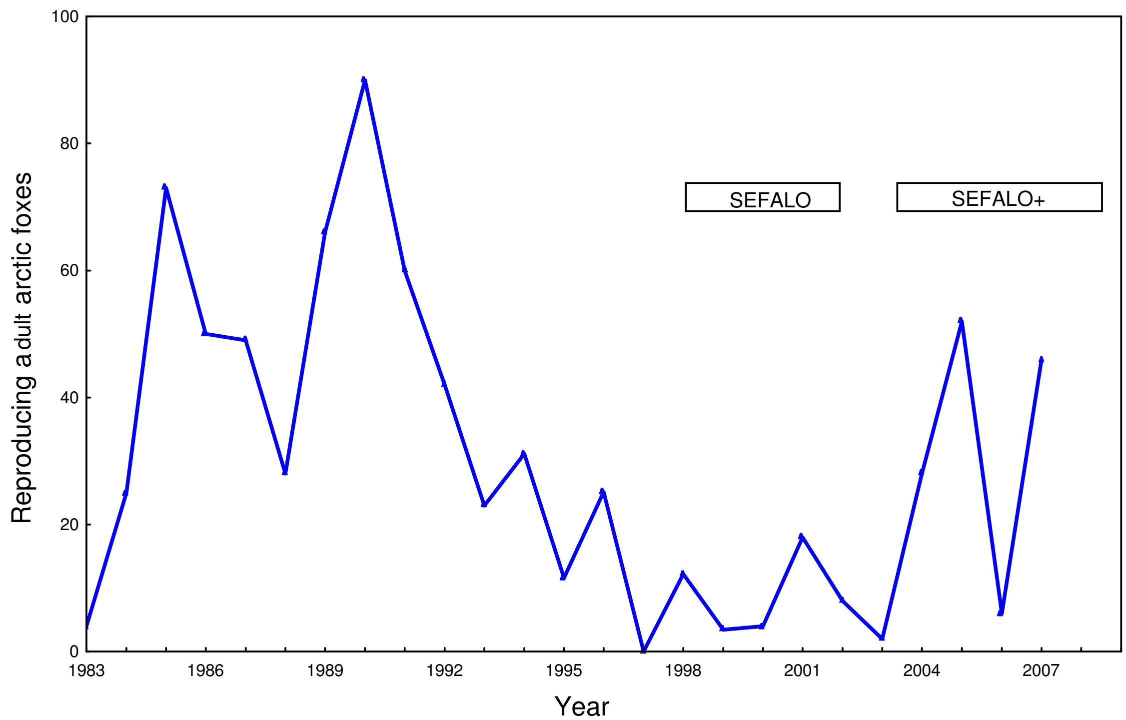

Figure 1. The number of arctic foxes that have reproduced in Sweden in 1983-2007.

