

# The arctic fox population in Finnish Lapland during 30 years, 1964–93

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We have monitored the number of arctic foxes and microtine rodents in northern Finland for 30 years. Arctic fox densities were estimated by inventories at den sites, and microtine abundance by snap trapping. Time series analyses showed that the arctic fox population fluctuated widely but always close together with the microtines in a five year cycle. However, there was no time lag in the numerical response of foxes on microtines. The strong dependence on microtines was confirmed by analyses of faecal droppings and food remains at dens. In summer time microtines consisted in average of 45% of the diet and reindeer 30%, but during winters reindeer was the most important food source with 45% compared to 15% for microtines. There was a surprising positive correlation between number of voles and reindeer carcasses, suggesting competition or alternatively an external correlation from e.g. weather. Mean litter size of the arctic fox was also highly dependent on microtine abundance but decreased during the study period despite that food resources had not changed. Further, when microtines had high densities during two consecutive years, arctic foxes only responded to the first year. A feeding experiment resulted in an increase in number of red foxes but had no or little effect on arctic foxes. So, it is difficult to single out one explanation to the decline and second year effect. Food was probably not involved and we do not know if diseases and parasites have been involved. However, both competition and predation, primarily from the red fox, may be responsible together with climatic or weather changes.

## 1. Introduction

The arctic fox (*Alopex lagopus*) population in Fennoscandia is very small at present and has been so for around 60 years, in spite of total protection for over half a century (Hersteinsson

et al. 1989). The cause of the initial decline from a healthy, harvestable furbearer population to one threatened with extinction is believed to be overhunting (Haglund & Nilsson 1977). Further, a new threat to the population, sarcoptic mange, has recently (Ericson 1984) been identified in

arctic foxes in Fennoscandia. However, the low number per se is probably the most important threat to extinction.

Arctic foxes have been protected by law in Finland since 1940, but nothing is known of the population size prior to protection. Emigration of arctic foxes is known to have occurred, the last known 'invasion' into central and southern Finland took place 1908 (Pullianen 1965). The distribution of the arctic fox in Finland covers only the northernmost part of the country, the mountain region. The most abundant population with a continuous range inhabits the most north-western part of the Finnish Lapland, the only part of Finland that reaches the Scandinavian mountain range (Kaikusalo 1971). Arctic foxes seem also to be present in Utsjoki, NE part of Finnish Lapland, almost every year (Pullianen & Ala-Kotila 1982). In addition, in 1980's we have one observation of successful breeding on an isolated treeless mountain Naltiotunturi in the middle of eastern Lapland.

Violent fluctuations in the number of breeding pairs and litter sizes have been found, depending on the state of microtine populations (Kaikusalo 1982, Hersteinsson et al. 1989, Angerbjörn et al. 1991, Angerbjörn et al. 1995), supporting earlier reports that rodents are the most important constituent of the arctic fox's diet in Fennoscandia (Collett 1912, Zetterberg 1945). Ptarmigan and reindeer carcasses have also been reported as part of arctic foxes' diet in Fennoscandia (Collett 1912, Haglund & Nilsson 1977, Angerbjörn et al. 1994).

Several hypotheses have been put forward to explain why the Fennoscandian fox population has not recovered in spite of full protection, see Hersteinsson et al. (1989) for a review. These hypotheses can be placed in four different groups, those related to food (Angerbjörn et al. 1991), to competition and predation (Kaikusalo 1971, Schamel & Tracy 1986, Frafjord et al. 1989), to parasites and diseases, and those related to climatic changes (Hersteinsson & Macdonald 1992). However, there are also many likely combinations of these hypotheses.

We summarise 30 years' data on number of arctic foxes and number of voles in this study, and discuss some of the available hypotheses about regulation and limitation of arctic fox numbers.

