Illegal killing of wolves in Scandinavia 1998 – 2011: variation in space and time.

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ABSTRACT

Mortality and illegal killing was investigated in the Scandinavian wolf population for the period December 1998-February 2011. We quantified the illegal killing of wolves in order to test for differences between Sweden and Norway and to test whether the gradual changes in Swedish wolf policy from 2004 and onwards have had any effect on the extent of illegal killing. The main method was analysis of cause specific mortality in radio-collared wolves. Retrieved dead wolves were examined post mortem for cause of death. All cases of lost radio contact were checked against a number of standardized criteria for classification of the disappearance to illegal killing or any other cause. A total of 123 wolves were radio collared, producing data from a total of 160.9 “radio-years”. At the end of the study we still had contact with eight of the 123 wolves. Six wolves died in connection with capture and handling and were excluded from analysis. 29 wolves were confirmed dead with radio collars still functioning of which 9 were due to natural causes, 5 were killed by road and railway traffic, 10 were legally shot, and 5 cases were verified illegal killing. We lost radio contact with 80 wolves of which 19 were classified as probably illegally killed.

Total annual wolf mortality rate for Scandinavia for the total study period was 0.26. Mortality from illegal killing was 0.13 and from other causes 0.13. Both total mortality (Norway 0.36; Sweden 0.22) and illegal killing (Norway 0.18; Sweden 0.11) was higher in Norway than in Sweden. There was a large inter-annual variation in the rate of illegal killing, but in Sweden there was a decreasing trend with time. Analysis of a possible well defined break point in this trend gave significance for 31st Dec in 2003, 2004 and 2005, with the highest probability for 2005, which we then used to split the material into two periods, 1998-2005 and 2006-2011. Both total mortality (0.31 vs 0.17) and illegal killing (0.16 vs 0.08) decreased from 1998-2005 to 2006-2011 in Scandinavia. However, the extent of illegal killing in Norway and Sweden showed opposite trends over the two time periods. Whereas Norway had a non-significant increase in this type of mortality after 2005, Sweden had a significant almost seven-fold decrease, from 0.169 to 0.025, which corresponds to a reduction with almost two thirds of the total number of wolves illegally killed per year. The decrease in illegal killing of wolves in Sweden after 2005 was supported by a larger dataset based on verified cases of illegal killing including both collared and un-collared wolves, but only weakly so by data on old shot wounds found during post mortem autopsy of dead wolves.

An alternative method for determining mortality for the whole Scandinavian population, based on annual censuses of the population combined with data on reproduction, gave support for a reduction of total mortality (corresponding figures given for the dataset based on radio collared wolves within brackets); 0.26 (0.31) in 1998-2005 and 0.20 (0.17) in 2006-2011. The decrease in total mortality rate of wolves in Sweden between the two time periods probably was the most important reason for an increase in the average annual growth rate of the Swedish wolf population from 14 % in the period 1998-2005 to 19 % in the period 2006-2010.

SAMMANFATTNING PÅ SVENSKA

Dödlighet och illegalt dödande av varg undersöktes i Skandinavien under perioden december 1998-februari 2011. Studiens syfte var att kvantifiera omfattningen av illegalt dödande av varg och eventuella skillnader mellan Sverige och Norge samt huruvida den gradvisa förändringen av vargpolitiken i Sverige från och med 2004 har haft någon effekt på nivån av illegalt dödande i Sverige. Huvudmetoden var analys av orsaksspecifik mortalitet hos radio-märkta vargar. Alla döda vargar som återfanns blev obducerade för fastställande av dödsorsak. Alla fall av förlorad radio kontakt kontrollerades mot ett antal standardiserade kriterier för klassificering av försvunna individer som antingen *sannolikt* illegalt dödande eller försvunna av annan orsak. Totalt omfattade vårt dataset 123 radio-märkta vargar vilket resulterade i totalt 160,9 s.k. "radio-år". När studien avslutades hade vi fortfarande kontakt med åtta vargar. Sex vargar dog i samband med fångst/märkning och exkluderades från vidare analys. 29 vargar registrerades döda medan deras radiosändare fortfarande fungerade. Nio av dessa dog av naturliga orsaker, 5 dödades av tåg eller bil, 10 sköts lagligen och 5 blev illegalt dödade. Vi förlorade radiokontakten med 80 vargar. Nitton av dessa klassificerades som *sannolikt* illegalt dödade.

Total årlig dödlighet i Skandinavien för hela studieperioden var 25,9 %. Illegalt dödande utgjorde 12,8 % och andra orsaker 13,1 % av den totala dödligheten. Norge hade högre nivåer än Sverige, både för total dödlighet (Norge 35,6 %; Sverige 22,4 %) och för illegalt dödande (Norge 17,9 %; Sverige 11,1 %). Mellanårsvariationen var stor både för total dödlighet och för illegalt dödande, men i Sverige visade den senare en klart avtagande tendens med tiden. Vi analyserade om det statistiskt gick att visa någon bestämd brytpunkt över tiden för denna dödlighet. Vi fann en säkerställd sådan för 31 december åren 2003, 2004 och 2005, med störst sannolikhet för 2005. På basis av denna analys delade vi därefter in materialet i två tidsperioder, 1998-2005 resp. 2006-2011.

Både total dödlighet (30,5 % vs 16,8 %) och illegalt dödande (15,7 vs 7,7 %) minskade från perioden 1998-2005 till 2006-2011 i Skandinavien. Den illegala dödligheten uppvisade dock motsatta tidstrender i Norge och Sverige. Norge hade en icke-säkerställd ökning av denna typ av mortalitet efter 2005, medan Sverige hade en statistiskt säkerställd, nästan sjufaldig, minskning från 16,9 % till 2,5 %, vilket motsvarar en minskning av antalet illegalt dödade vargar per år med två tredjedelar. Den s.k. censusmetoden för bestämning av total dödlighet (baserad på de årliga inventeringarna av hela populationen samt reproduktionsdata) gav samma trend för total dödlighet i Skandinavien som materialet från radio-märkta vargar, med 26 % för perioden 1998-2005 och 20 % för perioden 2006-2011.

Nedgången av illegalt dödande av varg i Sverige efter 2005 stöds även av data på verifierade fall av illegalt dödande i ett större datamaterial omfattande både radio-märkta och omärkta vargar men endast svagt stöd från data på gamla skottskador som upptäcktes vid obduktioner av vargar som dött av andra orsaker. Ett ytterligare stöd för en nedgång av illegalt dödande av varg i Sverige är en demonstrerad ökning av den genomsnittliga årliga populationstillväxten av den svenska vargstammen, från 14 % under perioden 1998-2005 till 19 % under perioden 2006-2010.

BACKGROUND

Large carnivores (LC) are controversial animals in most places where they occur (Treves and Karanth 2003). A consequence of this controversy is that human caused killing and specifically intentional illegal killing (poaching) often is a large problem for small threatened LC populations (Woodroffe and Ginsberg 1998, Creel & Creel 1998, Damania et al. 2003, Altrichter et al. 2006). There has been identified several different cause factors behind illegal killing of LC, but in affluent countries with low commercial incentives to poach, its existence might be an expression of disapproval of the prevailing conservation policy (Eliasson 2004). One major question of interest for the conservation of LC is whether a relaxed legal protection would lead to a decrease in illegal killing. A few studies have reported results that support a negative correlation between the extent of legal hunting of LC and illegal killing (Wielgus et al. 1994, Huber 2002, Andrén et al 2006), but the existence of such a trade-off also has been rejected (Treves 2009). Good data on this question are still lacking, although much needed considering its high relevance for the management of LC. In this report we use data from a long-term research project on wolf ecology to explore this subject, using differences in wolf policy between two countries sharing the same wolf population, but with a radical shift of wolf policy in one of the countries during the study period.