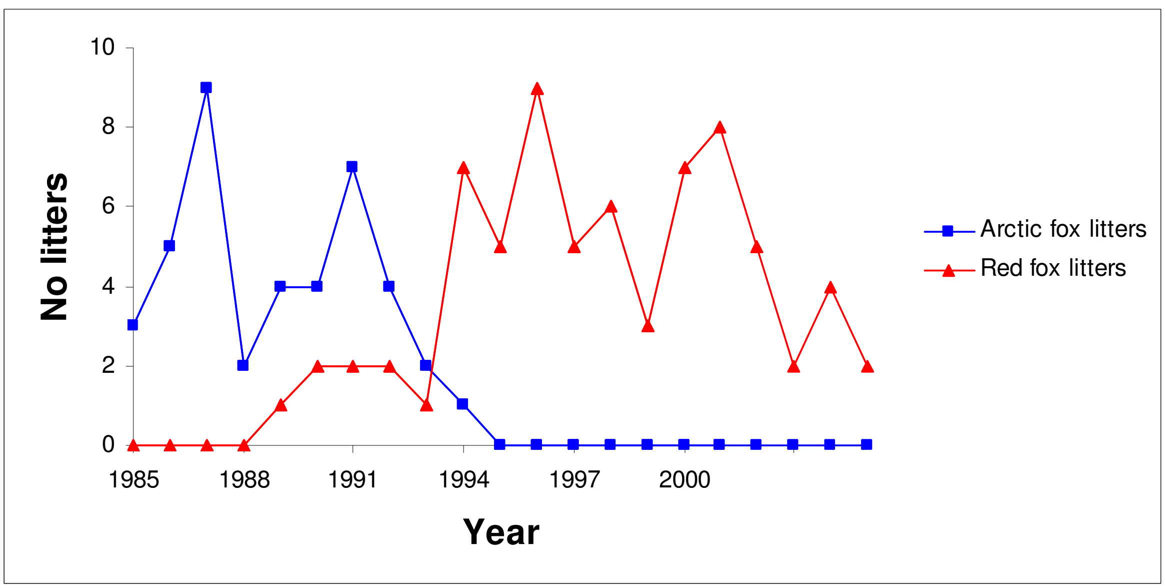

Figure 2. The number of arctic and red fox litters in Käsivari, Finland 1985-2005.

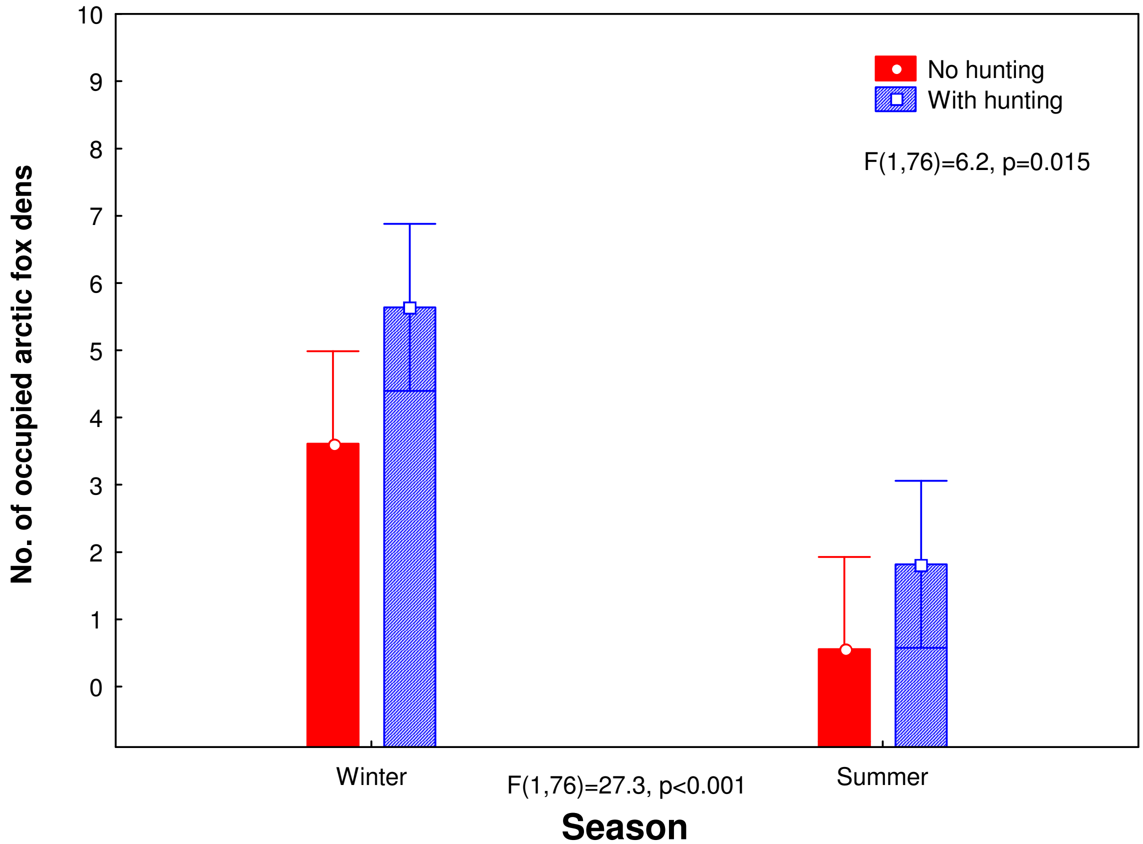

Figure 3. The number of occupied arctic fox dens in Helags, Borgafjäll, Vindelfjällen, Sitas, Råstojaure (1999-2006) in hunted vs. not hunted areas.

