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Estimating lynx kill rate on reindeer using GPS-locations and lynx movement pattern.

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Abstract

Large carnivores cause many conflicts in Scandinavia but depredation on livestock is one of the most central ones. Free ranging semi domestic reindeer is an important prey for all large carnivores within the reindeer husbandry area causing a complex carnivore-livestock conflict. In Sweden the state compensates reindeer owners who suffer depredation caused by protected large carnivores through a compensation system based upon presence of large carnivores. To understand the effects a predator has on their prey, estimates of individual kill rates are needed. This study had two main objectives; 1) to test the GPS-technique as a method for identifying kill sites and 2) to estimate lynx kill rate on reindeer. We used GPS-collared lynx within the reindeer husbandry area to evaluate the possibilities to use the GPS-technique to find kill sites by lynx and to develop a model based on GPS-data to estimate kill rate on semi-domestic reindeer in northern Sweden during winter. The GPS-collars on lynx gave a mean success rate of GPS positions over the study period of 82.5 % (range=76.5-87.8) and the proportion of 3D positions (the highest quality) averaged 85.3% (range=81.1-89.8), suggesting that the GPS-collars provided reliable data for studying kill rate by lynx. Using GPS-locations and movement patterns for lynx around visited kill sites and non-kill sites, I developed statistical models to estimate the probability that an unvisited cluster of lynx GPS-location was a kill site or not. Kill rate for 3 individuals, during 7.5, 7 and 4.5 months respectively, were estimated by combining the data from clusters visited in the field and the statistical model for unvisited clusters. The estimated kill rate including these statistical models gave a mean kill rate of 4.6 reindeer per month, ranging from 3.1 to 7.1 reindeer per month. This type of study can contribute to setting appropriate levels of compensation and thereby reduce conflict levels between reindeer owners and large carnivores.

Key words: lynx, reindeer, kill rate, predation, reindeer husbandry,

Introduction

Large predators interact with humans in a diversity of ways and have been persecuted because of the threat to livestock and as competitors for game species wherever humans settled (Breitenmoser 1998). Boitani (1995) described three distinct relationships between humans and the surrounding environment: hunting, sheepherding (both sedentary and nomadic) and agricultural. Humans have been hunters longer than they have been shepherds or farmers, and hunters developed a sense of respect for the predator (Boitani 1995). When hunters became shepherds and started to domesticate animals, a clear shift in attitude towards predators became evident and conflicts between humans and large predators arose and still exist today. Foremost among these conflicts is depredation on livestock (Mech 1995, Cozza et al. 1996, Kaczensky 1996, Pedersen et al. 1999).

Conflict because of depredation on domestic sheep is widespread throughout Europe and North America (Cozza et al. 1996, Kaczensky 1996, Linnell et al. 1996) while depredation on semi-domestic reindeer (*Rangifer tarandus*) is in focus in northern Scandinavia (Kjelvik et al. 1998, Pedersen et al. 1999, Linnell et al. 2001). Linnell et al. (2001) presents three major conflicts involving Eurasian lynx (*Lynx lynx*) in Scandinavia; depredation on domestic sheep, depredation on semi-domestic reindeer, and competition with roe deer hunters. Lynx main prey varies between different geographical areas and different seasons, but they prefer medium-sized ungulates (e.g. roe deer (*Capreolus capreolus*), chamois (*Rupicapra rupicapra*) or reindeer if present (Jedrzejewski et al. 1993, Okarma et al. 1997, Sunde & Kvam 1997, Pedersen et al. 1999, Sunde et al. 2000a, Valdmann et al. 2005, Odden et al. 2006, Schmidt 2008). The fact that large carnivores prey on semi-domestic reindeer is undisputed (Haglund 1966, Nieminen & Leppäluoto 1988, Bjärvall et al. 1990, Pedersen et al. 1999), but the extent is much debated. In northern Sweden, semi-domestic reindeer is the main prey species for lynx (Haglund 1966, Bjärvall et al. 1990, Liberg 1998, Pedersen et al. 1999), which causes a considerable loss for the reindeer husbandry (Nybakk et al. 2002, Danell & Andrén 2004). Pedersen et al. (1999) found that a lynx family group killed on average one reindeer every five days.