Sweden together with Norway constitutes the 837,000-km^2 Scandinavian peninsula, here referred to as Scandinavia (55°-72° N, 5°-31°; Fig. 1). The present wolf range covers 100 000 km^2 in the south-central part of the peninsula, but with the main part (c. 80%) in Sweden (Fig. 1). The two countries have rather different political and economic situations which also have formed their management policies for LC (Swenson and Andrén 2005). Sweden is highly industrialized and farming is strongly rationalized in large units with rural society proportionately small, and thus of less political influence. Norway, on the other hand, has pursued a policy of preserving and promoting rural communities and culture by subsidies for small-scale agriculture. As a result, a greater proportion of the Norwegian human population inhabits rural areas, and consequently is more politically empowered relative to its Swedish counterpart. In addition, Sweden is a member of the European Union and is bound to the strong protective legislation for large carnivores whereas Norway is not. Consequently, Norwegian wolf policy is more influenced by rural interests and less by those of nature protectionists as compared to Sweden.

These different situations in the two countries have led to different policies regarding the management of LC. The Swedish wolf management policy is regulated by the Predator Act “En sammanhållen rovdjurspolitik” passed by the Parliament in 2001 (Swedish Ministry of Environment 2000; MJU9, rskr 2000/01:174). The Act states that a preliminary national goal for wolves is to reach a minimum of 20 breeding packs. Before this goal is reached control of wolves (e.g. to reduce depredation or mitigate conflicts in other ways) should be kept to a minimum. Wolves shall be allowed to occur all over the country wherever there is suitable habitat, but with the restriction that breeding packs should not be allowed within the reindeer summer grazing range (mainly the alpine areas).

Before 2004 even the right to defend domestic animals from large carnivore attacks was very restricted, but from this year and onwards a number of steps were taken to liberalize this strict legislation. Earlier the care-taker was not allowed to kill the attacking carnivore before any of his livestock was wounded or dead but in 2004 this requirement was relaxed if the attack occurred inside a fenced area. After the election in 2006 a new Swedish government continued the movement towards a more liberal predator policy, starting with further relaxing conditions for control harvest of depredating carnivores, and for self-defense of domestic animals. Now it became allowed to kill an attacking carnivore before any damage had occurred, even outside fenced areas, also including defense of hunting dogs. This change in legislation resulted in an increase in the annual number of legally killed wolves from 1.3 annually during 1999-2006 to 4.0 during 2007-2010. In 2009 the national goal of 20 annual wolf reproductions was attained. In this year the Parliament passed an addendum to the Predator Act, introducing a temporary upper limit of the wolf population of 210 animals (but with the aim at still keeping a minimum of 20 annual reproductions, corresponding to approximately 200 individuals), and opened for a quota-based harvest to actively regulate the population to this upper limit. The first quota hunt occurred in January 2010 when 28 wolves were shot and in January 2011 another 19 wolves were harvested. The new wolf policy also included a decentralization of large carnivore management decisions and invitation to representatives for local stake holding interests to participate in these decisions.

Norwegian predator policy is regulated by the Predator Act “Rovvilt i Norsk Natur” (Norwegian Ministry of the Environment 2003), passed by the parliament in 2004. In this act the Norwegian Parliament established a specified “wolf zone” in south-eastern Norway, along the Swedish border, where wolves should be tolerated. Within this zone the sub-population goal was three Norwegian breeding packs, not including packs holding territories across the border to Sweden. When this goal is reached, control of additional wolves in the zone might be allowed if local authorities find it necessary to mitigate conflicts. Outside the zone, local governments may allow removal of wolves after they have received complaints, irrespective of whether the goal within the wolf zone is reached or not. Since 2004 there have been only minor changes of the Norwegian wolf policy.

Our objective in this study was to quantify the extent of illegal killing of wolves in Scandinavia during the period December 1998 - February 2011. Specifically, we investigated if there has been a change over time and we examined our data to find possible break points in our time series. Further, we used different datasets to test whether any changes in the rate of illegal killing may be due to a selective tendency among poachers for or against killing specifically radio-collared wolves. Finally, we discuss if the change found in the rate of illegal killing over time may have a causal relation to the shift in the Swedish wolf policy starting with 2004.

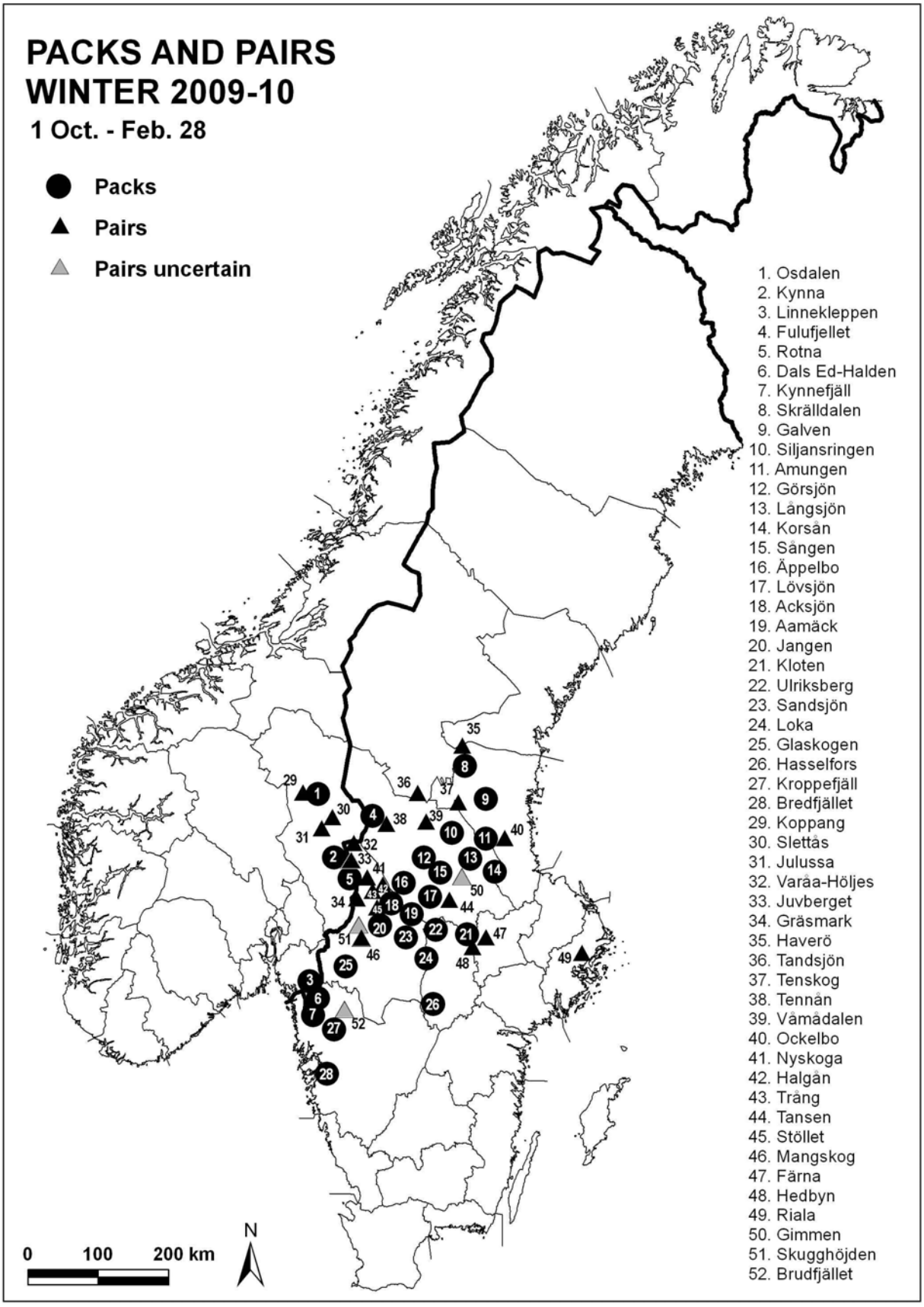

Figure 1. The distribution of wolf territories in Scandinavia the winter 2009-2010.