Since the management actions conducted have been governed by the impact on the arctic fox population rather than being designed for scientific evaluation, it is difficult to separate the effects of hunting from those of feeding. Thus, there has been a combined effect of both supplemental winter feeding and red fox culling in many cases. So, when testing both actions in the data set from 1999 – 2006 in the five Swedish areas (see above), we found significant effects on both hunting and supplementary feeding (Table 3B).

Table 3. Linear regression results for the number of reproducing arctic foxes in five Swedish areas (1980-2006) tested against: **A**: the no. of shot red foxes during previous winter, the estimated number of red foxes and rodent density (no. per 100 trap nights), **B**: the no. of shot red foxes during previous winter, and the number of dens with supplemental feeding during the winter.

A.				
Factor	**Beta**	**t**	**P**	**n**
No. of red foxes	0.01	0.06	0.95	54
Rodents (no./100trapnights)	-0.22	-1.25	0.23	28
No. of red foxes shot	0.73	4.16	0.0006	42
B				
Factor	**Beta**	**t**	**P**	**n**
No. of fed dens	0.43	3.31	0.0018	51
No. of red foxes shot	0.40	3.05	0.0037	51

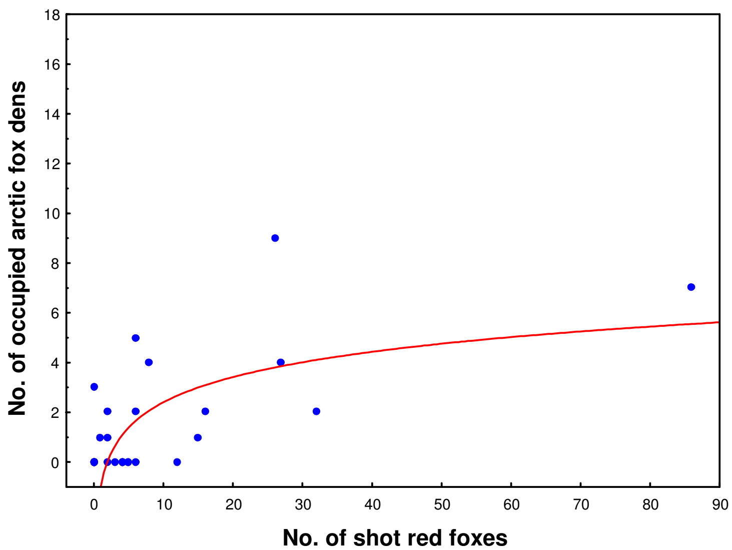

Figure 4. The number of annual arctic fox reproductions increased with the number of red foxes shot in Helags, Borgafjäll, Vindelfjällen, Sitas, Raustojaure (1999–2006).

So far our results demonstrate a clear effect of both hunting and feeding on the number of reproducing arctic foxes. However, we were also interested in the quantitative effect of our actions on the arctic fox population. In some areas, we have managed to conduct intensive feeding and intensive red fox hunting (Helags and Borgafjäll SE) whereas in other areas the actions have been less intensive. In Figure 7. the synchrony in the arctic fox population in different areas is obvious with a peak in strong increase in 2001 and 2005. As is argued above, the increase years are of greater interest and our focus is thus on comparing the effect of both hunting and supplementary feeding in Helags and Borgafjäll (Appendix 1), with those of minor or no actions at all during the increase years (i.e. 2001, 2004 and 2007). We found that the number of arctic fox litter has been doubled during each rodent cycle in these areas (Figure 8.). In the Helags area, the number of arctic fox litters increased from two litters 2001 to four and nine in 2004 and 2007 respectively. In Borgafjäll area the trend was from 0 to five and nine litters during respectively years. In all the other areas we saw no change in the number of litters (Figure 8.). Accordingly, the arctic fox populations in the areas with intense management actions (i.e.

Helags and Borgafjäll: dashed lines in Figure 4.) have increased considerable during one rodent cycle of three or four years.

