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ORIGINAL PAPER

The Arctic fox (*Vulpes lagopus* L.) on the Kola Peninsula (Russia): silently disappearing in the mist of data deficiency?

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Abstract

The Arctic fox (*Vulpes lagopus* L.) population on the Kola Peninsula occupies an intermediate, and potentially connecting, position between foxes living on the Scandinavian Peninsula and populations further east in Russia, but very little is known about the status of this population. Here we summarize data from the literature, forgotten archival sources about research in the first half of the twentieth century, and the results of several independent expeditions undertaken over the past two decades. These materials include data on fur harvesting, incomplete monitoring data from official winter track counts of game animals, local knowledge, and our own observations. Our research revealed the extremely poor state of the Arctic fox population on the Kola Peninsula. According to our estimates, the current population is likely isolated and consists of no more than a few dozen adults. The fur return data, together with long-term data on small rodent abundance, suggest that irregular and fading out lemming cycles were a major driver of the Arctic fox population decline. The thorough research from the 1930s contrasts strongly with the lack of interest in studying and monitoring the population in recent decades, which is not even listed as a threatened species in the regional Red Data Book. In fact, the work performed here filled a more than a half-century gap in the study of the population and allowed us to determine the urgent need to resume research and immediately take active measures to protect and promote the recovery of the species in the region.

Keywords Arctic fox · Kola Peninsula · Winter track counts · Population

Introduction

The Arctic fox is a widespread circumpolar species endemic to Arctic and mountain tundra landscapes (Heptner et al. 1967; Angerbjörn et al. 2004). It is rather well studied all over the Arctic and has been studied in Russia for more than a century. For instance, many aspects of the biology of Arctic foxes on Wrangel, Mednyi, and Bering islands have been studied in detail (Ovsyanikov 1993; Zagrebel'nyi 2000; Goltsman et al. 2003). Several extensive studies about Arctic foxes throughout the Russian Arctic have also been published during the time when this species was an important hunting resource. Nowadays, systematic monitoring of this key Arctic predator is carried out in many parts of its range. However, there is little monitoring in the Russian Arctic currently, with the exception of Yamal (Ehrich et al. 2017) and islands in the Bering Sea (Goltsman et al. 2005), and the knowledge about the different populations is highly variable. Thus, nearly nothing is known about the present status of the westernmost Arctic fox population in Russia on the Kola Peninsula. This region is particularly interesting because it is biogeographically a part of Fennoscandia, where the Arctic fox is Critically Endangered (Angerbjörn et al. 2013), but has a very different history of human use and natural resource management. In addition, Artic foxes on the Kola Peninsula may be important in connecting the endangered Fennoscandian population and the abundant populations further east in Russia.

On the Kola and Scandinavian Peninsulas, the Arctic fox has been a typical species of tundra areas for at least the past 5–7 millennia (Dinesman 1968; Frafjord and Hufthammer

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1994). Although the population was quite abundant in the nineteenth century, it declined dramatically in Fennoscandia early in the twentieth century, because of unsustainable harvesting when fur prices were very high. The species was protected in Sweden in 1928, in Norway in 1930, and in Finland in 1940, but has not recovered (Siivonen 1975; Hersteinsson et al. 1989; Kaikusalo and Angerbjörn 1995; Kaikusalo et al. 2000). On the contrary, the population decrease continued in all three countries, despite the hunting ban (Angerbjörn et al. 2013). In 2000, the Fennoscandian population was reduced to 30–60 adult animals and the species was classified as Critically Endangered in the region (Angerbjörn et al. 2004; Dalén et al. 2006). At that point, a comprehensive conservation and research plan was initiated, which has reversed the negative trend (Angerbjörn et al. 2013; Landa et al. 2017). The two major threats for Arctic foxes in Fennoscandia today are the presently erratic cycles of the Norwegian lemming (*Lemmus lemmus*), attributed to warmer and less stable winter weather, resulting in lower lemming abundance, and the expanding populations of red fox (*Vulpes vulpes*), which is a superior competitor (Angerbjörn et al. 2013; Ims et al. 2017). Elmhagen et al. (2017) pointed out that subsidies from increasing human activity, in addition to climate change, play a key role in the expansion of red foxes into the low Arctic. In eastern Finnmark, Norway, the area in Scandinavia closest to the Kola Peninsula, semi-domestic reindeer (*Rangifer tarandus tarandus*) have been highlighted as one of the potential drivers of red fox expansion into the mountain areas, which previously were some of the last strongholds for Arctic foxes (Killengreen et al. 2012; Ims et al. 2017). In ecosystems without resource subsidies for red foxes, the two species can coexist at stable proportions over longer periods of time (Gallant et al. 2014).

On the Kola Peninsula, the former range of the Arctic fox encompassed the entire Murman coast of the Barents and White Seas, as well as inland areas, including mountain tundra (Pleske 1887). Further west, the spatial distribution and abundance of the species declined, because of unsustainable harvesting in the first part of the twentieth century (Dubrovskii 1939). Arctic fox hunting for fur was indeed an important resource for local people. In the beginning of twentieth century, Arctic fox furs were the third most valuable fur in the Murmansk region (after red fox and European pine marten (*Martes martes*)), but they were only eighth in the number of skins delivered, illustrating the relatively low abundance of the species already at that time (Semenov-Tyan-Shansky, 1982). Harvesting of Arctic foxes continued with varying intensity until the end of the 1990s. The significance of the Arctic fox for the national economy was the reason for organizing large-scale surveys throughout its range in the former USSR, and research projects aimed at understanding the causes of population fluctuations. Early in the previous century, the basic ecology and biology of the species, including limiting factors and competition with red foxes and other carnivores, was studied also on the Kola Peninsula. Researchers observed notably that red foxes occupied the dens of Arctic foxes, especially on the coast of the Barents Sea, and concluded that this was the reason why the Arctic fox no longer denned in the coastal zone (Zolotov 1933; Dubrovskii 1939). This research resulted in recommendations on how to manage the Arctic fox and increase its population, including the following: 1. Supplemental feeding in the denning area, 2. Constructing shelters and artificial burrows, 3. Controlling competitors of the Arctic fox, including the complete extermination of the red fox in the Arctic fox area, 4. Interventions against parasites (den disinfection), and a number of other activities, such as releasing blue, captive-bred individuals (Zolotov 1933, 1940; Dubrovskii 1939). Many of these recommendations are very similar to the actions taken to rescue the population in Scandinavia (Angerbjörn et al. 2013), but they were never implemented on the Kola Peninsula.