A new system of economic compensation for predatory losses of reindeer was introduced in Sweden in 1996. This compensation system is unique and only exists in Sweden. The compensation is based upon number of reproductions and presence of large carnivores rather than the total documented number of carnivore-killed reindeers. This compensation system was created and implemented to enable reindeer owners to receive adequate compensation for actual losses connected to carnivore presence, and to increase tolerance for large carnivores among the various interest groups (Zabel & Holm-Müller 2008). The size and the relative distribution of the compensation among the Sami reindeer herding districts are based upon the number of reproductions and presence of lynx, wolverine (*Gulo gulo*) and wolf (*Canis lupus*). Golden eagle (*Aquila chrysaetos*) and brown bear (*Ursus arctos*) are instead compensated based on the area of the Sami reindeer herding districts. The Sami reindeer herding districts are presently compensated with 200 000 SEK for each lynx and wolverine family group. This amount is supposed to compensate not only reindeer losses but also include extra work that predators may cause to a reindeer herder. There is much debate and discussion whether the compensation system is correct and if the compensation level is sufficient to cover actual losses. To set appropriate levels of compensation and to find out the effects lynx have on their prey, estimates of the kill rates of individual carnivores are needed (Pedersen et al. 1999). Furthermore, a model for estimating the total number of reindeers killed by lynx would be a good addition to improve the compensation system (Falk 2009).

Traditional VHF telemetry and snow tracking have been used to estimate kill rate of large carnivores. However, with Global Positioning Systems (GPS) in collars on wild animals, new opportunities have been created (Rumble et al. 2001, Knopff et al. 2009). The development and availability of GPS-technology in collars used in large carnivore research may offer a more precise tool for estimating kill rates because animals can be followed in more detail than by VHF-collars (Anderson & Lindzey 2003, Sand et al. 2005). Compared to traditional VHF-telemetry, GPS-technology has a high temporal and spatial precision of positioning, and large amounts of data can be sampled with relatively low manpower efforts (Hulbert 2001, Millspaugh & Marzluff 2001, Rodgers 2001). High precision and intensity of animal positions allow detailed analyses such as habitat use, movement patterns, territory size, space use, social behaviour and predation (Hulbert 2001, Zimmerman et al. 2001). In several recent studies, GPS-locations have been used to find carnivore kill sites and to design models to estimate kill rate based on GPS-data (Anderson & Lindsey 2003, Sand et al. 2005, Zimmermann et al. 2007, Webb et al. 2008, Knopff 2009 et al.).

The aim of this study was to evaluate the possibilities to use GPS-technique in GPS-collared Eurasian lynx and to develop a model based on GPS-data to estimate kill rate by lynx on semi-domestic reindeer in northern Sweden during winter. This study was part of a larger project on lynx predation of reindeer and lynx interaction with wolverine.

Study area

The study was conducted in northern Sweden (66°99’-67°75’N, 17°41’-16°50’E) in the county of Norrbotten. The study area, which covers about 7000 km^2, is situated within the watershed of Lilla and Stora Luleälv (Fig 1). It is partly located within the three national parks; Stora Sjöfallet, Sarek and Padjelanta. The area is located within five Sami reindeer herding districts - from the north: Sörkaitum, Sirges, Jåhkågasska, Tuorpon and Luokta-Màvas.

The climate is continental with warm summers and cold winters with mean temperatures between 11° and 13° C in July and between -11° and -16° C in January (SMHI). Snow usually covers the ground from October to May, with snow depths regularly exceeding 1 meter. The weather is often shifting, and can vary within a very limited area such as a valley. The altitudinal gradient ranges from 200 m a.s.l. to over 2000 m a.s.l., with the tree-line at 600-700 m a.s.l. The vegetation varies according to elevation, the lower area consists mainly of old growth coniferous forests dominated by Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) with patches of birch (*Betula spp.)* and aspen (*Populus tremula*). At higher elevation the area is dominated by mountain birch (*Betula pubescens)* along with small shrubs and plants above the tree-line. A large percentage of the area consists of rocky terrain and a few percent consist of permanent snowfields and glaciers. Less than 1% of the study area is classified as cultivated land. Human settlement is minimal and infrastructure consists of only two dead end roads.

Reproducing populations of lynx, brown bear and wolverine occur in the study area and there is sporadic occurrence of wolves. Important scavengers in the area are red fox (*Vulpes vulpes,* golden eagle (*Aquila chrysaetos*), white-tailed eagle (*Haliaeetus albicilla*) and raven (*Corvus corax)*. Moose (*Alces alces*) is the only wild ungulate occurring in significant numbers. All reindeer present within the study area are semi-domestic.

Semi-domestic reindeer is the main prey species for lynx in the area (Pedersen et al. 1999). Other available prey species are red fox, mountain hare (*Lepus timidus*), capercaille (*Tetrao urogallus*), black grouse (*Tetrao tetrix*), hazel grouse (*Bonasa bonasia*), willow grouse (*Lagopus lagopus*), ptarmigan (*Lagopus mutus*) and various species of rodents.