STUDY AREA

The present wolf range in central Scandianvia covers approximately 100 000 km^2 (Fig. 1). Altitude varies between 100 and 1000 m a.s.l. Average temperature in February is -3 to -9 C, and in July 13 to 16 C. Annual precipitation is 700-900 mm. Snow cover lasts 2-5 months with maximum depths 50-100 cm (SNA 1991). Boreal forest dominates the landscape, and most of it is intensively managed with a dense network of forest gravel roads. In the north-west the wolf range includes some alpine tundra. The human population is sparse, from <1 human/km^2 in the northwest to 10 in the southeast where agriculture might make up as much as 40 % of the area (Swedish National Atlas 1991).

Coexisting large mammalian predators include brown bear (*Ursus arctos*) and European lynx (*Lynx lynx*). Wolverine (*Gulo gulo*) occurs sparsely in the northern part of the wolf range. The most important wild prey species is moose (*Alces alces*)) and roe deer (*Capreolus capreolus*). Wolves also prey on domestic animals, primarily sheep. Approximately 1200 sheep per year are economically compensated as killed by wolves in Norway, and 100-200 in Sweden. Also 30-50 dogs, mainly hunting dogs, have been killed or wounded by wolves annually the last five years in Sweden and Norway. Another source of conflict is competition with human hunters over game, especially moose. More than 150 000 moose are harvested annually in Scandinavia.

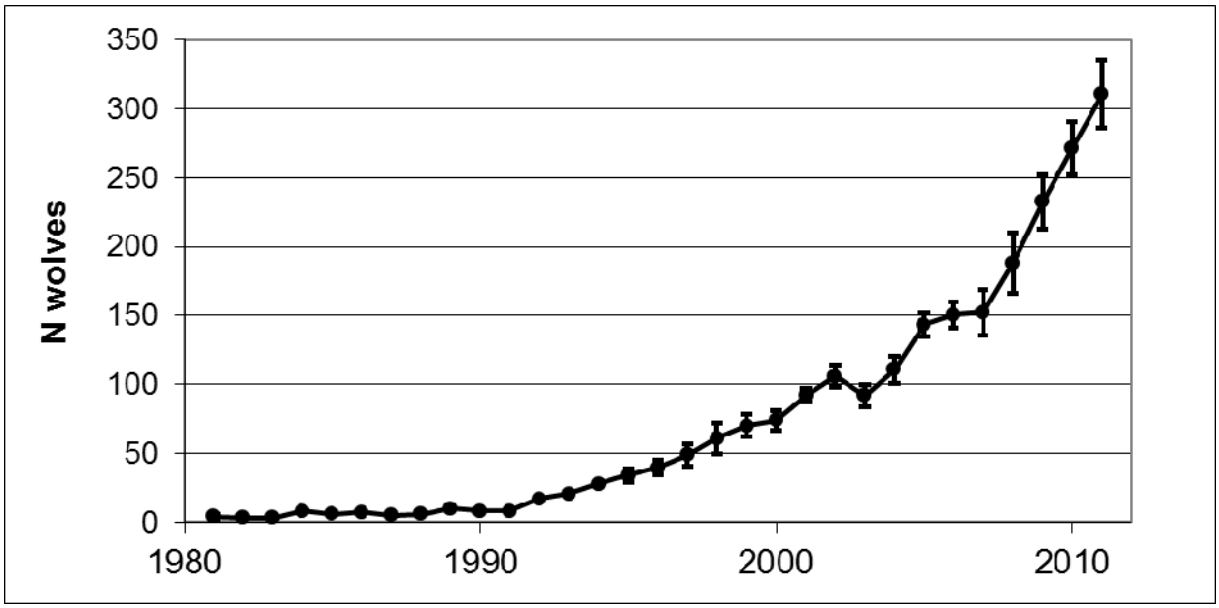

Figure 2. Development of the Scandinavian wolf population size 1981-2011. Data points give number of wolves in early winter for each year whereas bars give minimum and maximum estimates from census data, respectively.

Wolf population development

The Scandinavian wolf population started declining during the 19th century, and when finally protected, 1966 in Sweden and 1972 in Norway, the wolf was functionally extinct in Scandinavia (Wabakken et al. 2001). The nearest source population occurred in Russian Karelia along the eastern border of Finland. During the 1970's wolves expanded into eastern Finland, and by 1977 several wolves were recorded in northern Sweden. In 1982 a pair was formed in south-central Scandinavia and successful breeding was recorded in 1983 (Wabakken et al. 2001). This breeding pair and a third male immigrant arriving in 1990, also with origin in Finland/Russia, were the sole founders of the recent Scandinavian wolf population until 2008 (Liberg et al. 2005). In 2008 another two immigrants from the Finnish/Russian population entered the breeding Scandinavian population, making total number of founders by March 2011 to five. In spite of an increasing degree of inbreeding with negative effects on reproduction (Liberg et al. 2005), the wolf population has expanded (Fig. 2) and in early winter 2010/11 the total population size in Scandinavia was preliminary estimated to 286-335 wolves, of which 89 % occurred in Sweden or in border territories (Wabakken et al. 2011). Preliminary figures for reproductions in 2010 are 25 in Sweden, three in trans-border territories, and three in Norway.

METHODS

Estimation of population size and reproduction

Annual monitoring of wolf numbers and distribution was performed by volunteers and research project personnel until 2002, when the responsibility for performing annual census estimates was taken over by the regional county boards in Sweden. In Norway, Hedmark University College and the Norwegian Nature Inspectorate have been responsible for similar monitoring during the complete period of this study. Since 1998, Swedish and Norwegian wolf monitoring have been coordinated, evaluated and results concluded for each country and total Scandinavia in a joint published, annual Swedish-Norwegian status report (e.g. Wabakken et al. 2010). Field personnel search actively for wolf tracks on snow during the census period (1 October - 28 February), and follow several thousand kilometres of wolf tracks each season. Tracking data are registered including location and length (km) of tracking route, and details of the tracked wolves including number and social status. The search for tracks is aided by reports from hunters and the general public. As a complement to tracking data telemetry data from radio-collared wolves is used and provided by the research project within SKANDULV, and since 2002/03 DNA-analyses of mainly scats also constitutes an important source of information (Liberg et al. 2005, Wabakken et al. 2010).

In each territory the number of wolves was recorded during winter by repeated tracking efforts. We employed DNA and telemetry techniques to help distinguishing between wolves in adjacent territories. In cases where there was uncertainty of exact number in a group, a maximum and a minimum figure was given. All recorded wolves were summed up for a total population estimate, where mean, maximum and minimum figures were given (figure 1,

Wabakken et al. 2010). Annual reports on the size of the Scandinavian wolf population have been produced since 1999 (Wabakken et al. 2010).

