Mortality and poaching of lynx in Sweden

Dödlighet och illegal jakt på lodjur i Sverige

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ABSTRACT

We described causes of mortality and survival rate for 216 radio-marked Eurasian lynx (*Lynx lynx*) followed for 621 radio-years in two different study areas in Sweden. The northern study area was located in the county of Norrbotten around Kvikkjokk and the southern study area was located mainly within northern Örebro county. The main causes of mortality in adult Eurasian lynx in both study areas were anthropogenic, with starvation, intraspecific killing and disease having only a minor role. In the northern study area poaching and assumed poaching were the main cause of mortality in adult lynx (79 % of the mortality events), whereas poaching (including assumed poaching) and natural causes were equally important in subadults (45 %). In the southern study area natural causes, hunting and traffic were the main causes of mortality (62 % for these factors combined) and accounted for about twice the mortality caused by poaching and assumed poaching (29 %). The poaching rate (including assumed poaching) was significantly higher ($p<0.001$) in the northern study area (11.1 % ± 2.2 % SE) than in the southern study area (3.4 % ± 1.5 % SE). The estimated poaching rates were not significantly different between the two periods (1994-1999 versus 2000-2010) in neither the northern ($p=0.94$) nor the southern ($p=0.15$) study area. The estimated growth rates based on demographic data were not significantly different ($p=0.30$) from the observed change in the lynx population in either study area. Thus, the estimated rates of mortality (including assumed poaching) were probably not overestimated. If the two study areas are representative for the reindeer husbandry area and the area south of the reindeer husbandry area in Sweden, respectively, then the estimated number of lynx poached in the reindeer husbandry area would be around 77 lynx (± 16 lynx SE) per year and around 22 lynx (± 10 lynx SE) per year south of the reindeer husbandry area. To conclude, poaching is an important cause of mortality in lynx in Sweden, especially in the northern study area, and the poaching rate does not seem to have changed between two periods (1994-1999 versus 2000-2010).

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SVENSK SAMMANFATTNING

Den här studien beskriver dödsorsaker och överlevnad hos 216 radiomärkta lodjur (*Lynx lynx*) som har följts under 621 radio-år i två olika studieområden i Sverige. Det nordliga studieområdet ligger Norrbottens län i Kvikkjokk fjällen. Medan det sydliga studieområdet främst ligger i norra Örebro län. Dödsorsakerna hos vuxna lodjur var främst av mänsklig orsak (jakt, trafik och illegal jakt). I det nordliga området var illegal jakt (inklusive förmodad illegal jakt) den främsta dödsorsaken hos vuxna lodjur (79 % av dödsfallen), med illegal jakt (inklusive förmodad illegal jakt) var ungefär lika viktigt som naturliga dödsorsaker hos yngre lodjur (45 %). I det södra området var naturliga dödsorsaker, jakt och trafik de främsta dödsorsakerna (62 % för dessa tillsammans) och var ungefär dubbelt så stor som illegal jakt och förmodad illegal jakt (29 %). Den illegala jakten (inklusive förmodad illegal jakt) var signifikant högre ($p<0.001$) i det nordliga området (11.1 % ± 2.2 % SE) jämfört med det södra området (3.4 % ± 1.5 % SE). Den illegala jakten var inte signifikant olika mellan de två studieperioderna (1994-1999 jämfört med 2000-2010) i varken det nordliga ($p=0.94$) eller det sydliga området ($p=0.15$). Den beräknade tillväxttakten baserat på demografisk data (reproduktion och överlevnad) var inte signifikant skild från de observerade populationsförändringarna i respektive område ($p=0.30$). Därför är de beräknade mortalitetsvärdena antagligen inte överskattade. Om de båda studieområdena är representativa för renskötselområdet respektive söder om renskötselområdet, då är det beräknade antalet illegalt skjutna lodjur 77 (± 16 SE) per år i renskötselområdet och 22 (± 10 SE) per år söder om renskötselområdet. Sammanfattningsvis är illegal jakt på lodjur en viktig dödsorsak hos lodjur i Sverige, speciellt i det nordliga studieområdet, och den illegala jakten verkar inte har förändrats mellan studieperioderna (1994-1999 jämfört med 2000-2010).