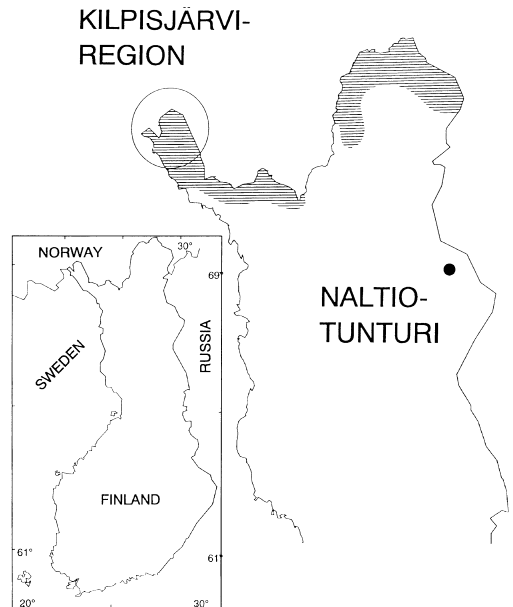


Fig. 1. The permanent distribution of the arctic fox in northern Finnish Lapland. The Kilpisjärvi region (the study area of this article) is encircled. The single denning observation at Naltiotunturi is shown separately.

## 2. Material and methods

The arctic fox can be found in all tundra areas above the tree line. We have monitored the arctic foxes in the Kilpisjärvi area in north-western Finland (69°N, 21°E; Fig. 1) with a varying intensity since 1964. In the beginning of the study, only a few dens were checked every year (1 to 7) and in some years no den was visited. However, one of us spent considerable amount of time during winters in the study area these years (1975–85) and we could thus confirm population estimates by the amount of arctic fox tracks in the snow. From 1985, however, between 15 and 27 dens have been checked every summer of the total 40 known dens. The number of known dens increased every year, although 17 dens have never been occupied during the study.

We visited the dens in July to August, but some times also during February and May. It was fairly easy to detect if a den was occupied or not during a visit in the summer. If no foxes were observed, other signs, as fresh scats or fresh digging, were used as an indication of foxes being present at the den. If occupied, we spent at least 24 hours of good observation possibilities to get an estimate of the minimum number of adult and juvenile foxes. It was always fairly easy to tell if a den was occupied by arctic or red foxes by the size of scats, hairs, or size of entrances. Litter sizes estimated by observa-

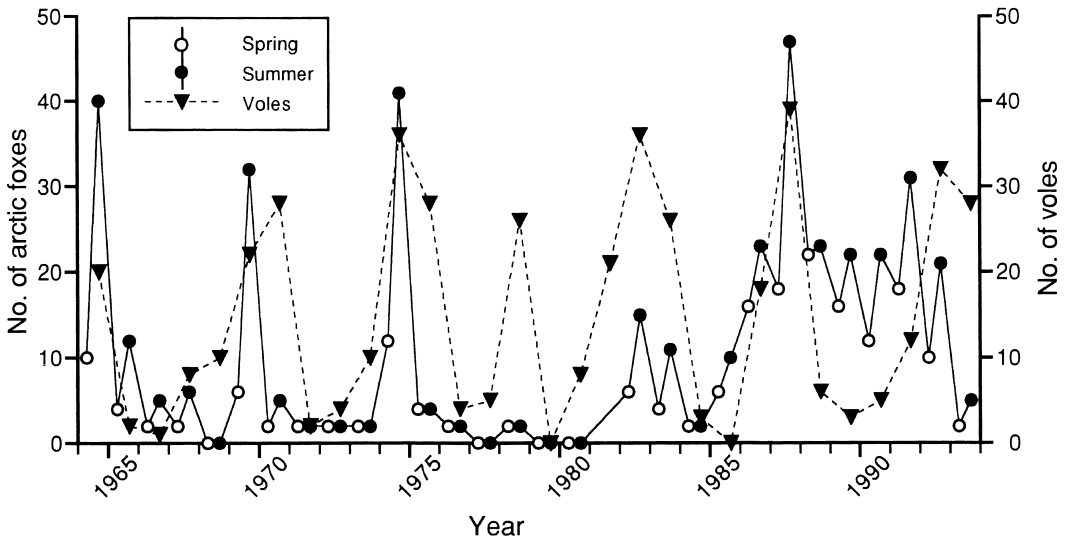


Fig. 2. Total number of arctic foxes at dens, with open circles showing spring numbers with only adult foxes, and closed circles showing summer numbers with an addition of juveniles. The relative number of voles (per 100 trap nights) are shown with filled triangles.

tions at dens must be considered to underestimate the real litter size. First, cubs appeared on the den at about 4 weeks of age and there is therefore an unknown mortality from birth. Second, it is very difficult to count all cubs playing and running around on a den. However, since the methods and time spent at each den was fairly constant, we assume the litter size measurement to be a fairly good indication of real litter size.