In the second part of the last century, the continuing shrinkage of the Arctic fox range on the Kola Peninsula has been documented by several authors (e.g., Danilov et al. 1979). In the mid-1960s, the population was estimated to be around 1000–2000 animals (Heptner et al. 1967). As in northern Fennoscandia, the decline accelerated towards the end of the century (Ims et al. 2017). In 2002, Dalén et al. (2002) estimated that there were only around 40 adult Arctic foxes left on the Kola Peninsula. Consequently, in the 2003 edition of the list of threatened species of the Murmansk Region, the Arctic fox was included among the species requiring special attention, but not in the list of threatened species (Red Data Book 2003). The chapter list also highlighted that there is a lack of data about the status of this species in the region. In the last edition, surprisingly, the Arctic fox was one of the species excluded from the list (Red Data Book 2014).

It is obvious that there is presently a lack of information on the status of the Arctic fox population on the Kola Peninsula. We have first investigated the change in the species' status over the last 100 years, based on available fur return data. Then we assessed the current state of the Arctic fox using all available data obtained during field work by researchers since 2000. We also present information available about the two most important drivers of Arctic fox population declines that have been identified in Fennoscandia, lemming population dynamics, and the expansion of red foxes (Elmhagen et al. 2000; Angerbjörn et al. 2013; Ims et al. 2017). Moreover, because human activities, including reindeer herding, have been hypothesized to contribute to red fox expansion (Elmhagen et al. 2017), we have discussed the potential role of regional differences in anthropogenic influences and the availability of subsidies. The main objective of this study is thus to assess the state of the species on

the Kola Peninsula and to evaluate the level of knowledge about this regional population.

Material and methods

Study area

The Kola Peninsula is a part of the Murmansk Region, located in Northwestern Russia, between 66°N and 70°N (Fig. 1). Landscapes of the peninsula are very diverse. The Khibiny Mountains occupy the western part of the peninsula and are surrounded by forest. To the east of the Khibiny Mountains, the Lovozero Tundras are an area of elevated landforms. The Murmansk Region is situated at the border of two biomes, the boreal forest and the Arctic tundra. Tundra occupies a coastal area 30–60 km wide in the north and northeast and a very narrow seaside stripe in the south of the peninsula, as well as the mountain areas. The width of the forest-tundra belt varies from 20–120 km and represents about 20% of the territory of the Murmansk Region (Semenov-Tyan-Shansky 1982). Using data from a survey of local residents, hunters, and the results of field work, Zolotov (1933) identified several areas in the tundra zone of the Murmansk Region, including the northwestern and eastern parts of the Kola Peninsula, as particularly suitable for the Arctic fox (Fig. 1). The eastern part, the Yokanga-Ponoy tundra, has historically been considered the most suitable area for Arctic fox denning (Zolotov 1933; Dubrovskii 1939; Zolotov 1940; Danilov et al. 1979). In this area, Zolotov (1933) highlighted four sites with the highest densities of Arctic foxes and breeding dens (Fig. 1). Interestingly, even some place names in this area are associated with the Arctic fox, for example, the brook Pestsovyy (the Arctic fox brook) (Fig. 1).

Due to the influence of the Gulf Stream, the climate on the Kola Peninsula is mild compared to other northern regions. According to long-term observations, the average temperature of the warmest month (July) varies from 10 °C to 14 °C in the central part and from 9 °C to 11 °C on the coast (Koroleva 1994). Winter conditions prevail for 8–9 months and the average temperature of the coldest month (February) is –12.3 °C in the central part of the peninsula and –11 °C on the White Sea coast. The annual sum of rainfall is about 600–700 mm in the Khibiny Mountains and 300–400 mm in the central part and on the coast. Most of