Recruitment of pups was determined if at least one of the following criteria was satisfied: 1) ocular observations of pups during summer (before October 1); 2) an active den with faeces from pups was found; 3) reproduction confirmed by DNA-analyses; 4) more wolves in the pack on snow than during the previous winter; 5) at least five wolves in the pack confirmed during the annual monitoring, October, 1^{th} - February, 28^{th}.

In primi-parous packs, the total number of wolves minus the breeding pair was registered as the number of pups recruited into the winter. In packs that had reproduced before (itero-parous), the number of pups were calculated the same way, but reduced by 15 % to account for remaining older offspring.

Capture of study animals

Wolves were captured on snow during the winter season. They were first located on ground by searching for tracks in known wolf territories, and then immobilized from helicopter using a CO_2-powered dart gun and a standard dose of drugs, either 500 mg of tiletamine-zolazepam (Zoletil®, Virbac) per animal or a combination of 5 mg of medetomidine (Zalopine®, Orion Pharma Animal Health) and 250 mg of ketamine (Narketan®, Chassot) per animal. All wolves captured were measured, sexed, aged, weighed, and ear tagged. Blood and hair samples were collected. Before 2003, wolves were equipped with conventional VHF radio collar (Telonics, Mod. 500, Mesa, Arizona). However, after we got indications that wolves were radio tracked by unauthorized persons, and suspecting that this practice could be used to facilitate illegal killing, in 2003 we replaced all old transmitters with GPS-collars that can not be abused. The GPS collars were manufactured by either TVP International, Sweden (GPS-Simplex) or by Vectronic Aerospace, Germany (GPS-plus). The handling protocol for wolves has been approved by both the Swedish Animal Welfare Agency and the Norwegian Experimental Animal Ethics Committee and fulfils their ethical requirements for research on wild animals.

Radio tracking and recording of mortality

Wolves with VHF-collars were positioned minimum once a week from ground or air, and during intensive predation study periods 1-5 times per day from the ground. GPS-collars were programmed for positioning 2-6 positions per day, and during intensive study periods at hourly or half-hourly intervals.

Most of the transmitters had a mortality function that enabled us to retrieve dead wolves soon after death which enhanced our chances of determining the cause of mortality. Wolves found dead in Sweden were sent to the Swedish National Veterinary Institute for examination of the cause of mortality, and in Norway carcasses were sent to the Norwegian Institute for Nature Research and examined in co-operation with the Norwegian Veterinary Institute. Mortality causes were classified as: *natural causes* (drowning and other non-human caused accidents, intra-specific strife, disease and malformations), *traffic* (both road and railway), *legal killing*

of wolves, in most cases in form of predator control, *verified illegal killing* and *probable illegal killing*. For definition of the last two, see below.

Bodies also were examined for other signs of disease or malformations. At the Swedish National Veterinary Institute all wolf bodies were x-rayed to search for shots, bullets or other traces of metal (Mörner et al. 2005). In Norway this praxis has not been consequent all through the study period.

Criteria for classifying wolves as poached

Criteria for *verified illegal killing* (enough if one criterion is satisfied):

1. The body is recovered and the post mortem show that is was deliberately killed by a human, and that this did not happen during a legal hunt.

2. The transmitter collar was found cut over where the only possible explanation was that this was done by a human being without reporting it to the authorities.

3. Wolf tissue (skin, muscle, bone etc.) determined by DNA-analysis to originate from the recent Scandinavian wolf population, was found in possession of a person that could not explain how he had acquired it

4. Snow tracking of a wolf chased by humans, where it with certainty could be concluded that the wolf was killed, even if the body was not found, e.g. by presence of a typical strong arterial bleeding in the snow (so called “pipe bleeding”).

These criteria were used both for wolves with radio-collars, and for non-instrumented wolves.

Criteria for *probable illegal killing* (either all of criteria 1-3 are satisfied, or criterion 4 is satisfied):

1. Sudden loss of radio contact where there is no reason to suspect transmitter failure (well working transmitter with more than half battery life left). For GPS-collars status of the battery voltage were checked just before contact was lost. A sudden reduction in voltage was used a strong indication that the loss of contact was due to malfunction of the collar.

2. The radio contact could not be re-established in spite of at least two aerial searches over a much larger area than the wolf’s territory (for GPS/GSM-collars this was not necessary).

3. The wolf was stationary and it could with certainty be determined missing in its territory after repeated snow tracking, and/or after DNA-analyses of faeces found in the territory.

4. Radio contact was suddenly lost and special circumstances indicated with a high degree of probability that the most plausible explanation was illegal killing (used only in two cases).

These criteria were used only for radio-collared wolves, and criterion 2 and 3 only for radio-collared territorial wolves.

All other cases of lost radio contact were classified either as *failure of radio collar*, if we had strong indications of that (expected life-time for battery expired, irregular or abnormal VHF-signals just before contact were lost, type of radio-collar known to be un-reliable, the wolf was observed alive with its radio collar after the signal was lost, or found dead and the time of death was determined to have occurred after the signal was lost), or otherwise as *unknown fate*.

Calculation of mortality rates

We used two methods to determine mortality rates, *the radio method* and *the census method.* With the *radio method* we used survival data from our radio-collared wolves and have estimated cause specific mortality rates and tested for difference among groups. We used the competing risk approach proposed by Heisey and Patterson (2006) and ran computations in R. The two competing risks analysed (i.e. cause-specific mortality rates) were illegal killing versus non-illegal killing ("other mortality") for periods 1998-2005 and 2006-2011 and for Sweden and Norway. A competing risk approach is required, as traditional survival analysis methods (e.g Kaplan Meier) introduce a bias when several different mortality causes operate simultaneously. In addition, statistical procedures used in biomedicine cannot be applied in this case because they often do not allow for staggered entry of individuals in the dataset (left censorship).

With the *census method* we could only calculate total mortality. It is based on the difference between consecutive annual censuses of the population and an expected population size based on data on recruitment rate. The mathematical formula we used for the calculation was

$$D = ((P\ t_{1+}\ R_2\ ) - P\ t_2) / P\ t_1$$

where:

D = total annual mortality in the population between year 1 and 2

$P\ t_1$ = population size year 1

$P\ t_2$ = population size year 2

R_2 = number of pups recruited to year 2

With this method no confidence limits could be calculated, nor cause specific mortality rates.

Analysis of possible break points in the material

We used the same competing risk analysis as above but broke the dataset into two sub-datasets with year break point changing from 2001 to 2009. For each sub-dataset, we computed cause-specific mortality rates and tested for statistical differences between the two periods.

RESULTS

Cause specific mortality in radio-collared wolves and lost radio contacts

During the study period we radio-collared a total of 123 wolves in both Norway and Sweden representing 160.9 "radio years" (Table 1). The number of "radio years" was three times as many in Sweden compared to Norway, but the number of recorded mortalities was less than double. At the end of the study 29th February 2011 we still had contact with eight of the radio collared wolves. Six wolves died during, or in connection with, handling of immobilized wolves and were not included in the analysis. Of the remaining 109 wolves, 29 were confirmed dead while their collars still were working, 9 died of natural causes (drowning or other accidents, disease and age), 5 were killed by road and railway traffic, 10 were shot legally, and 5 died in *verified* cases of illegal killing. We lost radio contact with 80 wolves. Nineteen of these were classified as *probably* illegally killed.

Table 1. Number of radio collared wolves (N ind), number of "radio years", total number of deaths among radio collared wolves, and cause specific deaths. Radio years, and deaths, excluding project related deaths, are also specified on countries and time periods. Number of radio collared individuals could not be specified in this way because the same animal might appear in both countries and/or time periods.