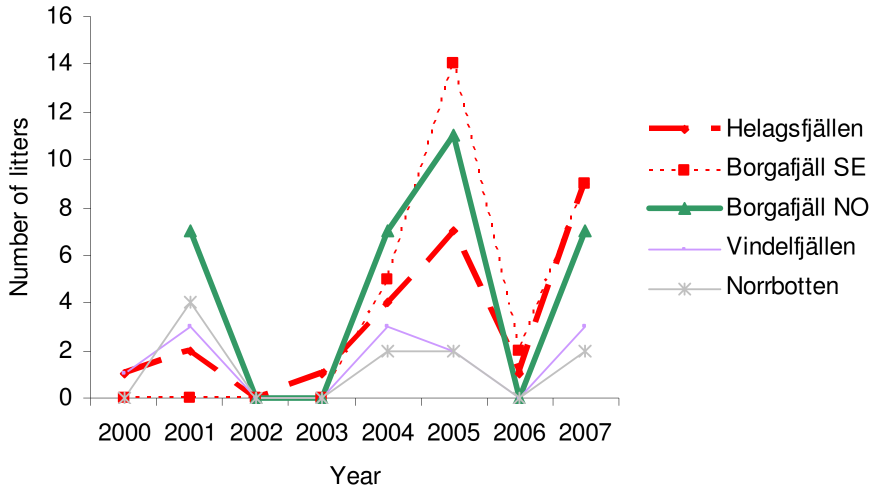

Figure 5. Number of arctic fox litters in Helagsfjällen, Borgafäll (SE), Børgefjell (NO), Vindelfjällen and Norrbotten (2001-2007).

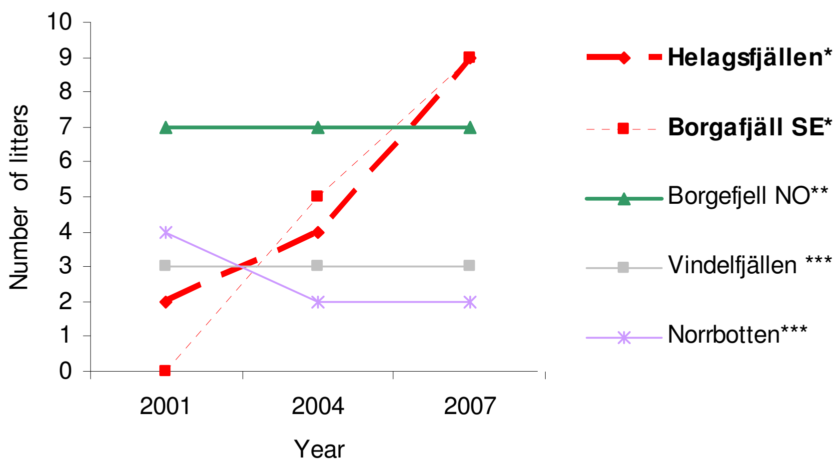

Figure 6. Number of arctic fox litters during years with increasing numbers of small rodents. * area with high intensity of actions ** area with no actions *** area with low intensity of actions.

Effects of hunting and feeding on a local scale

The Helags arctic fox population has gone through a remarkable increase after the years with very few reproductions around 2000, mainly through intensive management actions (Figure 4.). The intensive studies in this area have also enabled us to evaluate the effects of red fox culling and supplementary winter feeding in a more detailed manner. We investigated under what circumstances that there will be an arctic fox litter on the 25 natal dens in the area (Table 1).

In this analysis we have considered three variables. The first is the red fox hunting within the specific territory (hunted vs. not hunted), measured as one or several red foxes shot within 2.7 km from the den, which is equivalent to an arctic fox home range of 25 km^2 (Angerbjörn *et al.*, 1997). The second variable is whether winter feeding has taken place at the den (yes or no) and the third variable is the phase of the rodent population density (high or low).

Surprisingly, the supplementary feeding had a strong significant effect on the number of reproductive events in the Helags area (Table 4), but the rodent cycle was contributing as well. Red fox culling had a significant effect when it was treated separately (marginal χ^2=4.22, p=0.04; Table 4), but when looking at the combined effect of red fox hunting and winter feeding, there is a strong effect but the effect of hunting without feeding disappear (partial χ^2=0.33, p=0.56; Table 4, Figure 7.).

Table 4. There were significant effects of rodent phase, feeding and hunting on the reproductive events in the Helags area in a log linear statistical analysis.