During the whole period (1964–93) we determined the availability of food resources in the study area with snap trapping of small mammals (Kaikusalo 1982, Kaikusalo & Tast 1984). Although areas both below and above the tree line were included in the trapping program, we have only used data based on trapping above the tree line in the Kilpisjärvi area. The data presented in this paper are thus not equivalent to those published elsewhere (Kaikusalo 1982, Kaikusalo & Tast 1984). We also counted the number of reindeer carcasses found during the same 50 km route every year from 1985. The food of arctic foxes has been analysed by identifying all the prey remains found at dens and by analysing scats collected at dens in all seasons. The scats and prey remains were collected in a very heterogeneous way. During 1987–88, the scats were collected at seven dens with 12 foxes present in the winter and in the summer on four dens with 16 foxes present. The prey remains at dens were collected from 1985–91. We therefore pooled all data on scats and food remains respectively. Thus, they therefore represent an average over several years. It is further known that lemmings are difficult to trap and easy to detect at dens, so we can not draw any conclusions about feeding preferences based on these samples.

To give support to the arctic fox population and to test some hypotheses regarding food (Angerbjörn et al. 1991, Tannerfeldt et al. 1994), we added supplemental food at six

dens during 1989 to 1993. From February to May whole or cut reindeer carcasses and frozen fish have been transported to the vicinity of six dens situated close to each other. The extra summer food we provided was dry commercial dog food.

### 3. Results

#### 3.1. Population densities of arctic foxes and voles

Fig. 2 shows the total number of arctic foxes at dens and the number of voles per 100 trapnights from 1964 to 1993. There were drastic fluctuations in arctic fox numbers over years and with a clear cyclicity. The vole population went through seven cycles of three to five years, with a striking correlation between number of voles and foxes. Analyses of autocorrelation for both number of foxes and number of microtines respectively gave a five year cycle (Fig. 3).

With these population cycles it is possible to test a pattern and exceptions from this pattern. First, an analysis of cross-correlation between number of foxes and number of voles (Fig. 4) show a significant correlation between the two, but there was no time lag in the numeric response of arctic foxes on vole numbers. Second, there is another striking

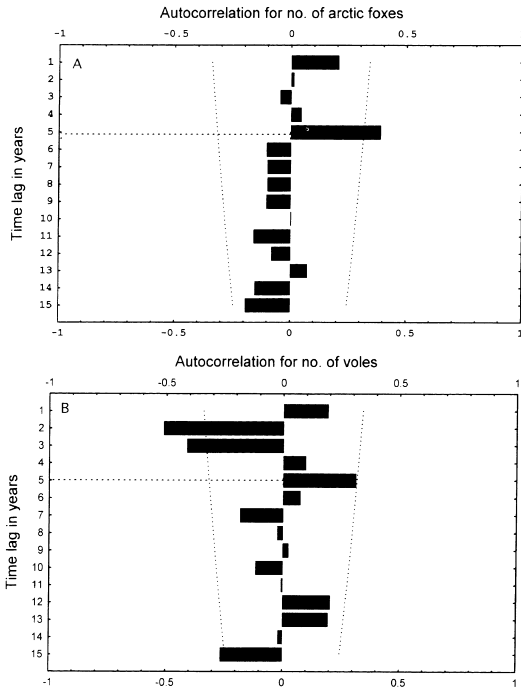


Fig. 3. Autocorrelation  $\pm 2$  S.E. for (A) number of arctic foxes and (B) number of microtines.