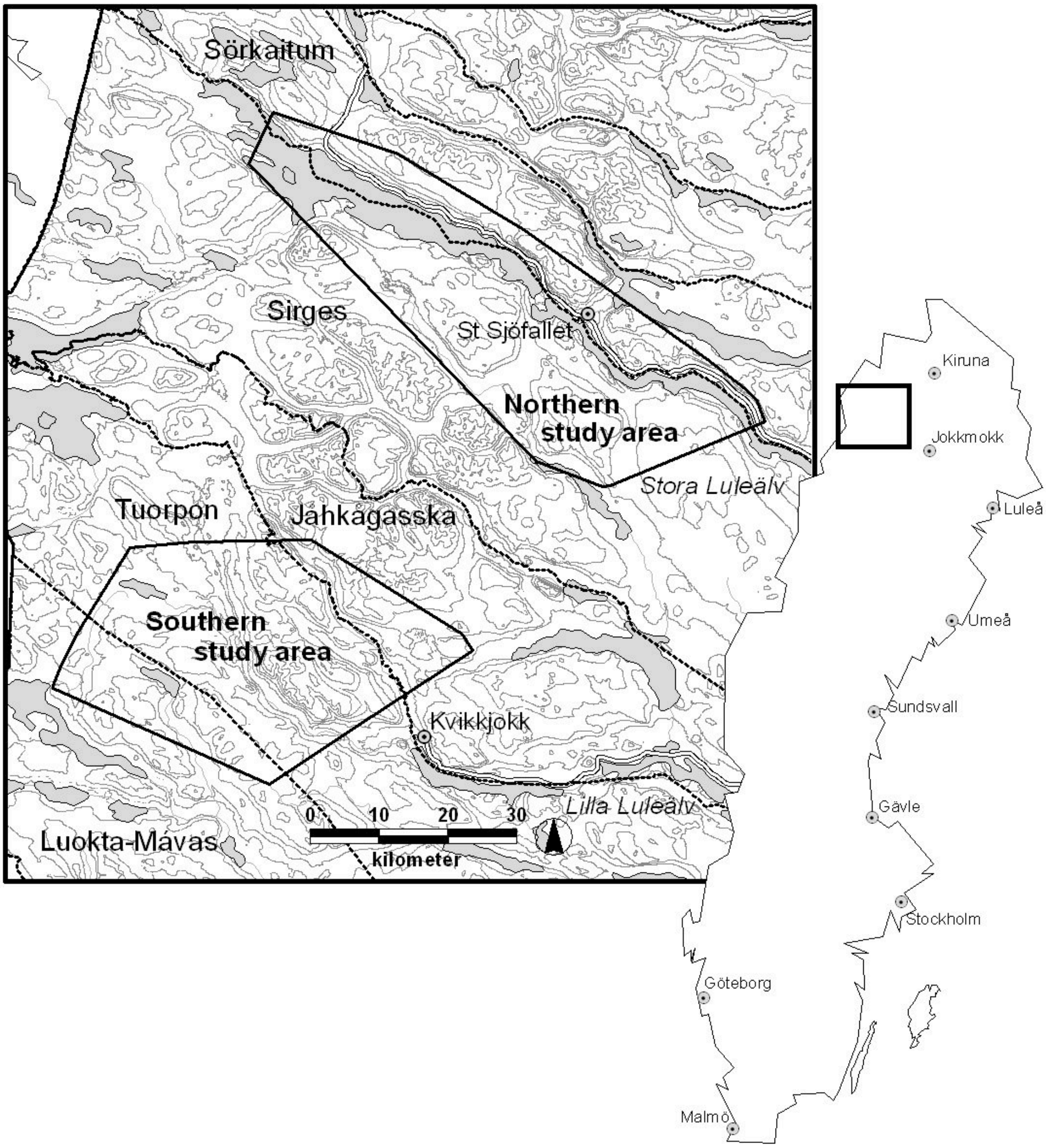

Figure 1. *The study area in northern Sweden. The northern polygon represents Rasmus' and Malin's home range (Malin's home range covers about half the size of Rasmus' in the same area) and the southern polygon represent Edward's home range.*

Reindeer husbandry in the area

The total herd size of reindeer in the five Sami reindeer herding districts has fluctuated between 20 000 to 30 000 individuals/year between 1996 and 2003. Over-wintering herd sizes in the season 2002/2003 were in Sörkaitum: 3 700, Sirges: 14 500, Jåhkågasska: 3 100, Tuorpon: 5 400 and in Luokta-Màvas: 3 800 (T. Raunistola, personal communication). The reindeer migrates between winter and summer ranges, thus utilizing different parts of the study area during different times of the year. Wintering grounds are located to the southeastern part in each of the reindeer herding districts. Although attempts are made to gather all reindeer prior to migration, a small but unknown number of reindeer remains in the study area during winter.