Associations	Partial X^2	P	Marginal X^2	P
Rodent phase (high-low)	5.84	0.016	4.85	0.028
Hunting vs Feeding	6.49	0.010	10.24	0.0014
Hunting (yes-no)	0.33	0.56	4.22	0.040
Feeding (yes-no)	32.5	0.0000	35.2	0.0000

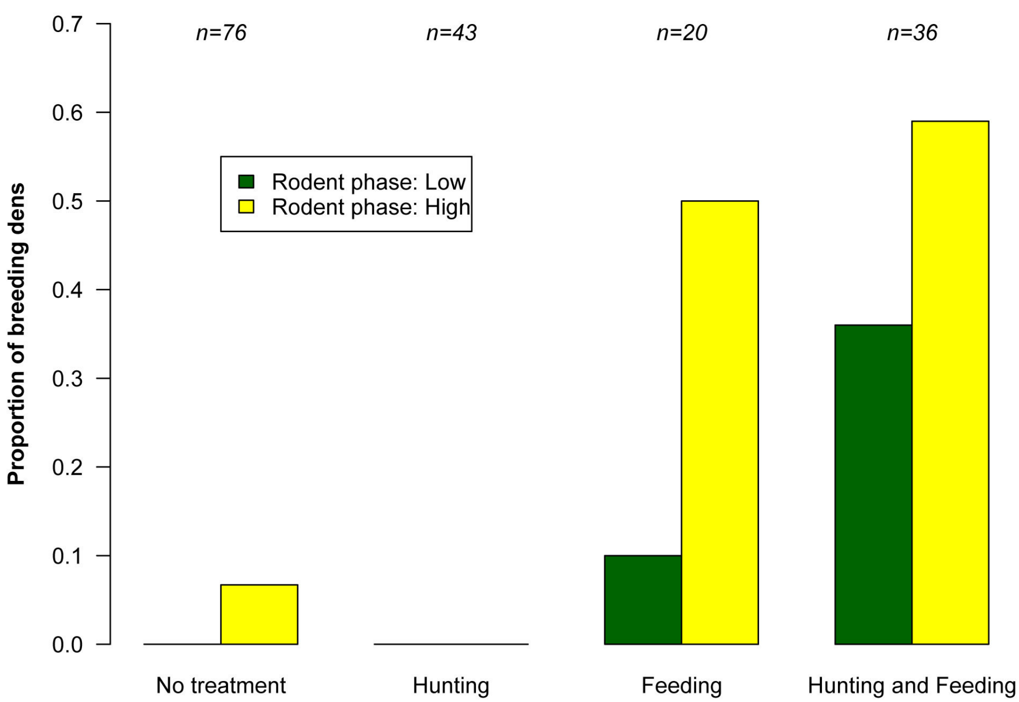

Figure 7. The proportion of breeding dens dived into the different treatment groups: no treatment, only hunting, only feeding, vs. hunting and feeding. The light bars show cases with a high rodent population phase whereas the dark bars show cases with high rodent phase.

For litter size at weaning, we found a significant effect of supplementary feeding during the winter (Figure 8; F(1,22) = 6.60, p=0.017) with about twice as many cubs at dens with extra food compared to control dens. There was also a tendency that the phase of the rodent cycle had an effect (p=0.06), but we saw no effect of hunting (p=0.54; Table 5). We also tested if a reproduction previous year at the same den had an effect which could have indicated that maternal quality or territory quality was important, but found no effect (p=0.46).

Table 5. The effect of hunting, feeding, rodent phase and reproduction last year on arctic fox litter size.

Source of variation	SS	Df	MS	F	p
Feeding (yes-no)	51.6	1	51.6	6.60	0.017
Rodent phase (high-low)	29.6	1	29.6	3.79	0.064
Reproduction last year (yes-no)	4.4	1	4.4	0.57	0.459
Hunting (yes-no)	3.1	1	3.1	0.39	0.538
Error	172.0	22	7.8		0.064