	N ind	N radio-years	N dead tot (excl. project related)	Natural causes	Traffic	Legal hunting	Illegal killing	Prob-able illegal	Project related
Sweden 1998 – 2005		71.0	25	6	3	2	3	11	
Sweden 2006 – 2011		51.1	6	2	1	2	0	1	
Norway 1998 – 2005		29.8	11	1	1	4	2	3	
Norway 2006 – 2011		9.0	6	0	0	2	0	4	
Scandinavia 1998 -2005		100.8	36	7	4	6	5	14	
Scandinav ia 2006-2011		60.1	12	2	1	4	0	5	
Sweden total		122.1	31	8	4	4	3	12	
Norway total		38.8	17	1	1	6	2	7	
Scandinavia total	123	160.9	48	9	5	10	5	19	6

Variation in time and space of annual rates of total mortality and illegal killing in radio collared wolves

Total annual mortality rate in the Scandinavian wolf population (Sweden and Norway together) for the whole study period 1998-2011 was 0.259 (25.9 %) (Table 2). Mortality from illegal killing was 0.128 (12.8 %) and from other causes 0.131 (13.1 %). Norway had a higher mortality rate than Sweden, mainly because of a higher rate of illegal killing.

Table 2. Mean annual rates of illegal killing (verified and probable illegal killing pooled), and other mortality (legal control, traffic, natural) in Scandinavian wolves, in two countries during two time periods (1998-2005 and 2006-2011). Log-rank tests of differences in illegal killing between groups are presented at the bottom of the table.

Data	Illegal killing	±SD	Other mortality	±SD
All	0.128	0.026	0.131	0.025
Sweden	0.111	0.028	0.113	0.026
Norway	0.179	0.054	0.177	0.053
All 1998-2005	0.157	0.033	0.148	0.033
All 2006-2011	0.077	0.034	0.091	0.029
Sweden 1998-2005	0.169	0.042	0.133	0.036
Sweden 2006-2011	0.025	0.025	0.075	0.028
Norway 1998-2005	0.134	0.056	0.181	0.061
Norway 2006-2011	0.323	0.114	0.116	0.078

Tests of differences in illegal killing:
Sweden vs Norway $p = 0.11$
All 1998-2005 vs All 2006-2011 $p = 0.10$
Sweden: 1998-2005 vs 2006-2011 $p = 0.0066$ (**)
Norway: 1998-2005 vs 2006-2011 $p = 0.13$

Annual illegal killing rates in Sweden varied heavily between single years due to small sample sizes, but with a clear decreasing trend in the latter part of the study period with a start of the decline in 2004 (Table 3). In the period 2006-2011 there was only one case of illegal killing among our radio-collared wolves in Sweden. Statistical tests for a change (break point) in this time series gave support for a significant change either after 2003, after 2004 or after 2005 (Fig. 3).

Table 3. Annual mortality rates from illegal killing and other mortality causes in Swedish wolves for the period 1999-2010.

Year	Illegal killing	Variance	Other mort	Variance	N dead	N poached	N radio years
1999	0.314	0.161	0.171	0.156	3	2	5.0
2000	0.318	0.116	0.068	0.068	3	2	9.7
2001	0.000	0.000	0.221	0.098	3	0	12.8
2002	0.234	0.093	0.134	0.044	7	5	16.9
2003	0.214	0.095	0.071	NA	4	3	10.8
2004	0.129	0.120	0.100	NA	2	1	7.4
2005	0.139	0.129	0.266	0.115	3	1	8.2
2006	0.000	0.000	0.071	NA	1	0	12.6
2007	0.000	0.000	0.000	NA	0	0	10.5
2008	0.000	0.000	0.234	0.107	2	0	5.7
2009	0.118	0.110	0.059	NA	2	1	11.5
2010	0.000	0.000	0.067	NA	1	0	9.5

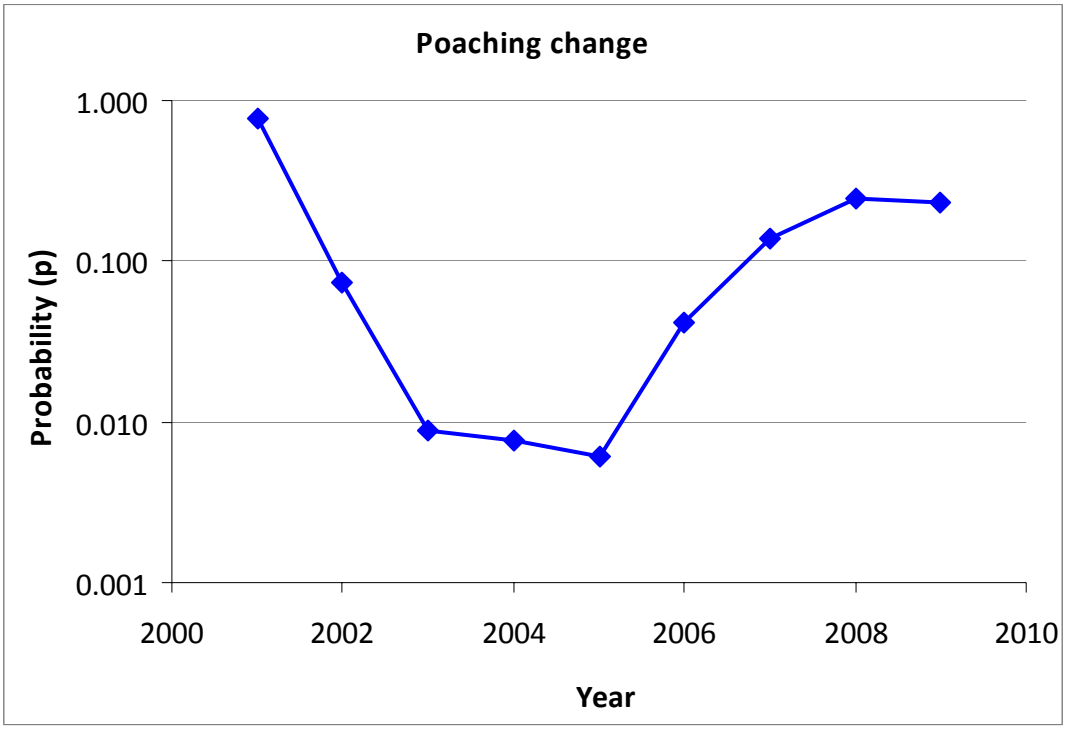

Figure 3. P-values for log-rank test of a break point in time trend of the rate of illegal killing (verified and probable illegal killing pooled) in Sweden. The time points indicate Dec 31st of the respective year.

Because the statistical test gave strongest support for a change after 2005, we have used Dec 31st 2005 as a break point and compared mortality rates of the two time periods 1998-2005 and 2006-2011 in our further analyses. Both illegal killing and other mortality showed a tendency to be lower during 2006-2011 compared to 1998-2005 also for the total dataset from Scandinavia (Table 2). However, the time trends were opposite in Norway and Sweden. Norway had an increase in illegal killing in the latter period, while Sweden had an almost seven-fold decrease, from 0.169 (16.9 %) to 0.025 (2.5 %). This corresponds to 9-20 animals illegally killed per year during 1998 to 2005 and 3-7 animals illegally per year during 2006 to 2010, which is a 65% reduction of the number of poached wolves per year. This change of illegal killing mortality in Sweden was the only difference that was statistically significant (p=0.007). In the period 1998-2005 there were 14 cases of illegal or probably illegal killing recorded in radio-collared wolves in Sweden, whereas there was only one case in the 2006-2011 period. Corresponding figures for Norway were 4 and 5.