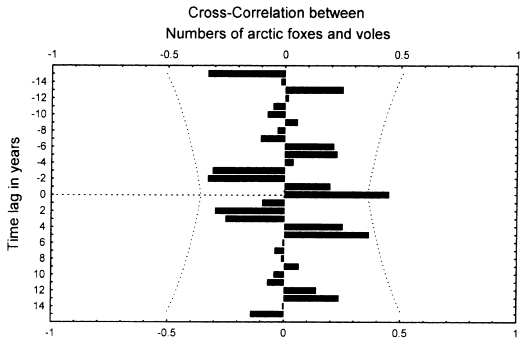


Fig. 4. A cross-correlation between number of arctic foxes and number of microtines showing no time lag.

pattern, in those cases when voles have a two year peak (1970, 1975, 1983, 1993) foxes only peaked in the first year. Third, during the vole peak of 1979, foxes did not respond at all. This vole peak was only four years after the last peak and there was no increase in vole numbers the year before the peak. Although only a few dens were inventoried in 1979, one of us spent considerable amount of time in the mountains those winters, and there were no tracks of arctic foxes, thus supporting the low

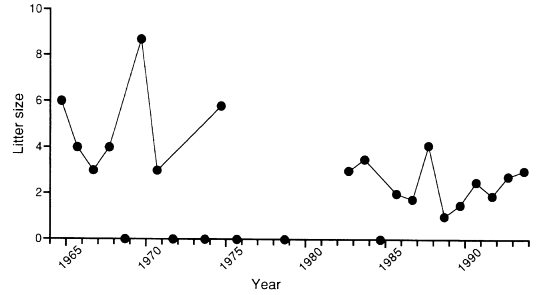


Fig. 5. Litter size at appearance outside the dens over time.

population estimate. The vole peak in 1993 was also without any response in fox numbers. Both these years had exceptional winter conditions with hard snow.

The mean litter size was closely related to the abundance of microtines with the same drastic shifts as fox numbers. However, mean litter size decreased during the study (Fig. 5), from 4.9 ( $n = 7$ ) before 1980 to 2.5 ( $n = 11$ ) after 1980, when we removed all years with no cubs ( $t = 3.52$ ,  $P = 0.03$ ). This decline was not concordant with microtine density.

### 3.2. Arctic fox diet

The diet of the arctic foxes was very much dependent on seasons. During winters they primarily consumed reindeer meat, probably as carcasses. Of the winter scats, 68% contained reindeer remains, with microtines and fish on 28 and 20% respectively (Fig. 6). This basic picture was supported by the data on food remains at dens. Here, 44% of all 55 food items found during winter were reindeer, while 15 and 26% were microtines and fish remains respectively. Of the microtines, seven were lemmings and one *C. rufocanus*, and of the fish, 11 were burbots *Lota lota* and 3 *Coregonus/Thymallus*. The burbots were abandoned by fishermen on ice. Ptarmigan *Lagopus* sp. and mountain hare *Lepus timidus* were also of some importance in the winter diet.

The summer diet was dominated by microtines (59% of the scats and 45% of the food items at dens) followed by reindeer (37 and 29% respectively, Fig. 6). Birds were found in 18% of both the scats and food remains, with passerine birds dominating (8 items) and 3 unidentified waterfowls, 2 *Pluvialis apricarius*, 1 each of *Gavia arctica*, *Anas*