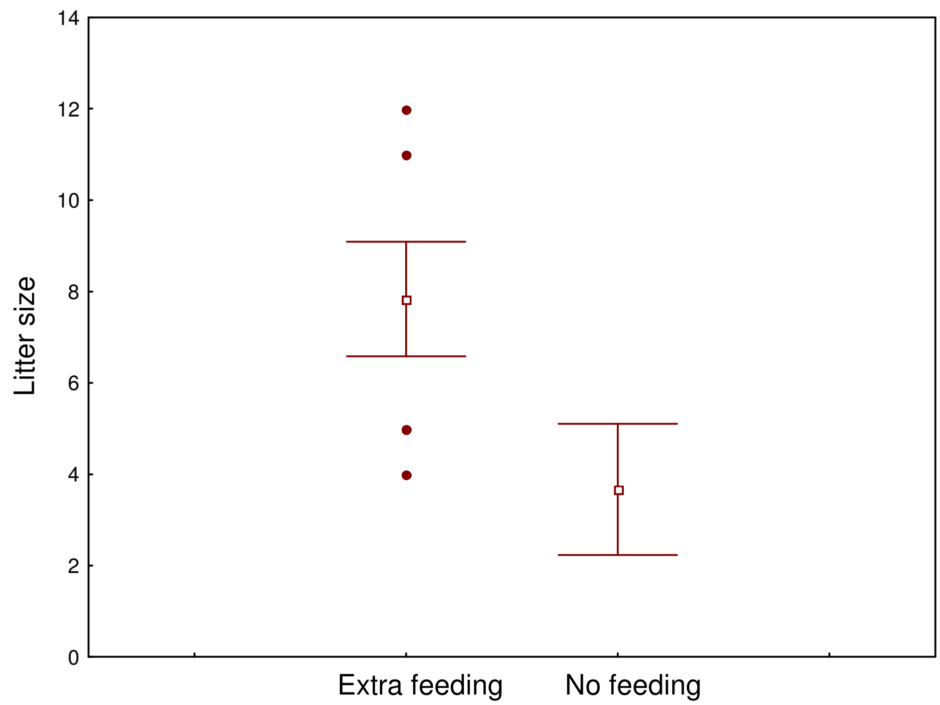

Figure 8. Arctic fox litter size ±SE in relationship to the experimental supplemental feeding, F(1,22) = 6.60, p=0.017.

Behavioural response

We have earlier showed that arctic foxes avoid red foxes during reproduction (Tannerfeldt *et al.*, 2002). Genetic analyses on faecal samples (Dalén, Götherström & Angerbjörn, 2004) were used to determine the spatial and temporal distribution of arctic and red foxes on the mountain tundra. An initial study (Dalén *et al.*, 2004) found that red foxes inhabit mountain areas of intermediate altitude during both summer and winter. Arctic foxes inhabited the same altitudes as red foxes during winter, but seemed to move to higher elevations during summer (Tukey *post-hoc* test p = 0.01; Figure 9.).

One prediction from this hypothesis is that arctic foxes should stay at the same, more productive, altitude if red foxes are absent. To test this, we investigated the spatio-temporal distribution arctic fox faeces in the Helags mountain area, where red foxes have been experimentally removed as part of the SEFALO+ conservation program. The results showed that there was no altitudinal difference between seasons in the area where red foxes were culled (Tukey *post-hoc* test p = 0.59; Figure 10.).

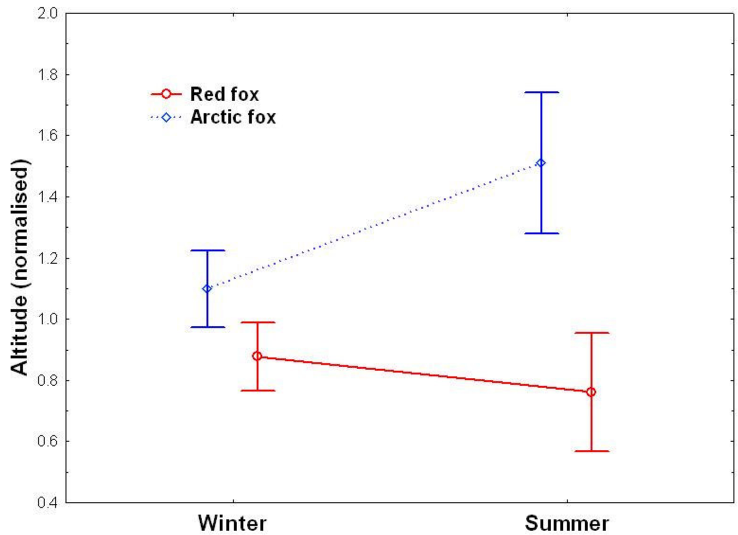

Figure 9. Mean relative altitude of arctic and red fox faecal samples in winter and summer. Altitude estimates from different mountain regions in Sweden were normalised to control for latitudinal differences among regions. Faeces from red foxes were found at the same altitude during winter and summer, whereas arctic fox faeces were found at higher altitudes during summer than winter.