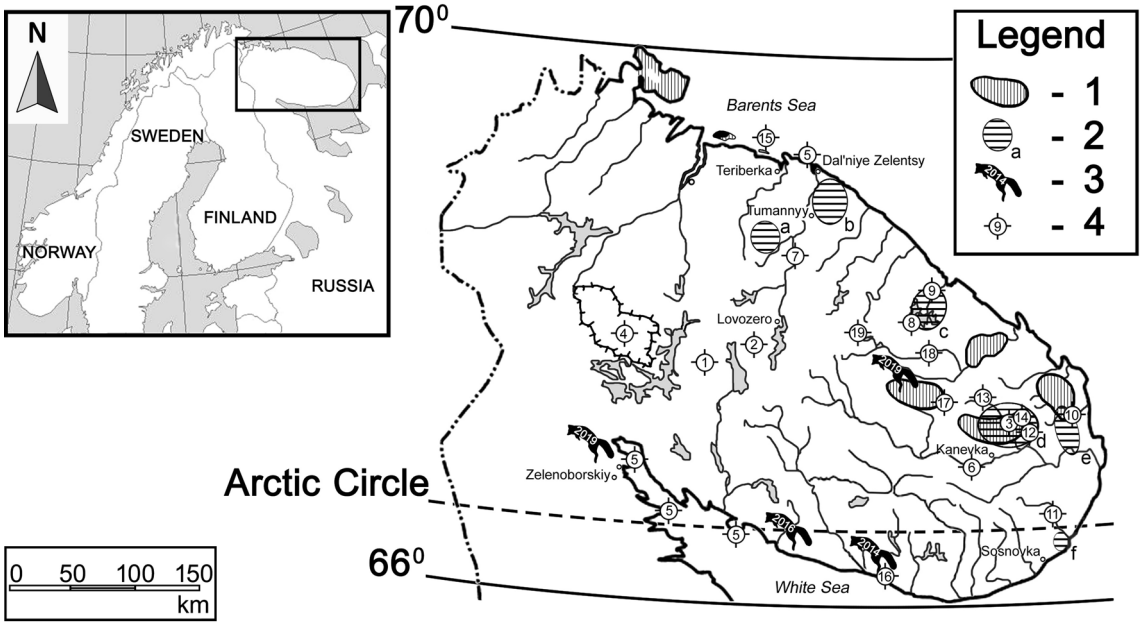

Fig. 1 The study area on the Kola Peninsula, northwestern Russia: 1—main denning area by Zolotov (1933); 2—territories of field surveys in 2002–2019; 3—single observation of the Arctic fox *Vulpes lagopus* during the period 2014–2019; 4—geographical locations mentioned in the text: 1—Khibiny Mountains (67°43′55"N, 33°41′10"E), 2—Lovozero tundra (67°48′54"N, 34°39′50"E), 3—Brook Pestsovyy (67°17′40"N, 39°38′00"E), 4—Lapland Nature Reserve (67°55′22"N, 31°54′38"E), 5—Kandalaksha Nature Reserve (several separately located territories), 6—Ponoy River (67°06′03"N, 39°27′20"E), 7—Serebryansky water reservoir (68°52′58"N, 35°35′16"E), 8—Lake Enozero (68°06′17"N, 37°56′24"E), 9—Varzina River (68°14′10"N, 38°03′38"E), 10—Kachkovka River (67°24′39"N, 40°48′51"E), 11—Snezhnitsa River (66°35′30"N, 40°40′34"E), 12—Kolmak River (67°18′49"N, 40°01′48"E), 13—Acherjok River (67°19′26"N, 39°27′25"E), 14—Tyuvinga River (67°15′40"N, 39°54′43"E), 15—Malyj Olenij Island (69°15′20 N, 34°42′27"E),16—Indera River (66°15′21 N, 37°07′28"E), 17—Keyvy (67°23′42 N, 39°11′41"E), 18—Yokanga River (67°50′20 N, 38°31′11"E), 19—Lake Porosozero (68°01′43 N, 36°41′22"E)

the rain falls during the summer and autumn (June-October). The snow cover normally lasts from the middle of October to the end of May (Koroleva 1994).

As elsewhere in the Arctic, the second half of 20th and beginning of twenty-first century was characterized by a noticeable warming (Masson-Delmotte et al. 2019). The average annual air temperature in Murmansk for the period 1881–1990 was about 0 °C, but increased to + 0.8 °C in 1991–2010, + 1.1 °C in 2001–2010, and + 1.7 °C in 2011–2019 (Demin 2012; http://www.pogodaiklimat.ru/history/22113.htm). Observed consequences of climate change in the region include the spreading of forest-tundra into the tundra zone and the rise of the upper limit the forest in the Khibiny Mountains (Myagkov et al. 1986; Demin and Zyuzin 2008). The present climate of the region is characterized by high interannual variability. In winter, periods of strong cooling can alternate with sharp thaws, leading to extensive ground icing, as has been observed in Fennoscandia and elsewhere in the Arctic (Hansen et al. 2014).

Ecosystem drivers

Lemming cycles

Reproduction in the Arctic fox in Fennoscandia is tightly associated with the abundance of small mammals, in particular the Norwegian lemming (*Lemmus lemmus* L.; hereafter lemming) (Dubrovskii 1939; Angerbjörn et al. 1999; Elmhagen et al. 2000). On the Kola Peninsula, small mammals have been monitored since 1929 in the Lapland Nature Reserve (Fig. 1; Kataev 2016), and since 1952 in the Kandalaksha Reserve (coast of the White and Barents seas; Semenov-Tyan-Shansky 1970). In some years, observations were carried out in other parts of the peninsula (Kataev 2016; Emelianova, Abaturov 2017). Until the mid-1940s, lemmings exhibited regular four-year population cycles, but later their outbreaks became more irregular (Fig. 2). There were few outbreaks between 1945 and the end of the 1960s, and a long period without peak years was recorded between 1983 and 2007 (Kataev 2016). Over the past three decades, the most important lemming peak was observed in 2011–2012. In these years, lemmings reached peak densities in most of the mountain tundra in Fennoscandia and the entire Kola Peninsula (Emelianova, Abaturov 2017; Ims et al. 2017; Le Vaillant et al. 2018). The next lemming peak was recorded in 2015 in the Lapland Reserve, however, not in other parts of the peninsula (Kataev 2016; Mammals 2017).

Red fox and semi-domestic reindeer

The red fox is a common species found throughout the Murmansk Region and occurs in most habitats (Danilov et al. 1979; Semenov-Tyan-Shansky 1982; Vaisfeld 1985). According to official statistics for the years 1991 to 2017, the number of red foxes in the Murmansk Region fluctuated between 1.500 and 4.900 individuals (Gubar' 1996, 2004, 2007; Komissarov 2010; Ministry of Natural Resources and Ecology of the Murmansk Region 2017). The data suggested an increase before 2009 and a decrease after that. According to studies carried out in the Lapland Reserve, the red fox exhibits population cycles associated with the vole cycles with a time lag of 1–2 years (Semenov-Tyan-Shansky 1982; Mammals 2017). There are, however, no observations of red fox dynamics from areas where it is sympatric with Arctic foxes.

The range of the Arctic fox on the Kola Peninsula is within the reindeer husbandry area. According to official statistics, the current number of domestic reindeer in the Murmansk Region is 58.100 animals. This is likely to be an overestimate, however, and since the end of the Soviet Union, reindeer numbers in the region have probably declined to as little as half of this figure (Klokov 2011; Konstantinov et al. 2018). Certainly, reindeer densities are significantly lower than in northern Fennoscandia. In summer, semi-free ranging reindeer migrate from winter pastures close to and south of the Ponoy River (Fig. 1) north to the Barents Sea coast and are followed by numerous