Lynx density

The number of lynx family groups in the five Sami reindeer herding districts in the study area was 9 in 2003 distributed as follows: Sörkaitum: 2.5, Sirges: 0.5 (one lynx family group was tracked and documented in two different Sami reindeer herding district and is divided between them), Jåhkågasska: 1, Tuorpon: 2 and Luokta Màvas: 3. The number of lynx family groups found during the annual population survey has varied between 5 and 20 between1996-2003 (The County administrative board of Norrbotten). Using a conversion factor of 6.14 from number of family groups to total population size (Andrén et al. 2002) this would equal an average total lynx density of 0.2 to 0.7 individuals per 100 km^2. Studies of lynx movement patterns in relation to reindeer migration found that lynx remained stationary even though reindeer migrated to and from the wintering grounds (Danell et al. 2006).

Methods

Lynx

Three radio-collared lynx, two adult males (Edward and Rasmus) and one adult female (Malin) with 2 cubs, were live-captured by darting from a helicopter. They were immobilized using a mixture of ketamine (5 mg/kg) and metetomidine (0.2 mg/kg; Kreeger et al. 1999) and equipped with store-onboard GPS-collars (PosRec; Televilt International, Lindesberg, Sweden). The handling scheme for the lynx has been examined by the Swedish Animal Ethics Committee and fulfils the ethical requirements for animal research. The two males were captured and equipped with GPS-collars in the beginning of October 2002, followed by a recapture and again equipped with new GPS-collars at the end of January 2003. The adult female was marked at the end of January 2003. Collars activated at the end of January fell off in mid-May and June (Table 1).

GPS technology

GPS-collars were programmed to take a position every third hour (at 03:00, 06:00, 09:00, 12:00, 15:00, 18:00, 21:00 and 24:00 hr), each day. The collars could store up to 1500 positions, but the GPS-collars drop-off function was activated when the battery power decrease to a critical level. Battery longevity depended on both temperature and satellite contact success. After drop-off a VHF-signal was activated so that the collars could be located, collected and sent back to Televilt International, Lindesberg, for data retrieval. Location data were plotted in ArcView version 3.2® (Environmental System Research Institute, Inc. 2002) for analyses.

Clusters of GPS-positions

Initially, the definition of a cluster was when ≥2 positions were within 200 meter of each other (Anderson & Lindsey 2003, Sand et al. 2005). As this study was part of the development of the methodology the selection of clusters was combined with a manual selection by studying accumulated GPS-locations in ArcView 3.2. A large number of positions and a long duration within a small area were manually selected and later on visited in the field. Selected clusters were visited in the field using a handheld GPS and carcasses of killed prey (reindeer) were intensively searched for at a 100 m radius of the center-point of each cluster. The search for reindeer carcasses within clusters from the first periods of the two males (GPS-collared for 3 and 4 months respectively) started in mid-March 2003 whereas the search for clusters from the second period started in June 2003. During March, April and May (winter) clusters were visited using snowmobiles and on skis, and during summer/autumn the same year clusters were visited using helicopter and by foot with dogs. The search at clusters for prey remains only started to yield results during the beginning of April and only in the high-alpine areas where the snow had blown away, as there was too much snow in the woodlands to carry out effective field work. Some clusters where there was too much snow during winter were revisited during summer.

Kill sites

When prey remains was found at a cluster coordinates were logged in a hand-held GPS. The amount of carcass remains, the gender of prey (where applicable), and the terrain (e.g. incline, distance to nearest forest edge) around the kill site was noted.

Creating a model

To build a statistical model to estimate lynx kill rate on reindeer several characteristics (listed below) were derived in ArcView 3.2 for visited clusters with and without carcass remains. Based on GPS-positioning, movement of the lynx around the kill-site was derived in ArcView 3.2 where movement was defined by position of animals in relation to different buffer zones around the carcass (see below). The following 10 independent variables were derived using ArcView 3.2; number of hours based on first and last GPS position at the cluster for 2 different buffer zones with a radii of 100 and 200 m, number of positions and number of visits at the cluster for 4 different buffer zones with a radii of 100, 200, 1000 and 2000 m respectively (Fig 2, Table 2).