1. INTRODUCTION

Reintegrating large carnivore populations into our modern landscapes is always a difficult task, largely because of the problem with predation on domestic animals and the competition between hunters and large carnivores for common prey (Swenson and Andrén, 2005). In Scandinavia, Eurasian lynx (*Lynx lynx*) occur mainly outside protected areas in the surrounding matrix of multi-use landscapes (Andrén et al. 2010, Linnell et al. 2010) where the potential for diverse conflicts is high. Furthermore, most protected areas in Sweden and Norway are smaller than the home ranges of large carnivores, which mean that the majority of large carnivores occur outside protected areas (Linnell et al. 2001).

Today, lynx are found in most of Sweden (Andrén et al 2010) and in most of Norway except in the southwestern parts (Linnell et al. 2010). In both Sweden and Norway, lynx are found within the Sami reindeer husbandry area, as well as in areas with sheep herding. In the reindeer husbandry area semi-domestic reindeer (*Rangifer tarandus*) are the main prey for lynx (Pedersen et al. 1999, Sunde et al. 2000, Mattisson 2011). In areas outside the reindeer husbandry area roe deer (*Capreolus capreolus*) are the main prey (Nilsen et al. 2009), but sheep (*Ovis aries*) are also preyed upon in these areas (Odden et al. 2002).

The rate of increase of large carnivore populations is most sensitive to changes in adult mortality (Sæther et al. 1998, 2005, 2010). Hunting mortality on large carnivores is often additive to other mortality (Swenson et al. 1997, Krebs et al. 2004, Linnell et al. 2010). Thus, from a conservation and management point of view it is very important to identify the primary causes of mortality. Furthermore, poaching has often been shown to be a major mortality factor in large carnivore populations (Andrén et al. 2006, Persson et al. 2009), and can potentially prevent the recovery of species with low or moderate rates of increase, especially for species that occur at low densities.

We have previously estimated the poaching rate of lynx (Andrén et al. 2006). Therefore, the aims with this report were to update the knowledge about poaching of lynx and to test whether the poaching has changed over the years.

2. STUDY AREAS

The study is based on radio-marked lynx from two different study areas in Sweden. The northern study area (Sarek; 8000 km^2) is located in the county of Norrbotten around Kvikkjokk (67°00' N, 17°40' E). Part of the area is within Sarek National Park (2600 km^2) and the Laponia World Heritage Site. The study area ranges from coniferous forest (Norway spruce, *Picea abies* and Scots pine, *Pinus sylvestis*) in the eastern parts (about 300 m. a.s.l.), through mountain birch forest (*Betula* sp.) and mountain meadows to high alpine areas with peaks around 2000 m a.s.l. and glaciers. The tree line is at about 800 m a.s.l. The area is located within the Sami reindeer husbandry area and includes the reindeer management units: mainly Tuorpon, Jåhkågasska and Sirges, but also parts of Luokto-Mávas and Sörkaitum. In addition to lynx, the study area also has reproducing populations of wolverines (*Gulo gulo*) and brown bear (*Ursus arctos*) that are also studied. Reindeer is the main prey for lynx in the area. Data on lynx survival for this study has been collected from 1994 to 2010.

The southern study area is about 8000 km^2 and is located around Grimsö wildlife research station (59°30' N, 15°30' E) in the Bergslagen region, mainly in Örebro county but also Västmanland, Värmland and Dalarna counties. The area is dominated by coniferous forest (Norway spruce and Scots pine) that is intensively managed for timber and pulp. The study area ranges from 30 to 500 m a.s.l. The proportion of agricultural land is higher in the southern parts (about 20 %) and decreases towards the northern parts (< 1 % of the area). In addition to lynx, the study area also has reproducing population of wolves (*Canis lupus*) that is also studied. Roe deer is the main prey for lynx in the area. Some lynx dispersed southwards and established in southernmost Sweden. In 2002, we also started to capture lynx in southernmost Sweden. We pooled the individuals from the Bergslagen region and southernmost Sweden in the survival analyses, as the sample size was too small for southernmost Sweden. Data on lynx survival for this study has been collected from 1996 to 2010.

3. METHODS

3.1. Capturing and types of collars

This study is based on radio-collared lynx. Young lynx were generally captured in February, when they were still together with their radio-marked mothers. Adult lynx were captured during autumn, winter and spring. Recaptures of radio-marked lynx were performed year round to replace old transmitters. Lynx were live-captured using a variety of methods, including darting from helicopter, unbaited walk-through box-traps, foot-snares placed at fresh kills, or treed with the use of dogs. The lynx were immobilised with a mixture of ketamine (5 mg/kg) and medetomidine (0.2 mg/kg) and equipped with either a radio-collar and/or an implanted transmitter. In late May – early June we intensively radio-tracked lynx females to confirm reproduction. We marked and counted the number of kittens found in the lair. The capturing and marking of lynx follow a pre-established protocol (Arnemo et al. 2011) that has been examined by the Swedish Animal Ethics Committee and fulfils the ethical requirements for research on wild animals.