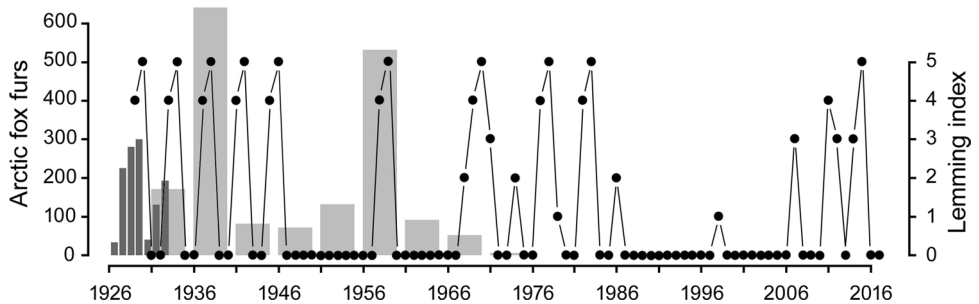

Fig. 2 Harvest data of the Arctic fox *Vulpes lagopus* in the Kola Peninsula, northwestern Russia, shown as the number of skins sold per year in 1926–1933 (darker gray bars; Zolotov 1933) and as average for 5-year period for 1931–1975 (lighter gray bars; Shilyayeva 1985). Dots show the annual lemming *Lemmus lemmus* abundance indices from the Lapland Nature Reserve (Kataev 2016)

predators, including brown bears (*Ursus arctos*), wolverines (*Gulo gulo*), and golden eagles (*Aquila chrysaetos*). Both the summer and the winter pastures are quite far from the most important areas of the Arctic fox denning. Until a few decades ago, reindeer were slaughtered on the tundra and slaughtering remains (skins, horns, bones, intestines, etc.) were left around the slaughtering points and represented a significant resource for scavengers. According to herders in the village Sosnovka (Fig. 1), both red and Arctic foxes, as well as other animals, fed actively in these places. In connection with the relatively recent organization of modern slaughterhouses with organized disposal, slaughter remains have become almost inaccessible to wild animals and the role of reindeer as a potential subsidy for foxes may have declined.

Arctic fox data

Fur return data were retrieved from Zolotov (1933) for the period 1926–1933 and from Shilyayeva (1985) for 1936–1975. Our assessment of the status of the Arctic fox during the last two decades is based on three sources of information: winter track counts (WTC) of game animals, field observations by scientists, and information from local residents.

Winter track counts of game animals

In Russia, in regions with a steady snow cover, there is a national monitoring program of game mammals based on snow track counts in winter (WTC). A surveyor (voluntary observer, hunter, or ranger) skis along a predefined transect line (8–15 km) and counts the intersections of animal tracks with the line. The method allows the estimation of the population density of animals, using daily travel distances according to the Formozov–Malyshev–Pereleshin formula, specifically developed for this purpose (Formozov 1932; Priklonsky 1972; Stephens et al. 2006; Keeping end Pelletier 2014). According to the methodology, routes should be constant from year to year and they should cover the entire area uniformly, but in practice, these requirements are often violated. It is notoriously difficult to distinguish tracks of Arctic fox and red fox. Nevertheless, we think that the WTC method provides at least some information about the presence of the Arctic fox in the area. We retrieved the primary data sheets from WTC in the Murmansk Region for the period 2009–2013 and summarized the information for both fox species. In total, 1133 data sheets were processed, each representing one transect line. In 2014, the Arctic fox was removed from the preprinted data sheets, so since then the WTC has not collected information on this species.

Field observations

One of the most widely used techniques for monitoring Arctic fox populations is the observation of dens (Berteaux et al. 2017). Systematic den surveys have not been carried out on the Kola Peninsula since the beginning of the twentieth century. We carried out den surveys in different parts of the peninsula in 2002, 2011, 2017–2019. Arctic fox dens are associated with characteristic landscape elements, such as the presence of sandy sediments, elevated landforms, and the proximity of water. Together with the lush green vegetation that often develops because of fox fertilization, this makes them quite visible and their search somewhat predictable (Prestrud 1992; Angerbjörn et al. 1999). The aims of the field observations were to search for dens, describe them, assess their status, look for breeding animals, and collect biological samples. Fox dens were described by counting the total number of entrances, how many appeared used, and recording the location in the landscape, exposure, substrate, distance to the nearest water source, as well as the main plants growing on the den. We registered signs of fox activity, such as feces, fresh digging, prey remains, or fur. It is well known that red foxes use arctic fox dens for breeding (e.g., Gallant et al. 2014), and many signs of activity, such as digging, footprints, prey remains, or feces cannot be assigned to Arctic foxes with certainty. Arctic fox presence was determined from white fur found in entrances or visual observations of the foxes. During fieldwork, all groups also carried out various wildlife observations and payed particular attention to small rodents.

In 2002, a group led by Dalén (4 people) explored the northwestern part of the Arctic fox distribution area, locations near the Serebryansky water reservoir, the villages of Tumannyy and Dalniye Zelentsy, and Lake Enozero (Fig. 1 area a, b, and c). The fieldwork took place between 1 July and 4 August, and a total of 820 km of surveys were covered on foot. In addition to the Arctic fox survey, line transects for fecal pellets and live vertebrates were conducted and fox feces were collected opportunistically for DNA analysis.

The same areas were partly surveyed in 2011 by a team led by Ehrich (2 people). From 20 to 27 July 2011, they explored the area around a fishing camp on the Varzina River (Fig. 1 area c), including the river valley with mountain birch forest, the surrounding rocky tundra areas, and the northern shore of Lake Enozero. They looked for fox dens and fox feces by walking 10–20 km per day. From 28 to 31 July, they surveyed fox dens that had been described in 2002 in the area of the junction between the roads to Teriberka and Tumannyi (Fig. 1 area a), a relatively flat, uniform, and humid tundra zone. From 1 to 3 August they investigated the surroundings of Dalniye Zelentsy (Fig. 1 area b), a hilly area with mountain birch woodland. In the area of the Varzina River (Fig. 1 location 9) and the Teriberka trapping

location (Fig. 1 area a), snap trapping of small rodents was carried out for two nights according to the small quadrat method (Myllymäki et al. 1971, 480 and 360 trap nights, respectively).

From 28 June to 3 July 2017, Tirronen and Panchenko visited Arctic fox dens that had been described in two areas surveyed in 2002 and 2011 (Fig. 1 area a and b). They walked a total of 100 km and noted all land vertebrates, and traces of their activity.