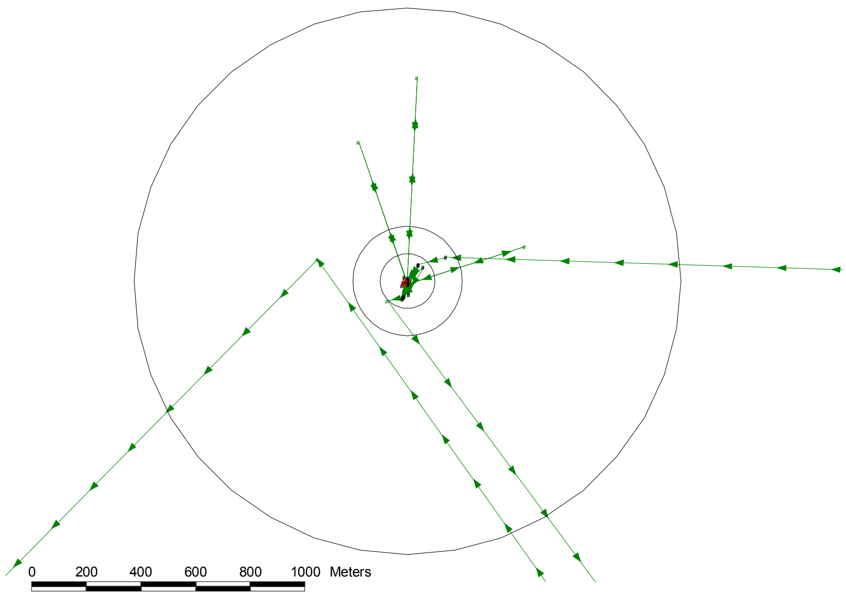

Figure 2. *The circles illustrate 100, 200 and 1000 m buffer zones. The points are an example of lynx GPS-positions plotted in ArcView. In the inner circle is an accumulation of positions – a cluster - that indicates a kill site.*

The buffer distance was created around the mean value of the cluster positions. When positions were continuously within a buffer zone it was considered to be one visit. It was considered a new visit if the individual lynx had positions outside the buffer and then returned back into the buffer zone again.

Clusters were classified into presence of prey remains (kill site) or absence of prey remains (non kill site). To find the best statistical model to separate between visited clusters with (1) and without (0) carcass remain 22 different logistic regression models (StatView 5.0, 1998) were tested, using the 10 independent variables described above (see Table 3 for candidate models). Akaike Information Criterion (AIC) was used for the model selection (Burnham & Anderson 2002). The probability that an unvisited cluster would have carcass remain was calculated from the logistic regression. If the estimated probability exceeded 50 %, it was assumed that a lynx killed reindeer was present at the cluster. The first position within the buffer zone assumed to be the time when the reindeer was killed.

Kill rate was calculated as documented reindeer carcasses plus assumable killed reindeer according to the model divided by the number of months in the study. This method of calculating lynx kill rate requires the assumption that lynx always kill their own prey and do not use other prey remains.

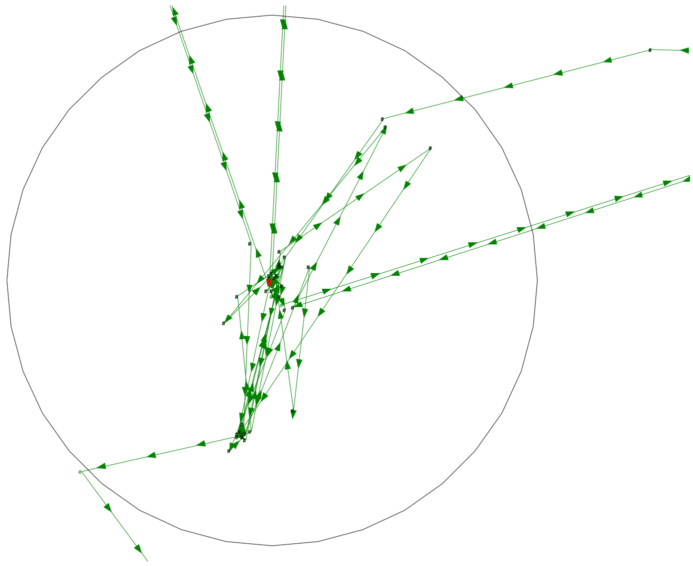

Figure 3. *The circle illustrates a 100 m buffer zone and is a zoom of the image in Figure 2. The points show lynx positions plotted in ArcView and the accumulation of positions - cluster - in the central of the circle indicate a kill site.*

Results

GPS positioning data

In total three GPS-collared lynx was studied; 2 adult males for two study periods each and 1 female with cubs for 1 study period. Total length of study period was 580 days, yielding total 3812 GPS-positions (range=534-949 positions and 85-138 days per period; Table 1). Success rate of GPS positions over the study period averaged 82.5 % (range=76.5-87.8) and the proportion of 3D of successful positions (highest quality positions) averaged 85.3% (range=81.1-89.8; Table 1). Of the total number of positions received, 1323 were classified as belonging to a cluster when defining clusters as ≥2 positions within 200 meter of each other.