Non radio-tracking data on mortality and illegal killing, and population growth over time in Sweden

There was a statistically significant reduction in total number (both radio-collared and non-collared wolves) of detected verified cases of illegal killing of wolves or obvious attempts (one case) of illegal killing in relation to exposure in the form of “wolf years” (see text Table 4) in Sweden from 1998-2005 to 2006-2010 (Table 4). We did not include 2011 as we needed complete years for this analysis. Poisoning attempts were not included.

Table 4. Number of cases of detected verified illegal killing plus attempts of illegal killing detected in both radio-collared and un-collared wolves in Sweden in two time periods. ”Wolf years” are defined as the sum of annually censused wolves in Sweden for all the years in respective period (X^2 = 6.48, p=0.011, Pearson´s two-sided chi-square test).

Period	N cases	N "wolf years"	N cases/1000 "wolf years"
1999 -2005	10	545	18.3
2006 -2010	4	883	4.5

Frequency of wolves with old shot wounds (number of cases in relation to exposure time, see table text for explanation), i.e. wolves that had survived a shooting attempt and in which traces of bullets or shots were found during a post mortem after the death of the wolf, also was slightly lower in the second period compared to the first period for wolves examined post mortem in Sweden, but the difference was not significant (Table 5). If an examined wolf had an old shot wound that it could have contracted in either of the two periods, the case was weighted according to the proportion of the total exposure time in each of the two periods respectively.

Table 5. Cases of old shot wounds found at post mortem examinations of dead wolves from other causes, in two time periods in Sweden. Exposure time was measured as the sum of the portions of longevity in the two periods respective, for all wolves examined post mortem. Shot wounds that could have been afflicted a wolf in either of the two periods were weighted according to exposure time of the concerned wolf in the two periods respectively (X^2 = 0.168, p=0.682, Pearson´s two-sided chi-square test).

Period	N observed cases of old shot wounds	Exposure time (years)	N cases per 100 years exposure
1999-2006	7.9	143	5.5
2007-2011	9.1	202	4.5

The "census method" for determining wolf mortality in Scandinavia, based on census and reproduction data, produced a total mortality for the whole study period of 0.23, which is close to the rate for the radio-collared wolves (0.26). The census method also indicated a reduction of mortality with time, giving a total mortality of 0.26 in 1998-2005, as compared to 0.20 in 2006-2011. The census method does not allow for calculation of cause specific mortality rates, nor for splitting of the data on Sweden and Norway.

The average annual growth rate of the Swedish part of the Scandinavian wolf population was 16 % for the whole study period. The average for the period 1998-2005 was 14 %, and for the period 2006-2010 it was 19 % (excluding the effect of the license hunts 2010 and 2011) (Figure 4).

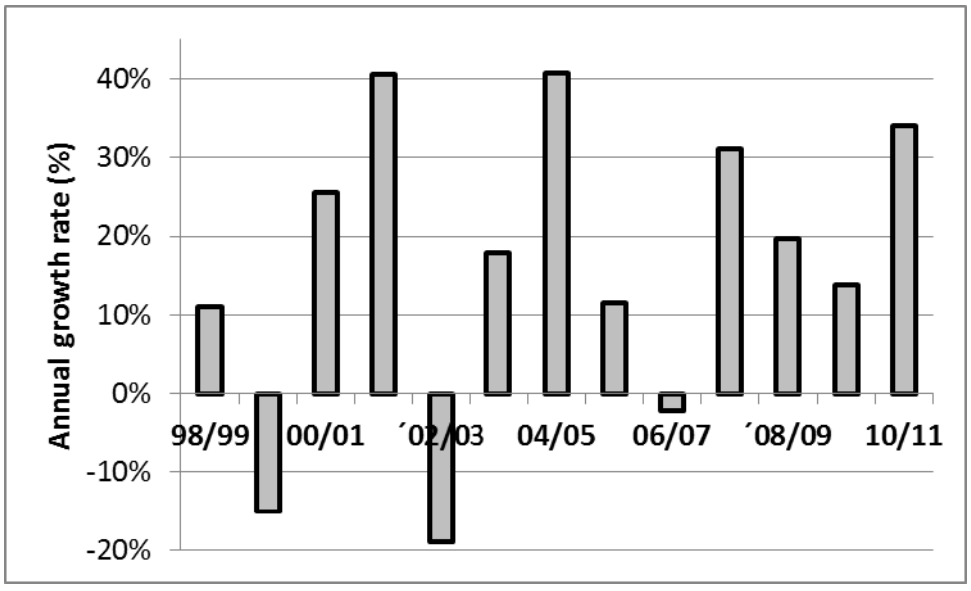

Figure 4. Annual growth rates in the Swedish part of the Scandianvian wolf population 1998-2010. The growth rates concern growth from early winter one year to early winter next year. The years on the x-axis indicate growth from year t-1 to year t (i.e. the growth of 08/09 in the figure refers to the growth from winter 07/08 to winter 08/09). The effects of the quota hunts are excluded from the growth rates of 09/10 and 10/11.

DISCUSSION

Are data on illegal killing and its demonstrated time trend in Sweden, reliable?

Illegal killing was the dominant mortality cause in Scandinavian wolves. Almost half of all dead wolves died from this type of mortality. One problem is that most of the illegal killings among radio-collared wolves could not be verified by the retrieval of a dead body, but were instead based on circumstantial evidence. However, several independent datasets support the high incidence of illegal killing. The "census method" gave a total mortality rate that was close to the one calculated from radio-collared wolves. If our calculation of illegal killing from radio-collared wolves had been a strong overestimate, there must exist some other unknown cause of mortality of similar magnitude that was not registered in our sample of collared wolves, and that simultaneously also would cause radio failure. We have not been able to identify any such alternative mortality cause. In a recently published paper (Liberg et al. 2011) we have presented a more elaborate model based on census and reproduction data where we could also single out illegal killing rate. Total illegal killing rate for Scandinavia 1998-2009 according to this model (0.149) did not differ much from the rate calculated from radio-collared wolves (including VHF-transmitters, see below) for the same period (0.134). The reason that these rates are somewhat higher than in the present report (0.128) probably is that the latter include also data from 2010 and 2011 when we had no cases at all of illegal killing among our radio-collared wolves. We believe this is the strongest support for the validity of the estimate of illegal killing rate and evidence against any suggested bias to this, e.g. the possibility that transmitter type might have influenced our data on illegal killing rate (see below). Our estimated level of illegal killing and total mortality also fits well with the figures we have on population growth. Finally, the data on cases of verified illegal killing and on old shot wounds demonstrate that illegal killing and illegal killing attempts are indeed prevalent in high frequency in the Swedish wolf population.

The data also clearly indicate a reduction of illegal killing of wolves in Sweden starting in the period 2004-2006. The decrease of mortality from illegal killing in radio-collared wolves in Sweden was dramatic, from almost 17 % annually in 1998-2005 to 2.5 % in 2006-2011. This reduction was supported by several independent or partially-independent data sets. Number of verified cases of illegal killing or attempts of illegal killing in wolves is for obvious reasons low, as we expect poachers to make efforts to conceal their activities. Still, in the first period there was more than one case detected each year. After 2005, the frequency of cases in relation to how many wolves that were exposed decreased with 80 %, a difference that was also statistically significant. Two of the cases that occurred in the first period concerned farmers that shot wolves moving close to their life stock, but although they believed they had a right to do this and reported to the police themselves, they were convicted in court according to the hunting laws at that time. These cases would have been legal after the liberalizations of the concerned laws in 2004 and 2006.