In 2018 and 2019, fieldwork focused mainly on the eastern part of peninsula. Tirronen's groups surveyed areas that had been neglected by researchers since the 1930s, but had been described as the most important for Arctic fox reproduction (Zolotov 1933; Fig. 1e). The locations to be visited were determined from public-domain satellite images and Arctic fox dens mapped by V.A. Zolotov in 1933 (Zolotov 1940). In June 2018, 3 people traveled more than 300 km along the shore of the White Sea in a small inflatable catamaran. Fieldwork was conducted mainly in the area between the rivers Ponoy and Kachkovka and along the River Snezhnitsa (Fig. 1 area f and e). During 9 days, they covered a distance of 140 km. Moreover, for 2 days they explored the area around the abandoned reindeer slaughtering point at the mouth of the River Snezhnitsa.

In 2019, surveys were carried out between the basins of the Kolmak, Acherjok, and Tyuvinga rivers flowing into the Ponoy River (Fig. 1 area d). This area appeared indeed well suitable for Arctic foxes, because it harbors different types of tundra providing good and relatively stable feeding conditions, as well as sandy glacial deposits necessary for the construction of dens. During the period 3–24 June, 2 people covered a distance of more than 250 km. They also used a quadcopter (DJI Mavic Pro) in search of characteristic landscape elements or patches of lush vegetation. In September 2019, they visited 2 dens (Fig. 1 area b) that had been described in 2002. This area harbors a hilly relief formed by glacial deposits (sandy loam, loam, sand), which are favorable for digging dens. During 2 days they walked 35 km accompanied by a dog that actively caught small rodents.

Information from local residents

During all field trips, we asked local residents for observations of Arctic foxes and their dens and discussed possible population trends for both Arctic and red foxes. In addition, we used data from a more systematic survey carried out in 3 settlements on the Kola Peninsula in 2012 (Ehrich et al. 2016). In Teriberka, Tumannyi, and Lovozero, interviews were carried out with residents, who were selected for their good local knowledge and expertise on wildlife around the settlements. The interviewees were asked if, and how frequently, they had observed different species (including Arctic and red foxes) or their tracks over the years they had been active outdoors, and whether they observed increasing or decreasing trends in frequency of encounters (Ehrich et al. 2016). Respondents were anonymized, and the conversations and interviews with local residents were in accordance with Russian regulations. Moreover, we included incidental observations reported by other researchers and consulted touristic internet forums for Arctic fox observations.

Results

Fur returns

Annual fur return data were retrieved for the period 1926 to 1933, but after that and up to 1975, only data summarized by 5-year periods were available. The data showed a clear congruence with the lemming dynamics recoded by the Lapland Nature Reserve (Fig. 2). At the beginning of the period, the Arctic fox fur returns followed the lemming cycle. After very high harvest numbers in 1936–1940, they declined, however, before the lemming cycles faded out after the peak in 1946. Later harvesting was low in periods without lemming peaks, but increased in the five-year period when the isolated lemming peak in 1959 was recorded.

Winter track counts

According to the results of the WTC for 2009 to 2013, only two encounters of Arctic fox (not specified whether track or observation) were recorded in the Lovozersky District in 2009. In 2010–2013, no Arctic fox tracks or observations were registered. The number of red fox tracks registered per 10 km between 2000 and 2014 for the whole Murmansk Region showed a negative trend, with fewer tracks observed on average after 2006. In the Lovozersky District, where the most important old denning areas of Arctic fox had been located, this trend was less clear and annual fluctuations were more pronounced (Fig. 3).

Den surveys and field observations

In 2002, we found and described 16 Arctic fox dens (Fig. 1 areas a, b, and c). One of these was inhabited by Arctic foxes (one adult Arctic fox was observed) and, based on the tracks and size of feces, it is likely that at least one cub was born at this den during 2002. This was the only adult Arctic fox observed by 4 people during 50 days of field work. In 2002, small rodent numbers were low and we observed one live vole, two dead small rodents, and 63 lemming winter nests.

In 2011, we did not manage to visit any of the dens described in 2002 near Lake Enozero (Fig. 1 area c). The only sign of Arctic fox was one possible feces close to the lake. Further west, we visited six of the dens described in

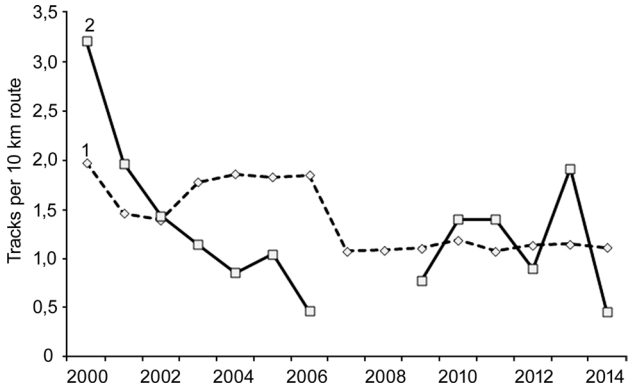

Fig. 3 Dynamics of the red fox *Vulpes vulpes* population in the Murmansk Region (1) and in the Lovozersky District (2), northwestern Russia, based on the annual Winter Track Count data

2002 (Table 1) and described two additional dens (D01, D02). Two of the visited dens still had clearly lusher vegetation than the surrounding tundra (D01, R01), but none of them showed sign of recent fox activity. We only found sign of activity from the current summer at one den (S01) in the form of fresh footprints, but these could have been from a red fox as well as from an Arctic fox. At all dens, many entrances were collapsed or disappearing in the vegetation. The results from the small rodent trapping revealed high small rodent abundances, including peak densities of lemmings, particularly in the eastern area (Figs. 1, 4).