The time of visit of the clusters ranged from 3 – 266 days after the lynx was last present at the site. There was great variation between clusters when it came to amount of remains found, ranging from actual intact carcasses to some bones and skin/hairs or just hair scattered over a large area. In total 69 clusters were visited and remains of reindeer were found in 50 of them (Table 1). Remains of reindeer carcasses were often found within 20-25 m from the center of the cluster.

Table 1. *Date and length of study periods, Global Positioning System data, home range size, numbers of clusters visited and numbers of carcasses (or carcasses remains) found. Data collected winter and spring 2002/2003 from field studies in northern Sweden.*

Lynx	**Edward**		**Rasmus**		**Malin**	**Total**
Study period	021003-021226	030131-030614	021002-030131	030131-030510	030131-030617	
No. of days	85	135	122	100	138	580
No. of GPS positions received	534	891	740	698	949	3812
Success rate of GPS positions (%)	79.0	82.8	76.5	87.8	86.4	82.5 (mean)
Proportion of 3D positions (%)	85.0	85.2	85.2	81.1	89.8	85.3 (mean)
Home range size (MCP; km^2)	1360	960	1215	1580	840	1191 (mean)
No. of positions belonging to cluster	183	299	232	249	360	1323
No. of clusters	28	62	36	38	102	266
Total number of clusters visited	15	9	17	12	16	69
No. of killed reindeer	8	9	12	9	12	50

Table 2. *Independent variables derived in ArcView for visited cluster.*

	Parameter
1	No. of hours within 100 m buffer zone
2	No. of hours within 200 m buffer zone
3	No. of positions within 100 m buffer zone
4	No. of positions within 200 m buffer zone
5	No. of positions within 1000 m buffer zone
6	No. of positions within 2000 m buffer zone
7	No. of visits within 100 m buffer zone
8	No. of visits within 200 m buffer zone
9	No. of visits within 1000 m buffer zone
10	No. of visits within 2000 m buffer zone

Model and kill rate

Two models were more prominent among the 22 different logistic regression models. According to model 1, the most important variables are number of visits within the 100 meter buffer, and the 2000 m buffer, while model 2 also includes the number of positions within the 100 m buffer zone (Table 3 and 4). According to model 1, the kill-rate varied between 3.1 and 7.1 reindeer/month with a mean at 4.6 reindeer/month (Table 5) when using all five study periods. The estimated kill rate for one of the males during winter (October – January) was 5 reindeer per month according to model 1 (Table 6a) and 4.5 reindeer per month according to model 2 (Table 6b).

Table 3. *To find the best model to separate between visited clusters with (1) and without (0) carcass remain 22 different logistic regression models (StatView 5.0, 1998) were tested, using 10 independent variables. Akaike Information Criterion (AIC) was used for the model selection (Burnham & Anderson 2002).*

	Parameter	**Delta AIC**
1	No. of visits in 100 m and 2000 m buffer zone	0
2	No. of visits in 100 m and 2000 m + no. of positions within 100 m buffer zone	1.584
3	No. of visits (100 m) + no. of hours (100 m) + no. of visits (2000 m)	1.882
4	No. of positions (100 m)+ no. of visits (2000 m)	2.202
5	No. of positions (2000 m) no. of visits (2000 m)	2.510
6	No. of visits (100 m)	2.840
7	No. of hours (200 m)	3.608
8	No. of hours (100 m) + no. of positions (100 m) + no. of visits (2000 m)	4.201
9	No. of visits (100 m) + (1000 m)	4.294
10	No. of hours (100 m)	4.377
11	No. of positions (100 m) + no. of visits (100 m)	4.630
12	No. of visits (100 m) + no. of hours (100 m)	4.637
13	No. of visits (200 m)	6.646
14	No. of positions (1000 m)	5.477
15	No. of positions (2000 m)	5.533
16	No. of visits (100 m) + no. of positions (100 m) + no. of visits (1000 m)	6.036
17	No. of visits (200 m) + no. of hours (200 m)	6.201
18	No. of positions (100 m)	6.845
19	No. of positions (200 m)	7.350
20	No. of visits (2000 m)	7.594
21	No. of hours (100 m) + no. of positions (100 m) + no. of visits (1000 m)	7.870
22	No. of visits (1000 m)	9.771

Table 4. Summary of the 2 best models describing the presence or absence of a reindeer carcass at the cluster of GPS-positions.