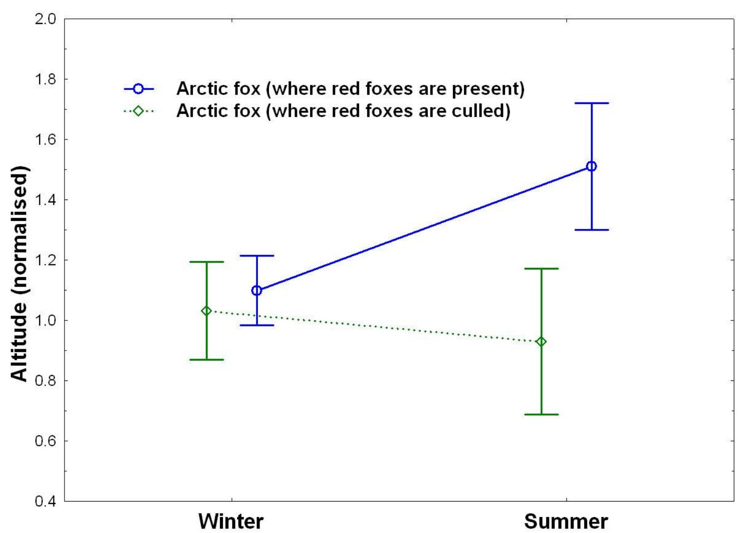

Figure 10. Mean relative altitude of arctic fox faecal samples in winter and summer, divided between areas where red foxes are present and where they have been experimentally removed. Altitude estimates were normalised as described in Figure 1. In areas where red foxes have been removed, arctic foxes stayed at the same altitude between seasons.

DISCUSSION

Effects of red fox hunting

Red foxes are twice the size of arctic foxes and they have about twice the size of home range as well. Further, the are known do be dominant over arctic foxes (Rudzinski *et al.*, 1982; Schamel & Tracy, 1986) and even suggested to work as a biological control (Bailey, 1992). There are many studies supporting the view as red foxes dominating and suppressing arctic foxes (Hersteinsson & Macdonald, 1992; Linnell, 1999a; Schmidt, 1985; Tannerfeldt *et al.*, 2002). However, there are no studies investigating demographic effects of competition between these two canids.

The SEFALO+ project focused on conservation actions to increase the viability of the Fennoscandian arctic fox. But, one of the tasks has also been to evaluate the actions for future management of the population. For an evaluation of the different actions, a robust field experimental with independent areas and different treatments is warranted. Factors like population size at start, climate and prey density should be reasonable equivalent in these areas to be able to evaluate the implemented actions. However, a robust experimental design has not been possible to obtain due to a trade off between conservation and evaluation. We have used supplemental feeding and red fox culling as an effective way to increase the number of arctic foxes in all areas. However, in Helagsfjällen we have been able to monitor actions and arctic foxes in a detailed manner in a local scale. This has given us the opportunity to analyse what effect the two actions have both separately and combined.

The local scale experiment in Helagsfjällen showed a clear response on red fox hunting. At the arctic fox dens where we decreased the abundance of red foxes we had significantly more arctic fox litters. We know from personal observations and from other studies (Frafjord, 1989; Tannerfeldt *et al.*, 2002), that red foxes sometimes kill adult arctic foxes but especially cubs. However, it is difficult to evaluate how often this is and what effect it can have on the arctic fox population. In our data, we could not detect any effect from red foxes on litter size and this suggests that such behaviour have no direct demographic effect although it can have a considerable fear effect. Furthermore, genetic analyses of faeces showed a temporal shift in arctic fox distribution due to red fox presence. One explanation to this pattern is that the threat from interactions with the dominant red fox varies between seasons. Therefore arctic foxes are forced to retreat to higher elevations during summer to reduce the risk of red fox predation on their cubs (Dalén *et al.*, 2004). So our results suggest that red foxes have a strong effect on arctic fox reproduction, but probably mostly due to a fear effect. Still, conservation actions with red fox control give positive effects on the arctic fox population, partly since it allow arctic foxes to breed at lower, and thus more productive, altitudes.