We used two types of radio-transmitters in this study; from the beginning of the study to 2002 we only used VHF-collars, from 2002 we use both VHF- and GPS-collars. The lynx with VHF-collars were generally radio-tracked at least twice a month, usually more often. Most of the transmitters had a mortality function, which enhanced our chances of determining the fate of the lynx. Some lynx were marked with an implanted VHF-transmitter in addition to the GPS-collar to allow for long-term monitoring, as the battery-life of the VHF-implants are considerable greater than the battery-life of GPS-collars. In GPS/GSM-collars there was a mortality function that sent an SMS if the collar had not moved during 4 hours.

3.2. Determining cause of mortality in radio-marked lynx

The lynx carcasses, if found, were carefully examined in the field and then sent to the Swedish National Veterinary Institute for examination of the cause of mortality. Cause of mortality was classified as natural (e.g. starvation, sarcoptic mange, wounds from violent interaction with other lynx), traffic (i.e. lynx carcass found very close to a road showing violent death or direct report of car accident), harvest (i.e. lynx being shot during the legal hunting season), poaching (see below), assumed poaching (see below), or unknown cause of mortality (i.e. lynx confirmed dead but the cause of mortality could not be determined).

Poaching is generally very difficult to quantify. However, it was sometimes easy to conclude that the lynx was illegally shot, as when the lynx carcass was found with a gunshot wound or when the radio-transmitter was found smashed or had been cut off the lynx and thrown/hidden in a location where lynx do not naturally occur (e.g. in a river). We also considered that the lynx was illegally shot if the individual had two separate transmitters, i.e. one radio-collar and one implanted radio-transmitter, and both of the transmitters failed at the same time and we had been radio-tracking the area carefully after the disappearance.

However, lost contact with the radio-transmitter can result from several reasons, 1 – the lynx has been poached and the transmitter has been destroyed, 2 – the lynx has dispersed and we have lost contact with the individual, 3 – the transmitter has failed. Therefore, we used several criteria to separate between assumed poaching and unknown disappearance (such as rapid long distance dispersal or transmitter failure). We assume poaching if a resident adult lynx suddenly disappeared and we had been radio-tracking the area carefully from the air immediately after the disappearance. Furthermore, there had to be no signs of technical problems with the radio-transmitter (e.g. strange or weak signals) before the disappearance, and that at least half of the expected lifetime of the radio-transmitter was still available. Young lynx that had not established their own home range and were in the phase of dispersal were classified as assumed poaching if the disappearing lynx had a new radio-transmitter, we had followed parts of the dispersal phase, i.e. we had a dispersal direction, and we had been radio-tracking the area carefully from the air immediately after the disappearance. Otherwise, the lynx was classified as unknown fate.

3.3 Methods for estimating survival

Survival rates of radio-marked lynx were calculated using the staggered entry design, which is a modified Kaplan-Meier estimate (Pollock et al. 1989, R-development core team 2010, R library *survival*). We estimated survival for two age classes (subadults and adults), for the two study areas. The subadult age class included lynx from 6 months of age to the age of 2 years, and adults were lynx older than 2 years. We did not include lynx younger than 6 months in our analyses because of very limited data for this age category. We estimated two survival rates. The first rate included all mortality and the second rate excluded poaching and assumed poaching. The effect of poaching and assumed poaching on survival rate was estimated using competing risk models and cumulative proportional hazard (R library *cmprsk)*.

4. RESULTS

4.1. Cause of mortality in radio-marked individuals.

In the northern study area we followed 99 individuals for 326 radio-years. We determined the cause of mortality for 39 of these individuals (including assumed poaching). We lost contact with an additional 47 individuals for which we were not able to determine the cause of disappearance. The main cause of mortality for adult in the northern study area was poaching and assumed poaching (79 %). The second most important cause of mortality was natural causes adults (18 %; Table 1 and Figure 1). For subadults poaching (45 %) and natural causes (45 %) were equally important (Table 1 and Figure 1).

Table 1. Cause of mortality in radio-marked lynx in the two study areas in Sweden in 1994 to 2010.