	Parameter	DF	Log Likelihood	Intercept Log Likelihood	Deviance	AIC	Delta AIC
Model 1	Number of visits in 100 m and 2000 m buffer zone	2	-17.539	-33.371	31.664	21.539	0
Model 2	Number of visits in 100 m and 2000 m + number positions in 100 m buffer zone	3	-17.123	-33.371	32.496	23.123	1.584

Model 1; *Logit (Probability of a carcass at a cluster of GPS-positions) = -17.275 + 1.417 (Number of visits at 100 m buffer zone) + 14.544 (Number of visits at 2000 m buffer zone)*

Model 2*; Logit (Probability of a carcass at a cluster of GPS-positions) = -18.551 + 1.211 (Number of visits at 100 m buffer zone) + 15.574 (Number of visits at 2000 m buffer zone) + 0.105 (Number of positions within 100 m buffer zone)*

Table 5. *The estimated number of reindeer killed according to Model 1 during the 5 study periods for the 3 lynx individuals.*

Lynx	**Edward**		**Rasmus**		**Malin**	**Mean**
Study period	021003-021226	030131-030614	021002-030131	030131-030510	030131-030617	
Number of reindeer killed – model 1	10	14	20	14	32	
Kill rate – model 1 (reindeer/month)	3.3	3.1	5	4	7.1	4.6
Kill rate – model 1 (days/reindeer)	8.5	9.6	6.1	7.1	4.3	7

Table 6a. *A single lynx male kill rate on reindeer. (Oct-Jan) according Model 1 (20/4=5 reindeer/month).*

No	Date	Median date	Days between	Probability Model 1	Found at cluster
1	05 Oct	2002-10-05		0.526	*
2	13-18 Oct	2002-10-15	10	0.997	Reindeer
3	21-22 Oct	2002-10-21	6	1.000	*
4	31 Oct-4 Nov	2002-11-02	12	0.997	Reindeer
5	19 Nov-21 Nov	2002-11-20	18	0.987	*
6	24-29 Nov	2002-11-26	6	1.000	Reindeer
7	1-2 Dec	2002-12-01	5	0.821	*
8	5-8 Dec	2002-12-06	5	0.950	Reindeer
9	13-14 Dec	2002-12-13	7	0.526	Reindeer
10	16-17 Dec	2002-12-16	3	1.000	Reindeer
11	25-27 Dec	2002-12-26	10	0.950	*
12	30-31 Dec	2002-12-30	4	0.526	*
13	3-6 Jan	2003-01-04	5	1.000	*
14	7-8 Jan	2003-01-07	3	0.526	Reindeer
15	10-11 Jan	2003-01-10	3	0.526	*
16	12-14 Jan	2003-01-13	3	0.821	Reindeer
17	15-16 Jan	2003-01-15	2	1.000	Reindeer
18	19-21 Jan	2003-01-20	5	0.526	Reindeer
19	24-28 Jan	2003-01-26	6	1.000	Reindeer
20	28-31 Jan	2003-01-29	3	1.000	Reindeer

* - indicates a not visited cluster

***Table 6b**. A single lynx male kill rate on reindeer. (Oct-Jan) according Model 2. (18/4=4.5 reindeer/month).*

No	Date	Median date	Days between	Probability Model 2	Found at cluster
1	13-18 Oct	2002-10-15		0.999	Reindeer
2	21-22 Oct	2002-10-21	6	1.000	*
3	31 Oct-4 Nov	2002-11-02	12	0.998	Reindeer
4	19 Nov-21 Nov	2002-11-20	18	0.986	*
5	24-29 Nov	2002-11-26	6	1.000	Reindeer
6	1-2 Dec	2002-12-01	5	0.783	*
7	5-8 Dec	2002-12-06	5	0.931	Reindeer
8	13-14 Dec	2002-12-13	7	1.000	Reindeer
9	16-17 Dec	2002-12-16	3	0.765	Reindeer
10	25-27 Dec	2002-12-26	10	0.540	*
11	30-31 Dec	2002-12-30	4	0.519	*
12	3-6 Jan	2003-01-04	5	1.000	*
13	7-8 Jan	2003-01-07	3	0.440	Reindeer
14	12-14 Jan	2003-01-13	6	1.000	Reindeer
15	15-16 Jan	2003-01-15	2	1.000	Reindeer
16	19-21 Jan	2003-01-20	5	0.692	Reindeer
17	24-28 Jan	2003-01-26	6	1.000	Reindeer
18	28-31 Jan	2003-01-29	3	1.000	Reindeer

* - indicates a not visited cluster

Discussion

The main objective in this study was to evaluate the possibility to use GPS-technique in GPS-collared Eurasian lynx and to develop a model based on GPS-data to estimate kill rate on semi-domestic reindeer in northern Sweden during winter. The GPS technique in this study gave a large number of positions and a high success rate in those positions that were received. This study shows that it is possible to study lynx kill rate on semi-domestic reindeer based on GPS-technique. Today there are more sophisticated and better technology with communicative collars where data is available more rapidly than for the collars used in my study. This new techniques allsows for better studies because now the potential kill sites can be visited and checked more rapidly. Moreover, the new technique also provides more data and more frequent positioning than did the collars in my study. Nevertheless, my study showed that GPS technology can be used to determine lynx kill rate on their prey.