Effects of supplemental feeding

Earlier studies have demonstrated positive effects of supplemental feeding for arctic foxes with increasing number of reproductive females and number of litters (Angerbjörn *et al.*, 1991) and an increase in juvenile survival (Tannerfeldt *et al.*, 1994). In addition to this we also found a strong effect of supplemental feeding on the litter sizes. There are many studies showing the strong effect of maternal physical condition on litter size in canids (e.g. (Tannerfeldt *et al.*, 1998)) so it is not surprising to find that the supplementary feeding also affected arctic fox litter size. Our data also demonstrates that the amount of food that we have provided have been appropriate to reach the positive effect on the arctic foxes. The abundance of natural food, i.e. rodent density, would probably also have effects if it could be tested on a more detailed scale. We have only classified years with low vs. high rodent abundance.

Combined effects of feeding and hunting

The number of reproductive events was affected by red fox culling when treated the management actions separately. However, looking at the combined effect of red fox hunting and winter feeding, there was a strong effect but the effect of hunting without feeding disappeared. Thus, hunting works only together with winter feeding, but feeding alone has also an effect, probably in absence of red foxes. This suggests that red foxes affect arctic fox reproduction through exploitative competition rather than interference competition or through intraguild predation. Further, our results on the regional scale, including the larger part of the distribution range, also supports the combined effect of red fox hunting and supplemental feeding during the winter. We had positive effects in several areas and especially in the two areas where we have managed to keep intensive actions during several years.

Management implications

The SEFALO+ project have shown that extensive conservation actions can be an important tool to save the endangered Fennoscandian arctic fox population. In areas where intensive and continuous actions have been performed the number of litters has been doubled during a small rodent cycle, i.e. three to four years. It is however of major importance to disseminate the results to be able to implement the most efficient actions in the future. One of the most important standpoints is that winter feeding must be combined with red fox culling. The culling should be performed to avoid attraction of red foxes into inhabited arctic fox territories. If culling is not performed, the effect of winter feeding can be reversed and even have a negative effect on arctic foxes. Further, to avoid attraction of other carnivores, like the wolverine, lynx, raven and other raptors that also are potential threats to the arctic fox, feeding has to be carefully applied. For feeding with commercial dog pellets, it is important to built feeding stations that reduce the possibilities for other species to reach the food. Several county rangers have built and tested their own feeding stations with good results. When using carcasses for supplementary feeding, it is important to hide the food to avoid attracting other carnivores, for example by digging it under the snow (at least 1 m). Putting carcasses or meat directly at the dens, without hiding it, can be negative for the arctic foxes by attracting for example golden eagles (observed to kill arctic foxes).

Another issue connected to feeding is the location and how many feeding stations that should be used in an area. The goal during the SEFALO+ project has been to put supplementary feeding stations in connection to all inhabited dens. This can be very difficult since breeding pairs often move between several dens. In the Helagsfjällen and Borgafjäll areas a larger number of dens have been fed than the number of inhabited dens. However, this enables arctic foxes to seek food in a natural way and to move between dens, further, it can also give juvenile dispersing arctic foxes a chance to settle in new areas. The feeding using carcasses can be in conflict with the interest of reindeer management since it might attract other carnivores such as the wolverine. It is there important to keep a discussion between the county rangers and the reindeer herders to avoid future conflicts.

The arctic fox in Fennoscandia is spread over a vast area and they are often far away from human settlements. For both logistical and economical reasons it is thus difficult to implement intensive actions in the whole distribution area. An alternative might therefore be to channel extra resources to core areas of the arctic fox. A positive population trend in such core areas will then hopefully have a positive effect on more remote areas and on the Fennoscandian populations as a whole. Before starting large scale actions, however, it is important to investigate if there are enough number of arctic foxes for a population increase. If not, translocation of arctic foxes might be necessary (Dalén & Angerbjörn 2007) in combination with other actions.

Intensive conservation actions can increase the numbers of arctic foxes and thus reduce the risk that the Fennoscandian population go extinction. However, conserving threatened specie is a long time obligation that must span over several years. Even though intensive actions are implemented, most of the demographic parameters will still follow the small rodent cycle with high survival and strong reproduction during peaks every 3-4 year. If for example actions start with one litter, it will then take a minimum of nine years of actions to reach eight litters, if the number of litters can be doubled between every rodent peak as our data suggests. We would like to stress that actions are important during all phases of the rodent cycle. During low rodent years intensive support will increase adult surival and during increase and peak years actions will increase reproductive output with both more and larger litters. During crash years adult survival is also important but actions can also increase the possibility for juvenile foxes to settle down in new areas.

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Appendix

Figure 1. Feeding station for commercial pellets (Photo: Tomas Meijer)