Also mortality estimates based on the census method, and data on annual population growth in Sweden gave support to a decrease of illegal killing in the latter part of the study period.

The only data set that did not give a clear indication of a declining illegal killing in Sweden was number of old shot wounds. It decreased after 2005, but the reduction was small, less than 20 %, and not statistically significant. We cannot explain why we do not see the same trend here as in the other data sets. Most of the old shot wounds were superficial, consisting of one or a few small shots from a shot gun, often found in the skin or other superficial tissues (in one case the only shot discovered was found in an ear), probably results of shooting at wolves with shot guns from too large distances to be mortal (mortal range for a shot gun is below 35 m). Perhaps this type of behaviour does not follow the same dynamics as illegal killing with decided mortal intent.

Interestingly, data did not show a corresponding decrease of illegal killing in Norway. However, because more than 80 % of the Scandinavian wolves live in Sweden, the reduction of illegal killing there had an overall effect on total mortality in Scandinavia, from 30 % in the first period to 17 % in the second. This decrease showed a relatively good fit with calculation of total mortality based on census data (from 26 to 20 %), which supports the notion that this reduction was in fact true and to a large extent caused by a reduction of illegal killing.

There was also a decrease in traffic mortality and natural deaths, both in Sweden and Norway between the two time periods, which indicates that there was little, if any, compensatory effects in illegal killing, meaning that most of it was additive to other mortality. This pattern was also supported by the increase in growth rate observed in the Swedish part of the wolf population after 2005.

Possible reasons for the decline of illegal killing in Sweden

The coincidence of the gradually changing wolf policy in Sweden and a reduction in illegal killing of wolves can support the hypothesis that there is a cause-effect, but is not conclusive evidence of this. There are a number of suggested alternative reasons for the decline in illegal killing, where some have support by data while others have not.

One possibility is that there all through our study period have been a relatively constant small number of people that have been prepared to commit themselves to this type of criminal activities. If this is the case, the relative impact of illegal killing would have been reduced as the wolf population grew and expanded its distribution, and a gradual decrease of illegal killing rate with the continuous increase of the wolf population would be expected all through the study period. Indeed, when plotting illegal killing rates in Sweden against population size, there was a significant decreasing trend ($R^2 = 0.37$, $p = 0.035$, linear regression), albeit with a large inter-annual variation (Fig. 5). We compared this trend with a simulated trend where we have assumed a constant number of wolves killed illegally each year and received a relatively good fit between the two trends (Fig. 5).

Alternatively there could also have been a change in behaviour within the group of offenders. It has been suggested that their motivation to continue killing wolves illegally might gradually have eroded when they have realized that they are fighting a hopeless fight, as the wolf

population has continued to grow in spite of their efforts. Also a gradually increasing law enforcement activity against illegal killing of large carnivores during the last decade might have had effect.

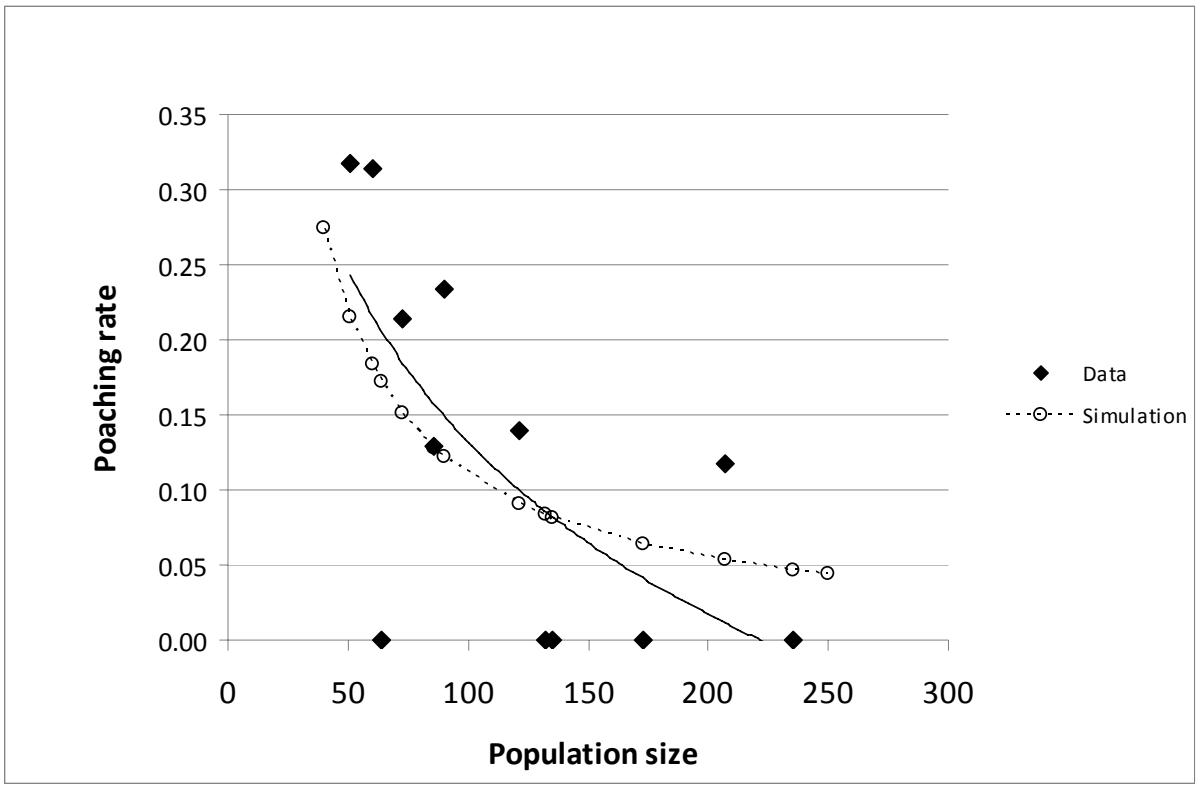

Figure 5. The rate of illegal killing in relation to population size of wolves in Sweden. Also included is a simulation of illegal killing rates when number of wolves killed per year is kept constant. The best fit with data occurred when this constant number was 11 wolves.

There is less support for the assumption that poachers gradually have learned to avoid radio-collared wolves and increasingly focused on non-instrumented animals in an effort to conceal their activity. If this had been the case, the decline of illegal killing would only have occurred in our radio-collared wolves, not in the whole population. The two independent data sets used in this study both infer a real decline of illegal killing in the whole population thus contradict the possibility of a selective killing of animals

Another suggested reason for a declining trend in illegal killing is our change of transmitter type during the study period. In the first years we used VHF-transmitters where poachers may have had the possibility to scan the collar frequency and exploited the transmitter to get in range of the carriers to kill them. However, in winter 2001/02 we started to exchange this type of transmitters to a more secure type of GPS-transmitters, which do not emit signals that can be misused, and by March 2003 all transmitters in operation were of the new type. If this had been an important source of error, our estimates of illegal killing up to 2003 would have been overestimates. However, our modelling based on independent data does not support this

possibility (Liberg et al. 2011). Also, the lack of a decline in illegal killing in Norway, supports the conclusion that this possible bias, if real, had a small magnitude.