Area	Age (years)	Natural	Traffic	Hunting	Poaching	Assumed poaching	Unknown cause of mortality	Unknown fate
North	0.5-2	5	0	0	0	5	1	28
	> 2	5	0	1	5	17	0	19
South	0.5-2	2	6	2	5	1	1	14
	> 2	7	3	8	4	3	3	42
Total	All	19	9	11	14	26	5	103

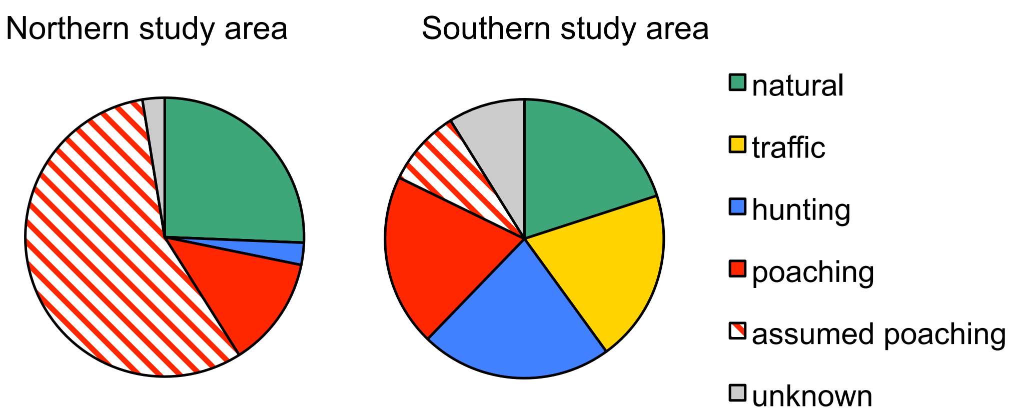

Figure 1. Causes of mortality in lynx in the northern study area (left, n=39) and in the southern study area (right, n=45) in 1994 to 2010.

In the southern study area we followed 117 individuals for 295 radio-years. We determined the cause of mortality for 45 of these individuals (including assumed poaching). We lost contact with an additional 56 individuals for which we were not able to determine the cause of disappearance. In the southern study area natural causes, hunting and traffic caused the majority of mortality (62 % for these factors combined) with poaching and assumed poaching accounting for 35 % of the cause of mortality in subadults and 25 % in adults (Table 1 and Figure 1).

In the northern study area the number of poached lynx was higher in later winter/early spring, as well as in autumn (Figure 2). In the southern study area there was no clear seasonal differences in number of poached lynx, but the number of dead lynx was higher in February and March, because of legal hunting (Figure 2).