Lynx movement back and forth between a carcass and a rest site (numbers of visits) was the most important variable indicating a kill site according to the models in this study and this movement pattern was also described by Okarma et al. (1997) and Falk (2009). Other important variables that in combination with revisits indicate a kill site, is the number of positions, i.e. total time spent around the kill site. Falk (2009) found that lynx spent on average 40 hours around kill site, which is similar to other studies (Jedrzejewski et al. 1993, Okarma et al. 1997, Pedersen et al. 1999, Jobin et al. 2000).

According to model 1 in this study, the kill-rate varied between 3.1 and 7.1 reindeer/month with a mean at 4.6 reindeer/month (Table 5) when using all five study periods. There are only a few studies describing individual lynx kill rate on reindeer (Pedersen et al. 1999, Mattisson & Andrén 2008), and our two best models estimates a kill rate equal to these studies, which supports our models. This also corresponds to lynx bio energetic calculations (Danell, A. pers. comm.). There is not enough data to draw any general conclusions from my study, but previous studies on lynx predation on reindeer showed that lynx family groups, on average, kill up to one reindeer approximately every fifth day, which amounts to 6 reindeer per month (Pedersen et al. 1999). However, there is a large individual variation in kill rate as well as variation between different lynx categories, during different time of year (Mattisson & Andrén 2008), which makes it very difficult to create a simplified model.

The kill rate for lynx predating on reindeer is similar to their kill rate on roe deer (Pedersen et al. 1999, Andrén et al. 2004) but reindeer predation shows a greater variation (Andrén pers. com). Lynx family predation was estimated to 5.6 roe deer per month or one roe deer every fifth day (Andrén et al. 2004) and up to one reindeer approximately every fifth day, which amounts to 6 reindeer per month (Pedersen et al. 1999). Kill rate studies in the reindeer husbandry area show great variation in kill rates, from 0 to 7 reindeer per lynx family (average 3.6) depending on season and study area (Mattisson & Andrén 2008).

Several studies show that single females have the lowest kill rate of all categories of lynx (Okarma et al. 1997, Moshøj 2002, Mattisson 2003) while other studies show a slightly higher kill rate for single females than for males (Molinari-Jobin et al. 2007). Okarma et al. (1997) found that the average kill rate by lynx was 5.5 deer/month where lone female lynx killed on average 3.6 deer/month, most of them being roe deer and an adult male lynx killed 6.3 deer/month. Several studies on lynx predation on roe deer show that family groups have the highest kill rate (Okarma et al. 1997, Nilsen et al. 2009) and that family groups utilize more of their prey (Breitenmoser & Haller 1993).

This study had restrictions in precision as the cluster analysis did not capture all the carcasses, and not all of the carcasses were found since some clusters were visited as long as up to six months after the lynx was at the site. Carcasses and carcass remains may quickly be moved or degraded because of scavengers and other factors such as weather and wind. Defining clusters as ≥2 positions within 200 meter cause a great number of clusters and shows a great deal of rest sites and therefore demands a large-scale effort in the field. Therefore this method was supplemented with manually identified clusters as we realized rather immediately that clusters with a large number of positions and situations where the lynx returned indicated a possible kill site.

An improved knowledge regarding lynx predation on reindeer of all categories of lynx throughout the whole year is needed. Now there is new GPS technology that allows us to get information directly from GPS collars and this makes it possible to visit GPS location more rapidly to search for prey remains. A combination of more frequent positioning and continuous tracking can definitely improve the accuracy in estimating lynx predation and create possibilities to develop an improved and more precise model to identify kill sites by lynx based on GPS-locations and movement patterns and a model like this may function as an important tool for both lynx and reindeer management. Specifically, estimating kill rate by lynx is important for developing correct levels of compensation for lynx killed reindeer. For all different actors involved in wildlife management within the reindeer husbandry area (wildlife research, management, reindeer herding), it is central to accomplish accurate predation studies in order to establish correct levels of compensation for losses to predators and thereby increase the acceptance of predators. There are several studies showing the importance of evidence-based conservation in order to facilitate decisions by authorities which will probably lead to a more effective and concrete natural resource management and conservation (Meffe et al. 1998, Sutherland et al. 2004, Pullin & Stewart 2006, Bottrill et al. 2008). Meffe et al. (1998) says "making well-informed decisions regarding the use and protection of natural resources requires that we fully consider and employ the most reliable and accurate scientific information and judgment available" and this kind of thinking hopefully leads to a higher level of acceptance and tolerance and ultimately conflicts hopefully can be reduced.

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