In summer 2017, we checked nine of the dens described in 2002 (Table 1). The spring was abnormally cold, with phenological events delayed 2–3 weeks compared to the climatic norm, which resulted in difficulties in checking some of the dens. Four of the visited dens had traces of fox presence (scats, food remains), which could have belonged to either species, whereas only one den contained Arctic fox fur (L03). This den, on the shore of a small lake, must have been a natal den, but at the time of our survey most of its entrances were flooded by intensive snow melt. At the same time, we found fresh footprints, fur, remains of prey, and scats that clearly indicated Arctic fox activity. A formerly quite large natal den (R01) proved to be inactive, and only 3 of its burrows remained intact; the rest had collapsed. Two very old scats were found. Although there were no traces of animal presence, we left some food as a lure and deployed camera traps for one day, but no animals were observed. We did not observe a single Arctic fox. It is worth noting that the entire tundra, and especially area b (Fig. 1) was covered with feces and old bones of reindeer. The number of small rodents was probably extremely low, including in the previous year, because there was almost no sign of winter activity, and no animals were not observed.

In 2018, in area e (Fig. 1), we described four dens (T01-T04; Table 1). Den T01 was located 5 km north of the Ponoy River on a sandy hill and had 10 old collapsed entrances and 4 with fresh digging. Two fresh scats and prey remains were found. This was the only den with fresh signs of activity, but we could not determine whether they belonged to Arctic or red foxes. Den T02 was located on the edge of a sand hill, 100 m from a creek. In the past it had been a large natal den with more than 20 entrances, but it was abandoned and likely had not been visited by foxes for several years. Dens T03 and T04 were smaller dens abandoned very long ago. We found one dead and two live voles, but did not see any lemmings. Traces of winter activity of small rodents were, however, ubiquitous.

In 2019, we described 7 dens of Arctic fox in area d (Fig. 1; T05-T11), but all except one were abandoned (Table 1). Dens T05, T07, and T08 were small dens and T10 was a large natal den; all had been abandoned a long time ago. Den T06 was a large natal den (the area covered was 470 m^2) and may have been occupied as recently as a few years ago. However, an all-terrain vehicle road crossed the edge of the den and may have driven the foxes away. Den T11 may have been abandoned because of changes in the water level of the stream flowing in its immediate vicinity and inundating the den. The last den (T09) was located on a hillside in the forest-tundra subzone. This was the only den with two entrances with recent digging, but this activity could probably be attributed to red fox and the den was not active in 2019. Traces of small rodent winter activity (grazed vegetation, abundant feces, winter nests of lemmings and voles as well as runways) were observed everywhere. We found two dead lemmings and two voles and observed one live lemming and two voles.

In September 2019, we checked dens L04 and S02 (Fig. 1b). Den L04 had been abandoned a long time ago and only traces of the entrances could be discerned. Also, den S02 was no longer in use. One collapsed burrow was all that was left of it. Small rodents were extremely numerous, and we observed scurrying voles constantly, but did not see any lemmings.

Information from local residents and incidental observations

In 2011, the employees of a fishing camp on the Varzina River said that they had observed Arctic fox regularly in winter and early spring that year. A staff member of the Kandalaksha Nature Reserve, based at a field station close to Dalniye Zelentsy, told us that he occasionally saw Arctic foxes in winter, but that, as far as he knew, they were not reproducing in the area, whereas red foxes were.

In 2012, the year after the last documented lemming peak on the Kola Peninsula, we interviewed 19 experienced outdoor people (Ehrich et al. 2016). Six of them had never seen Arctic foxes in the surroundings of their settlement.

Table 1 State of surveyed arctic fox *Vulpes lagopus* dens on the Kola Peninsula northwestern Russia, 2002–2019

		ID of the den																												
		C01	C02	C03	L01	L02	L03	L04	L05	L06	L07	R01	R02	S01	S02	S03	Z01	D01	D02	T01	T02	T03	T04	T05	T06	T07	T08	T09	T10	T11
2002	State	V	A	V	V	A	V	V	V	V	V	V	A	V	A	V														
	Unused holes	8	6	0	1	15	25	10	22	9	10	25	3	0	2	14	0													
	Used holes	0	0	2	0	6	27	15	53	18	26	22	12	1	4	28	0													
	Activity																													
2011	State	?	?		NV			NV				NV		V				NV	NV											
	Unused holes	5	4		1			8				20		1				17	≤20											
	Used holes	4	4		0			0				1		1				3	0											
	Activity	P	P		N			N				N		Y				N	N											
2017	State	V	A		A	NV	V					NV	A	A			A													
	Unused holes	5	3		1	5	?					17	3	0			0													
	Used holes	5	0		0	1	5					3	0	0			0													
	Activity	P	N		N	P	Y					P	N	N			N													
2018	State																			V	NV	A	A							
	Unused holes																			10	>20	<10	5							
	Used holes																			4	0	0	0							
	Activity																			Y	N	N	N							
2019	State							A							A									A	NV	A	A	V?	A	Ava
	Unused holes							0							1									≤10	≥14	≤10	≤10	2	≤20	>10
	Used holes							0							0									0	0	0	0	2	0	0
	Activity							N							N									N	N	N	N	Y	N	N

State: *V* Visited, *NV* No signs of visiting, *A* Abandoned, *Ava* Abandoned very long ago; Activity: *N* no, *Y* yes, *P* possibly

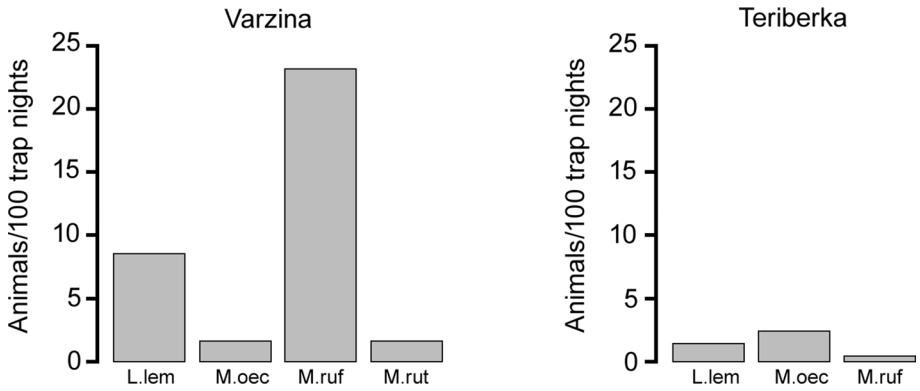

Fig. 4 Results of the small rodent trapping carried out in 2011 in areas near the village Teriberka (68°51′10"N 34°48′26"E), and River Varzina (68°11′21"N 38°02′08"E), presented as animals captured per 100 trap nights for each species: L.lem = Norwegian lemming *Lemmus lemmus*; M.oec = tundra vole *Microtus oeconomus*; M.ruf = gray-sided vole *Myodes rufocanus*; M.rut = red-backed vole *Myodes rutilus*