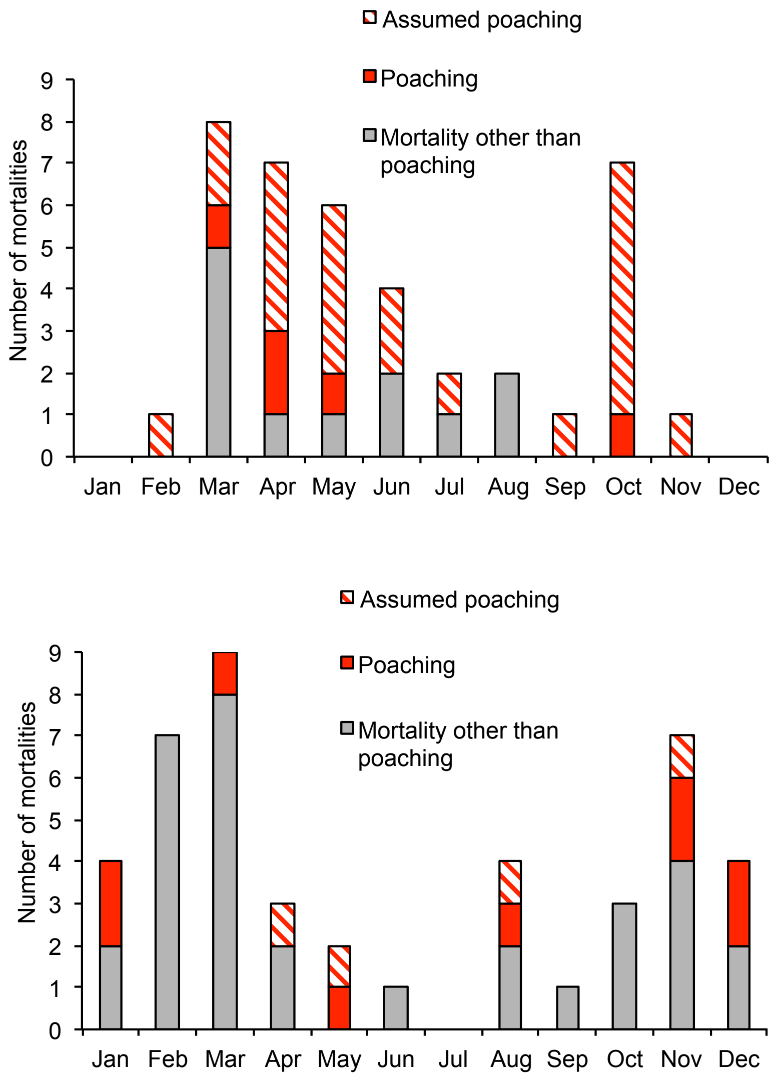

Figure 2. Number of mortalities of radio-marked lynx in relation to the month of the year in the northern study area (upper graph) and in the southern study area (lower graph) in 1994 to 2010.

4.2. Annual survival for radio-marked individuals

The mean annual survival for subadults was lower than for adults in both study areas (Table 2), whereas there was no significant difference in overall survival between the two study areas (χ^2=1.2, df=1, p=0.28, Table 2).

The estimated poaching (including assumed poaching) was significantly higher in the northern study area when compared to the southern study area (competing risk regression, p<0.001). However, the estimated poaching was not significantly different between the two periods (1994-1999 versus 2000-2010) in neither the northern (competing risk regression, p=0.94) nor the southern study area (competing risk regression, p=0.15). The average annual poaching rate (including assumed poaching) was 11.1 % (± 2.2 % SE) in the northern study area and 3.4 % (± 1.5 % SE) in the southern study area. The effect of miss-classification of one individual as assumed poached or unknown fate changed the poaching rate by approximately 0.3 %-units.

Table 2. Mean annual survival (±SE) for lynx, separated on two age classes in the two study areas in Sweden in 1994 to 2010.

Area	Age (years)	N (individuals)	N (radio-years)	Annual survival, all mortality (mean ± SE)	Annual survival, excluding poaching and assumed poaching (mean ± SE)
North	0.5 – 2	64	114	0.807 ±0.056	0.854 ± 0.054
	> 2	56	212	0.821 ± 0.031	0.962 ± 0.015
South	0.5 – 2	64	100	0.688 ± 0.058	0.758 ± 0.054
	> 2	78	195	0.793 ± 0.034	0.839 ± 0.032

5. DISCUSSION

The main cause of mortality of lynx in both study areas in Sweden was anthropogenic (hunting, traffic and poaching; Figure 1), with starvation, intraspecific killing and disease only having a minor role. Poaching (including assumed poaching) was quite substantial in the northern area (average annual rate 11.1 %), whereas it was lower in the southern area (average annual rate 3.4 %). However, it is always difficult to estimate poaching. For example, we have verified poaching in both study areas (5 cases in the north and 9 cases in the south), but the overall poaching rate is highly influenced by the number of assumed poaching (22 cases in the north and 4 cases in the south). The estimated poaching rate changes with about 0.3 %-units when one individual was wrongly classified as either assumed poached or unknown fate. Moreover, there were several lynx (47 cases in the north and 56 cases in the south) that disappeared and for which we do not know whether they died, performed long-distance dispersal or the transmitters failed. Thus, most of the lynx that disappeared were not classified as assumed poached. Individuals in the dispersing age group (from 7-8 months of age to almost 2 years old) can be very difficult to follow with radio-transmitters because they might disappear because of long-distance dispersal. Young inexperienced and dispersing individuals are often subjected to higher mortalities than residents (Blankenship et al. 2006). Therefore, one might underestimate the mortality rate in subadults. In the northern study area disappearance from unknown causes was common in subadults. Whereas, in the southern area dispersal of subadults has been one aim of the study so we therefore have fewer lynx that have disappeared from unknown causes.

The poaching rate was significantly higher in the northern study area than in the southern study area. The lynx conflict differs in the two study areas. In the northern study area the conflict is mainly with the reindeer herding industry loosing reindeer to lynx and resulting in a reduction in the harvest of reindeer. In the southern study area, the conflict mainly considers competition with hunters for the same prey, i.e. the roe deer. Thus, an explanation for the difference between the north and south could be a stronger economical incentive for poaching in the northern study area than in the southern study area. However, poaching of large carnivores has several other causes, such as a conflict between "the rulers and the ruled" or between urban and rural areas (Pyka et al. 2007)