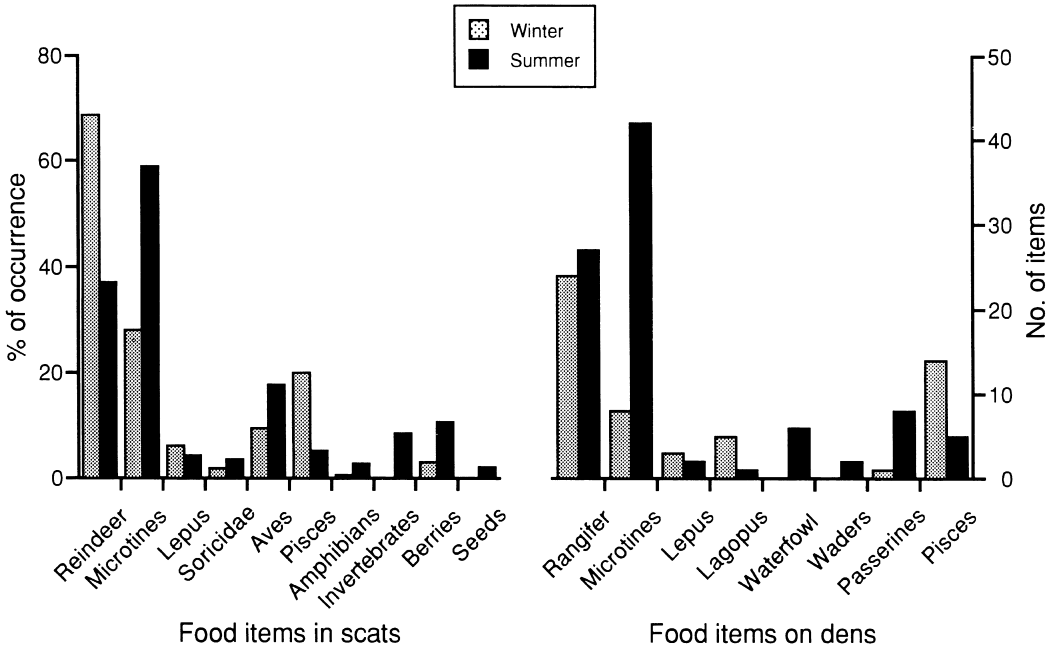


Fig. 6A–B. —A: Prey remains in scats, % of occurrence for different species. —B: Number of food items found on dens.

*platyrhynchos*, *Lagopus* sp. and *Corvus corvus*. Of the species of microtines identified at the dens, 24 were *Lemmus lemmus*, 11 *C. rufocanus*, 5 *Microtus oeconomus*, and 2 *M. agrestis*. This could be compared with the availability of the different species during the same period (Fig. 7). Clearly lemmings were found at the dens in a much higher proportion than they were trapped.

We have recorded different microtine species since 1985. *C. rufocanus* was dominating during the two peak years, 1987 and 1992, with a varying number of *C. rutilus*, *M. agrestis*, *M. oeconomus*, and *L. lemmus* (Fig. 7). The alternative food source, reindeer carcasses, was also estimated from 1985 during a 50 km standardised walk. The number of carcasses (Fig. 7) was surprisingly correlated with number of microtines ( $r = 0.67$ ,  $P = 0.046$ ). The reindeer mortality was higher during years of high microtine abundance than during years of low abundance.

### 3.3. The feeding experiment

To test how food availability was related to presence of arctic foxes, we added winter food to six

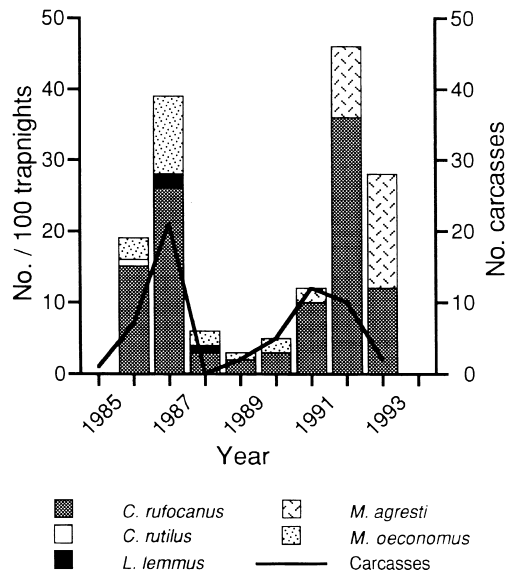


Fig. 7. Number of voles of different species per 100 trap nights and number of reindeer carcasses found during inventories from 1985–1991.

dens from 1989–93, plus summer food during 1992 and 1993. The feeding had no effect on the number of arctic foxes occupying dens. During

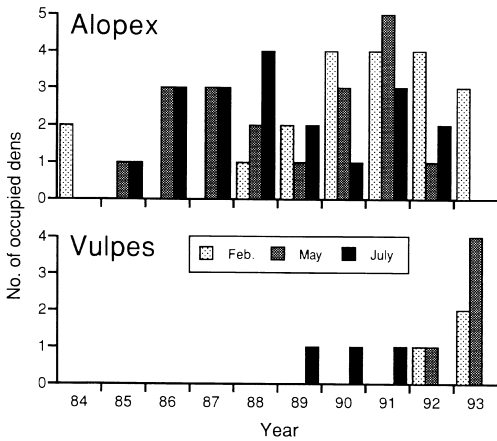


Fig. 8. The effect of supplementary feeding (from 1989), with occupancy of arctic and red foxes in February, May and July.