In Lovozero, one person said that he had seen many Arctic foxes in August 2011 close to the village Sosnovka in the very east of the Peninsula. In Tumannyi, two people reported single observations from the winter 2011–2012. They said that Arctic foxes are usually close to the coast in winter. In Teriberka, people reported three observations from 2012, and mentioned that a young man had shot two Arctic foxes not far from the village that year. One man told us that he had observed breeding on Malyj Olenij Island in 2002. Another man told us that he observed Arctic foxes regularly on that island, where there are many old dens. He had not observed reproduction in recent years, but had seen a barking fox there in 2011.

During the years 2017–2019, single observations were reported from the southmost part of the Kola Peninsula. Local people who we interviewed in the villages of Lovozero, Kanevka, and Sosnovka expressed the opinion that the Arctic fox had eaten all the ptarmigans (*Lagopus lagopus* and *L. muta*), and that depletion of this important resource could explain the decline. Two hunters from Sosnovka claimed that there was an Arctic fox den 10 km from the village, where they regularly caught blue foxes, and which, in their opinion, was still active. They observed single animals in the vicinity of the village almost every year. The staff of a fishing camp at the mouth of the Ponoy River, however, never met Arctic foxes in this area. In June 2014, the ichthyologist Denis Efremov observed a pair of Arctic foxes that came to the mouth of the Indera River, where they scavenged on pinniped carcasses. In the winter of 2016, a game manager from the Tersky District, Murmansk Region, encountered an Arctic fox on the shore of the White Sea and photographed it with a car dashboard camera. In January 2019, a single Arctic fox was seen near the village Zelenoborsky in the southwest of Murmansk District, and in March one animal was observed in Keyvy, on the watershed between the Ponoy and Yokanga rivers (Fig. 1). Moreover, in 2019 we questioned reindeer herders in Lovozero. They noted that 10 years ago Arctic foxes, as well as red foxes, were numerous close to their base on Lake Porosozero, but now both species were observed much less often. No Arctic fox observations were reported in the touristic internet forums.

Discussion

Our study summarized rather disparate data. This was due to the objectives of the study, to assess the state of the Arctic fox population on the Kola Peninsula based on all available literature sources and field data. In addition, the extreme scarcity of the available information encouraged the detailed reporting of any observations. Thus, the study combined published research characterizing the population on the peninsula, including archival reports of expeditions of the 1930s, with our own field research in the new millennium and various observations made by local people. In general, the results were quite consistent and suggested a dramatic population decline in the area. This decline paralleled the decline of the Arctic fox population in Fennoscandia (Dalén et al 2002, 2006; Angerbjörn et al. 2013), although it may have occurred slightly later. Similarly, over the past century, there has been a decrease in the species' abundance and denning range in the tundra in European Russia up to the Urals (Anufriev 2003).

Three key points emerged from the literature: First, during the past century, the Arctic fox numbers apparently reached more than 1,000 individuals in some periods. In the 1930s, the population size increased also due to fugitives from fur farms, when in some years up to 300 individuals escaped (Zolotov 1933). Hybridization between wild and farm-bred individuals might have a negative effect on the viability of the wild population, through loss of local adaptations (Noren et al. 2009). As far as we know, no measures were taken at that time to counteract hybridization and the genetic composition of the population on Kola Peninsula has not been studied, thus, it is unclear what role these events may have played in the future development of the population. Second, the population decline at the beginning of the twentieth century can be attributed to excessive hunting, similar to what happened in Fennoscandia (Dalén 2005;

Angerbjörn et al. 2013; Ims et al. 2017). Because of the high fur prices, the incentive to hunt Arctic foxes was probably very high. The crash in fur returns after the peak harvesting period in 1936–1940 may have resulted from excessive hunting, but it may also have been related to World War II. Third, the fur return data showed a clear relationship between lemmings and Arctic fox harvest data (Fig. 2), suggesting that the irregular lemming dynamics were an important factor for the decline. This result suggested that periods without lemming peaks may also have been the main cause of the Arctic fox decline in the second part of the twentieth century in Scandinavia. There are no data to show whether the population benefited from the lemming peak years between 1966 and 1986. The recent dramatic decline has gone nearly unnoticed by officials and seems to be of little concern, as indicated by the mention of the species in the list of excluded species of the last edition of the regional list of threatened species.

During our field work, only one possible breeding event of Arctic fox was observed in the area in 2002. Most dens described in 2002 were found to be decaying when they were revisited in subsequent years. From survey to survey, the number of entrances decreased and the dens were becoming grown over with vegetation. This was the case also in 2011, the year of the largest lemming peak in northern Fennoscandia in several decades. Our trapping data confirmed that lemmings were also abundant on the Kola Peninsula, and 2011 was the last year when a good reproduction of Arctic fox was observed in northeastern Norway (Ims et al. 2017). As in earlier decades there was a strong correlation between lemming and Arctic fox abundance, the chance to observe breeding of Arctic fox was thus high, but none of the visited dens was active. The reports from local people collected in 2012 indicate, however, that Arctic foxes have probably been breeding both in the southeastern part of the Kola Peninsula and in the more western areas, as several observations were reported from both areas from the winter 2011–2012. After that year, however, it is likely that the decline continued, as it did in northeastern Norway (Ims et al. 2017). All dens described in 2018–2019 in the areas that had been identified as core areas for the species, had been abandoned some time ago. Also, in places where local people stated that the Arctic fox was still breeding, we found only abandoned dens.