We could not detect any change in poaching rate between the two periods (1994-1999 and 2000-2010). During the same period the Swedish EPA has issued hunting quotas on lynx that have lowered the lynx numbers within the reindeer husbandry area. The main reduction of lynx has occurred in Jämtland county. Within Norrbotten county, where our study area is located, neither the growth of the lynx population (mean growth rate in Norrbotten county, $\lambda = 1.0 \pm 0.07$ SE; Andrén et al. 2010) nor the management practices have changed during the study period (harvest rate less than 2 % of the estimated lynx population, until 2010 when it increased to 10 %; Andrén et al. 2010). In the southern study area the lynx population has gone through an increase and then a decrease. The legal hunting quotas have been fairly low during the study period (less than 6 % of the lynx population until 2009 when it increased to 9 %; Andrén et al 2010). Thus, there have not been any major changes in lynx management policy during the last years. Therefore, we cannot evaluate, for example, if there is a relationship between legal harvest and poaching.

We estimated the poaching rate in two study areas in Sweden and an important question that arises is whether these areas are representative for other parts of Sweden. The northern study area is largely located within the mountain range, whereas most of the lynx in the reindeer husbandry area are found within the boreal forest (Andrén et al. 2010). Thus, from a landscape perspective the northern study area is not representative for the entire reindeer husbandry area. Poaching in the northern study area was higher in later winter/early spring, probably because the snow conditions make it possible to cover large areas with snowmobiles. This might result in a higher poaching rate in the mountain range with good snow cover late into the spring. On the other hand, the rugged slopes in the mountains might be areas where lynx can escape poaching and rugged slopes are also preferred habitat for lynx (Mattisson 2011). The research activities in the area might decrease the poaching risk. Thus, it is difficult to determine whether the poaching rate in the northern study area is higher or lower than in other parts of the reindeer husbandry area.

The southern study area is completely dominated by boreal forest with small and scattered patches of agricultural land that is typical for south-central Sweden. Thus, the southern study area is a fairly good representation of the landscape where most lynx south of the reindeer husbandry area are found. On the other hand, the attitudes towards lynx vary quite a lot among different municipalities in Sweden (Ericsson and Sandström 2005). The poaching rate might therefore vary among areas because of different attitudes towards them and not because of ecological factors, like lynx density, roe deer density or landscape composition. Thus, it is difficult to evaluate whether the southern study area was representative for other areas in south-central Sweden, especially for poaching, as it is very hard to study.

Andrén et al. (2006) estimated the annual growth rate of the lynx population in the northern study area to be 7% ($\lambda = 1.07 \pm 0.071$ SE) based on demographic data. However, this growth rate was not significantly different from stable population growth (i.e. $\lambda = 1$; $p=0.34$). In another study, Andrén et al. (2010) estimated the mean growth rate of lynx population for the entire Norrbotten County to be 0% ($\lambda = 1.0 \pm 0.07$ SE) between 1998 and 2010.

The estimated annual growth rate for the southern study area in 1996 to 2002 was 19% ($\lambda = 1.19 \pm 0.097$ SE, significantly higher than 1, $p = 0.05$), based on demographic data (Andrén et al. 2006). The lynx population in the southern study area has first increased (1994 to 2001) and then decreased (2002 to 2010). During the period that overlaps the period when the demographical data was collected (1996-2002), the lynx population in south-central Sweden had an annual increase of 11% ($\lambda = 1.11 \pm 0.03$ SE; Andrén et al. 2010).

As the growth rates based on demographic data were slightly higher than the observed population growth rates (but not significantly different, $p=0.30$) in both study areas, the estimated rates of mortality (including assumed poaching) were probably not overestimated; if anything mortality might be underestimated.

If the two study areas are representative for the reindeer husbandry area and the area south of the reindeer husbandry area in Sweden, respectively, then the estimated number of lynx poached in the reindeer husbandry area would be around 77 lynx (± 16 lynx SE) per year and around 22 lynx (± 10 lynx SE) per year south of the reindeer husbandry area. It was not possible to estimate a specific effect of poaching in southernmost Sweden, because of few radio-marked individuals in this area. Specifically, we have no confirmed cases of poaching and only one case of assumed poaching from this area, and cannot make an independent estimate of poaching on a small sample size that small. However, it is important to remember that during the colonisation phase of southernmost Sweden, poaching of the few females present in the area can be very efficient in preventing the establishment of a population.

To conclude, poaching is an important cause of mortality in lynx in Sweden, especially in the northern study area, and the poaching rate does not seem to have changed between two periods (1994-1999 versus 2000-2010).

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