the control years (1984–88) at six dens, arctic foxes were present at 9 and 12 dens in May and July respectively (Fig. 8), whereas during the winter feeding experiment (5 years) at the same six dens, they were present at 10 and 8 dens during May and July respectively ( $\chi^2 = 0.63$ ,  $P = 0.43$ ). However, red foxes were never present during the control years before the feeding experiment started, but responded significantly to the feeding experiment and were present at 5 dens in May and 3 dens in July (0 vs. 5 binomial,  $P = 0.06$ ). The number of cubs produced in these dens followed the same pattern, with arctic foxes having 18 cubs during the five control years and 18 cubs during the feeding experiment. Red foxes, on the other hand, increased from 0 to 7 cubs during the experiment (binomial,  $P = 0.02$ ). It is difficult to evaluate effects of the summer feeding experiment, since it was only running during two years and parallel with the winter feeding experiment. However, red foxes were in one case occupying a den already in February 1993. Further, the 5 dens occupied by red foxes in May (i.e. before summer feeding started) were actually during the summer feeding years (Fig. 8). This strongly suggests that the effect was from winter feeding rather than from summer feeding.

#### 4. Discussion

The number of arctic foxes in the Kilpisjärvi region and the reproductive success depended

primarily on food supply, especially microtine rodents and reindeer carcasses. The carrying capacity for this arctic fox population was thus very closely related to abundance of microtines as it has been in all areas where arctic foxes depend primarily on microtines (Macpherson 1969, Bannikov 1970, Østbye et al. 1978, Hersteinsson et al. 1989, Angerbjörn et al. 1995). In the absence of big predators, as in the Kilpisjärvi region, the supply of carcasses depends on whether winter grazing and calving of reindeer takes place in the vicinity of fox dens, and how unfavourable weather and other conditions are during calving.

The basic pattern for population fluctuations for both microtines and arctic foxes was a five year cycle with a very close timing between the predator and its prey. Arctic foxes have been reported to follow a four year cycle in other areas (Norway, Johansen 1929; Canada, Finerty 1980; Sweden, Angerbjörn et al. 1995). These differences in cycle length are most likely due to differences in the vole cycles and illustrate how important voles and lemmings are to arctic foxes. Hanski et al. (1991, 1993) showed microtine cycle length to be five years at Kilpisjärvi, and in all Fennoscandia related to latitude. They presented a model on voles where specialist predators with a time lag could cause cyclicity or chaotic fluctuations in vole numbers. However, arctic fox numbers showed no detectable time lag to the increases in microtine numbers. Arctic foxes can thus not be fitted into that model. It is also difficult to separate a specialist from a generalist predator, but about 60% to 100% of the arctic fox summer diet consisted of microtines (e.g. Frafjord 1995). A generalist predator should according to models (Hanski et al. 1991, 1993) have stabilising effects on microtine fluctuations. According to the division in generalist and specialist predators by Andersson and Erlinge (1977), arctic foxes in Fennoscandia are more resident specialists than generalists. However, microtine numbers declined independent of arctic fox density. So, this seems to be a classic example of a predator being dependent on prey species, but where the prey species are independent of the predator.

During the last 10 years we found that *C. rufocanus* was the dominating species and that other

species varied in their occurrence. This is in agreement with other studies of vole population dynamics on the tundra (e.g. Henttonen et al. 1987, Oksanen & Oksanen 1992). The abundance of the other major food source for arctic foxes, reindeer carcasses, was surprisingly positively correlated with the number of microtines. This implies that reindeer mortality was higher during microtine peak years and can be explained in three alternative ways. It is possible that reindeer and voles or lemmings on the tundra actually are competitors. Alternatively, weather factors as e.g. snow depth (Henttonen and Kaikusalo 1993), or vegetation cycles (Laine and Henttonen 1983), can affect microtines positively and reindeer negatively, thus generating the close correlation. A third explanation could be a predator switching between microtines and reindeer, but in such a case we would expect a time lag in the relationship. Theoretically a parasite could also produce the observed correlation, but no such parasite is known. If this relationship between reindeer and microtines is common, it certainly needs to be studied in detail.