This desolate state of the population was corroborated by the absence of Arctic fox encounters in the WTC records. Although this did not prove the absence of the species, this fact confirms a tangible reduction in its abundance and range. Surveyors no longer encountered animals along transects, although their rare footprints could be easily confused with those of red foxes. Moreover, most local people with whom we talked reported that Arctic foxes had become rare on Kola Peninsula. This was confirmed by people in touristic internet forums, which regularly cross the Peninsula from the Barents Sea to the White Sea by snowmobiles. These people could not remember a single observation of the Arctic fox in recent years. Furthermore, in 2012 and 2014–2016, Tirronen and Panchenko covered more than 1000 km of walking routes in the southern part of the Kola Peninsula along the White Sea coast for another project and did not encounter a single Arctic fox, although red foxes were observed regularly.

Among the possible causes of the recent decline and range shrinkage of the Arctic foxes on the Kola Peninsula, we can confidently exclude hunting, because hunters have lost interest in fur for decades. Originally, the reason for the reduction in fur hunting was the large-scale development of fur farming in the former USSR, and the subsequent drop of fur prices suppressed the market for wild fur. From our interviews of local residents and hunters from the villages of Lovozero, Kanevka, and Sosnovka, we were convinced that Arctic fox hunting had absolutely no interest for these people during more than the last two decades.

In Fennoscandia, the decline of the Arctic fox and its difficult conservation situation today has been attributed to two main drivers: the absence of regular lemming peaks and competition with expanding red foxes (Angerbjörn et al. 2013; Ims et al. 2017). We did not observe signs of interspecific competition between red and Arctic foxes on Kola Peninsula, as has been recorded for many parts of the ranges in sympatric zones (Hersteinsson and Macdonald 1992; Elmhagen et al. 2017). We did not see red foxes in any of the examined dens, nor could we reliably document any case where a red fox had settled in an Arctic fox den. Interestingly, the available data about the red fox population in the Murmansk Region do not suggest an increase of this generalist predator during the last decades. However, it is likely that the red fox has increased in this region over a longer time period, as documented elsewhere in the Arctic (Hersteinsson and Macdonald 1992; Kaikusalo and Angerbjörn 1995).

The increase in the abundance of red foxes in the northern parts of its range, where it overlaps with Arctic foxes, has been related to the availability of food subsidies (Elmhagen et al. 2017). In northern Fennoscandia, intensive reindeer herding, and notably the availability of reindeer carcasses, has been shown to be an important driver for the increase of generalist predators (Killengreen et al. 2011; Henden et al. 2014). In comparison to Finnmark, reindeer densities on the Kola Peninsula are presently low. This was corroborated, for instance, by our observations of thick lichen mats in the tundra close to Tumannyi. Although recreational use in the areas accessible by road is probably increasing (Ehrich et al. 2019), human use of tundra areas is likely to be much lower than in Finnmark. Altogether, there may thus be fewer resources for red foxes, which might make the competition between the species less important. The observations of

Arctic foxes along the northern coast of the peninsula near Tumannyi and Dalniye Zelentsy (a and b on Fig. 2) could support such a suggestion. At the same time, some factors are affecting Arctic foxes and other Arctic species negatively. Thus, ptarmigan populations have recently declined to critically low levels, and the ptarmigan hunt was closed in the 2018–2019 season in the Murmansk Region. A similar decline has been observed in Finnmark and has been related, among other things, to increasing populations of generalist predators (Henden et al. 2020).

Decline and fragmentation of populations leads to a loss of genetic diversity and inbreeding depression (Norén et al. 2017). The evolutionary capacity of such populations is impaired, because genetic diversity is the basis for evolution (Franklin 1980; Soulé 1980) and, as a consequence, ensures population persistence. It is likely that the Arctic fox population of the Kola Peninsula is now in nearly complete isolation. The discontinuous, short-lived, and mobile ice cover of the White Sea (Tolsticov 2016) cannot serve as a solid basis for bidirectional migrations of Arctic foxes. At the beginning of the previous century, the situation was probably different, because hunters claimed that the Arctic fox regularly migrated from the Peninsula towards the Arkhangelsk Region and back. This is also supported by the capture of animals on the southern coast of the Kola Peninsula escaping from the Solovetsky Archipelago fur farm (Dubrovskii 1939). More recently, genetic analyses of samples collected 20–30 years ago indicated connectivity between the Kola Peninsula and Russian populations further east, as well as some genetic exchange with northern Scandinavia, whereas differentiation among subpopulations increased in the more southern populations (Dalen et al. 2006). At the same time, it is unlikely that there was exchange of individuals with an extremely small population in eastern Finnmark during the last decade.

Based on our field studies, we have attempted to estimate the species abundance on the Kola Peninsula. We visited a significant part of the Arctic fox denning areas on the peninsula and carried out fieldwork during several years, but did not observe a single Arctic fox after 2002. However, reliable observations continue to be reported. Therefore, the number of Arctic foxes on the remaining unexplored part of the peninsula can hardly exceed several tens of individuals, close to the estimate of 40 individuals provided by Dalén et al. (2002). We are witnessing an increasingly real threat of extinction of this formerly common element of the Palaearctic fauna from the most western part of mainland tundra of Russia. Targeted research is urgently needed to assess the status of the species, identify the threats and perspectives for the Arctic fox in the region, and to develop a conservation strategy for this charismatic Arctic species. As a first step, a large-scale field study is required to determine the population size and identify the remaining breeding areas. After that, targeted recommendations can be developed. However, considering the similarity of processes occurring in the tundra ecosystems of Scandinavia, it is likely that the efforts being made there can be effective here as well.

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Authors' Contributions KT and DP initiated the study and carried out the field work in 2017–2019. LD carried out field work in 2002 and DE in 2011. KT obtained the archive data and assembled all the material from the different sources. KT and DE wrote the text with contributions from all authors.

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Data Availability All data collected by the authors are presented in the paper, and sources are indicated for older data.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The research followed all relevant laws and ethical standards. Respondents answering to questions about Arctic and red fox observations were anonymized, and the conversations and interviews with local residents were in accordance with Russian regulations. Mainly noninvasive methods were used in the study. Small rodent trapping was carried out according to Russian regulations at that time. As no Arctic foxes or other vertebrates were impacted directly by the research, no special approvals were needed for this work.

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