Although Norway all through the study period had a more liberal legal hunting policy of wolves than Sweden, it had a higher incidence of illegal killing. This could seem to contradict the idea that more legal hunting reduces illegal killing, but in fact it is rather the opposite. Most of the illegal killing of wolves in Norway occurred inside the Norwegian wolf zone in south-eastern Norway along the border to Sweden where wolves enjoy an even stronger degree of protection than in Sweden. After the Norwegian Parliament established the wolf zone in 2004, the Norwegian management authorities have not given any permission to wolf control within the zone. All legal hunting has taken place outside the zone, where there are very liberal regulations for control, and no permanent establishment of wolf territories are allowed. So, most illegal killing occurs inside the zone where there is no legal hunting, while there is almost no illegal killing outside where legal hunting is very liberally issued.

It is not possible to point out a single factor that explains the reduction of illegal killing in Sweden, but we think there is strong evidence that a reduction really has occurred, i.e. ruling out the possibility that it is just an artefact caused by our replacement of one transmitter type with another or a change in poacher focus towards non-instrumented wolves. The different alternative explanations suggested here for a declining trend in illegal killing are not mutually exclusive. In fact, they may all have contributed to this positive trend.

Unfortunately there is very little data on the association between legal and illegal killing of large carnivores in the literature. Treves (2009) found no evidence for such a trade-off, but he based his conclusion on only three publications. One of these (Andrén et al. 2006) actually was ambiguous on this point, and the other two (Adams et al. 2008, Person & Russell 2008) studied wolf populations in remote areas in North America with relatively little contact with people. There are a few papers that indicate a certain association between legal and illegal take off of large carnivores (Wielgus et al. 1996, Huber 2002), but firm conclusions may not be drawn. This issue if of such great importance for conservation policy makers and large carnivore managers worldwide, that there is a great need for more studies to focus on these aspects. Ideally ecological/demographic data should be complemented with studies of attitudes of local people concerned, especially studies of attitudes in the same group of people before and after certain management changes towards large carnivores has been implemented in their area.

CONCLUSIONS

Illegal killing was the dominant mortality cause for wolves in Scandinavia during 1998-2011 and accounted for half of total mortality. We found differences in the extent of illegal killing between Norway and Sweden and between the two time periods 1998-2005 and 2006-2011, but with opposite trends in the two countries. The only difference that was statistically significant was the reduction of illegal killing in Sweden after 2005 (from 16.9 % in 1998-2005 to 2.5 % in 2006-2011). Several different independent data sets show the same pattern

and support that there has indeed occurred a reduction of illegal killing in Sweden, and we could rule out that it was an artifact caused by a change of radio transmitter technique or a selective behavior of poachers towards radio-collared wolves. We conclude that we cannot point out a single factor explaining this positive trend, but suggest that several factors might have contributed, including lack of numerical/functional poaching response to the increasing wolf population and a falling motivation in poachers as well as the various elements in a changed wolf policy after 2004, such as increased control of depredating wolves, a temporal freezing of the population with a regulating quota-based hunt, more local participation of management decisions and a strengthened law enforcement. In fact, there is a possibility that several, or all of these factors have contributed to the observed trend, and that they have influenced each other so that, for example number of poachers or intensity of poaching have failed to increase with the expanding wolf population due to one or several of the changes in wolf policy.

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REFERENCES

Adams, L.G., Stephenson, R.O., Dale, B.W., Ahgook, R.T. and Demma, D.J. 2008. Population dynamics and harvest characteristics of wolves in the Central Brooks Range, Alaska Wildlife Monographs, 170: 1–25.

Altrichter, M., Boaglio, G. and Perovic, P. 2006. The decline of jaguars Panthera onca in the Argentine Chaco. Oryx 40(3): 302-309.

Andrén, H., Linnell, J.D.C., Liberg, O., Andersen, R., Danell, A., Karlsson, J., Odden, J., Moa, P.F., Ahlqvist, P., Kvam, Y., Franzén, F. and Segerström, P. 2006. Survival rates and causes of mortality in Eurasian lynx (*Lynx lynx*) in multi-use landscapes. – Biological Conservation 131: 23-32.

Creel, S. and Creel, N. 1998. Six ecological factors that may limit African wild dogs. Animal Conservation 1: 1-9.

Damania R., Stringer R., Karanth K.U. and Stith B. 2003. The economics of protecting tiger populations: linking household behavior to illegal killing and prey depletion. Land Economics 79: 198–215.

Eliason, S.L. 2004. Accounts of wildlife law violators: motivations and rationalizations. Human Dimensions of Wildlife 9: 119-131.

Heisey D.M. and Patterson B.R. 2006. A review of methods to estimate cause-specific mortality in presence of competing risks. Journal of Wildlife Management 70(6): 1544-55.

Huber, D., Kusak, J., Guzvica, G., Gomeric, T. and Frkovi, A. 2002. Causes of wolf mortality in Croatia in the period 1986-2001. Veterinarski Arhiv 72: 131-139

Liberg, O., Andrén, Pedersen, H-C., Sand, H., Sejberg, D., Wabakken, P., Åkesson, M. and Bensch, S. 2005. Severe inbreeding depression in a wild wolf (Canis lupus) population. Biol. Lett. 1: 17-20.

Liberg, O., Sand, H., Wabakken, P and Pedersen, H.C. 2008. Dödlighet och illegal jakt i den skandinaviska vargstammen. Rapport från Grimsö forskningsstation och Viltskadecenter. 42 sidor.

Liberg, O., Chapron, G., Wabakken, P., Pedersen, H.C., Hobbs, N.T. and Sand, H. 2011. Shoot, shovel and shut up: cryptic illegal killing slows restoration of a large carnivore in Europe. Proc. Roy. Soc. B. doi:10.1098/rspb.2011.1275

Person, D.K. and Russell, A.L. 2008. Correlates of mortality in an exploited wolf population. Journal of Wildlife Management, 72: 1540–1549.

Peters, R.P., and Mech, L.D. 1975. Scent marking in wolves: a field study. American Science 63: 628-637.

Swedish National Atlas (1991). Befolkningen (The population). Svensk National Atlas Förlag, Stockholm.

Swenson, J.E. and Andrén, H. 2005. A tale of two countries: large carnivore depredations and compensation schemes in Sweden and Norway. - Pp 323-339 in: Woodroffe, R., Thirgood, S. & Rabinowitz, A. (eds.). People and Wildlife: Conflict or Co-existence? Cambridge University Press.

Treves, A. 2009. Hunting for large carnivore conservation. Journal of Applied Ecology 46: 1350–1356.

Treves A, and Karanth, K.U. 2003. Human carnivore conflict and perspectives on carnivore management worldwide. Conservation Biology 17: 1491–1499.

Wielgus, R.B., Bunnell, F.L., Wakkinen, W.L. and Zager, P.E. 1994. Population dynamics of Selkirk Mountain grizzly bears**.** Journal of Wildlife Management. 58: 266-272.

Wabakken, P., Aronson, Å., Sand, H., Steinset, O. K. and Kojola, I. 1999. Ulv i Skandinavia: Statusrapport for vinteren 1998-99. Høgskolen i Hedmark, rapp. 19/99. 46s.

Wabakken, P., Sand, H., Liberg, O. and Bjärvall, A. 2001. The recovery, distribution, and population dynamics of wolves on the Scandinavian peninsula, 1978-1998. Canadian Journal of Zoology 79: 710-725.

Wabakken, P., Aronson, Å., Strømseth, T.H., Sand, H. E. Maartmann, L. Svensson, Ø. Flagstad, E. Hedmark, O. Liberg and I. Kojola 2010. Ulv i Skandinavia: Statusrapport for vinteren 2005-2006. Oppdragsrapport nr. 4 - 2010. Høgskolen i Hedmark.

Woodroffe, R. and Ginsberg, J.R. 1998. Edge effects and the extinction of populations inside protected areas. Science 280: 2126-2128.