When we added supplemental food, single foxes or pairs stayed at the dens despite the poor supply of natural food. Breeding success did not improve, however, maybe because the supplemental feeding finished in early June due to transportation problems. On the other hand, 1 or 2 red fox litters have yearly been raised in these dens at the same time. So, our feeding made it possible for red foxes to occupy areas higher up on the tundra, areas that previously were dominated by arctic foxes. Red foxes are almost twice the size of arctic foxes and they also have larger home ranges and higher energy demands (Hersteinsson & Macdonald 1982, 1992). At medium or low food abundance it is probably impossible for red foxes to reproduce and survive on the tundra, but with our extra feeding, this became possible. This is a good example how important it is to have good control groups even for conservation attempts. So, if extra feeding should be used as a conservation method, it ought to be combined with red fox control. In Sweden, supplemental food increased both number of arctic foxes occupying dens, litter size, and juvenile survival (Angerbjörn et al. 1991, 1995, Tannerfeldt et al. 1994), suggesting that arctic foxes in Sweden were more food stressed. However, red foxes increased in that study as well (Angerbjörn unpubl.) with

negative effects on arctic foxes.

Litter size estimates have been based on the number of young observed at dens. There is an alarming decreasing trend in the litter size. This difference was not related to any observable trend in microtine fluctuations or abundance of reindeer carcasses. Such a decrease in litter size was also observed in Sweden, but there together with a decrease in microtine numbers (Angerbjörn et al. 1995). So, there are two puzzling observations with litter size and arctic fox numbers. The first is the decrease over time despite good abundance of food. The second is the low litter sizes the second year of a two-year high. If we go back to the alternative hypotheses about the decline in arctic fox numbers, we have the alternatives of factors related to 1) food, 2) competition/predation, 3) parasites or diseases, 4) climatic changes (Kaikusalo 1971, Frafjord et al. 1989, Hersteinsson et al. 1989, Angerbjörn et al. 1991, Hersteinsson & Macdonald 1992). (1) The food hypothesis seems not to be applicable for this population, since no decline in number of microtine or carcasses was detected. (2) We know that the red fox can be both a competitor and predator to the arctic fox (Frafjord et al. 1989, Hersteinsson & Macdonald 1992). The relationship between the red and the arctic fox was illustrated in the feeding experiment (see above). If the red fox has a one year time lag to an increase in microtine numbers on the tundra, this would confer that intraguild competition with the arctic fox would be much higher the second year of a peak than the first. Any other predators dependent on microtines (such as mustelids and birds of prey) with a time lag (Hanski et al. 1991, 1993) could have the same effect. Further, it is possible that the decline in fox litter size also was related to an increase of intraguild competitors especially the red fox. However, we could not detect any increase in red fox number over the years except during the feeding experiment. (3) The effect of parasite or diseases was not tested, and certainly needs further investigation. There is a possibility that parasites or diseases might build up in numbers during a first year to get an outbreak the second year of a two year high. (4) Hersteinsson & Macdonald (1982, 1992) discussed the effect of climatic changes on the competition between the two fox species. They explained the earlier decline in arctic fox number as an effect of climatic change giving red foxes opportunities to increase their dis-

tribution to tundra areas. However, the climatic change took place between 1940 and 1965 and the decline we observed was from 1980. It is unclear if the warming continued after 1980. Further, the second year-high effect could not be related to long term climatic changes, but maybe to specific weather situations. For example, the winter conditions in 1979 and 1993, years with high microtine abundance but few foxes, were exceptional with very hard snow that made it difficult for foxes to dig.

The conclusion is that it is difficult to single out one explanation to the decline and second year effect. Food was probably not involved and we don't know if diseases and parasites have been involved. However, both competition and predation, primarily from the red fox, was probably responsible together with climatic or weather changes. Our recommendations regarding the conservation of arctic foxes are that further studies should concentrate their efforts to conduct field experiments on parasitic treatments and reduction of red foxes.

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