Causes of mortality, especially illegal killing, among Swedish brown bears, 1984-2010

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(Photo: Djuro Huber)

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Abstract
We analyzed the fates of 305 brown bears that were radiomarked when they died or we lost contact with them during the period 1984-2010 in two study areas in southern and northern Sweden. The proportion of nonresearch deaths attributable to illegal killing was significantly higher in the north (44.8-58.6%) than in the south (4.1-26.9%). We found no area differences in the frequence of illegally killed bears due to sex, age, or study period ($\leq$1997 and $\geq$1998). We estimated annual rates of illegal mortality among adult females to be 0.1-0.6% in the south and 2.3-3.1% in the north. The documented and suspected illegal deaths showed no seasonal trend in the south, but were concentrated to spring and autumn in the north. Generally, illegal killing does not seem to be an important factor affecting population trends among brown bears in Sweden, but it may be important locally, and then it may affect the bears' life-history traits. It is important that managers attempt to identify areas of high illegal killing. Managers should also recognize that the level of illegal mortality appears to be stable, probably is not related to the level of legal hunting mortality, and that it probably is additive to legal hunting mortality.

Introduction
In human-dominated landscapes throughout the world, human-caused mortality is one of the major causes of mortality in large carnivore populations (Woodroffe & Ginsberg 1998). This is also the case for the four species of large carnivores in Scandinavia, brown bear (*Ursus arc*tos), wolverine (*Gulo gulo*), Eurasian lynx (*Lynx lynx*), and gray wolf (*Canis lupus*) (Andrén et al. 2006, Liberg et al. 2008, Bischof et al. 2009, Persson et al. 2009). At least in parts of Scandinavia, illegal killing is an important source of mortality for the populations of all of these species, (Swenson & Sandegren 1999, Andrén et al. 2006, Liberg et al. 2008, Bischof et al. 2009, Persson et al. 2009).

WWF-Sweden has requested an updated evaluation of the effect of illegal killing on the brown bear population in Sweden. The last evaluation of this was in 1998 (Swenson & Sandegren 1999). Swenson & Sandegren (1999) estimated the mortality due to illegal killing among radiomarked brown bears to be 2.8 times higher than the legal hunting mortality in their northern study area and 0.6 of the legal hunting mortality in the southern study area. During their study period, 1984-1998, the average legal harvest of brown bears in Sweden was 38.5 bears annually, compared with over 200 bears annually today.

In this updated study, we compare the proportion of illegally killed bears by study area, sex, age, and study period. The latter was to investigate whether the level of illegal killing changed over time and whether levels of illegal killing decreased as levels of legal killing increased, which often is expected (Andrén et al. 2006). Here, we also estimate the annual rate of illegal mortality specifically for adult females, which is the demographically most important segment of the population (Sæther et al. 1998). We conclude with an evaluation of the effects of illegal killing on the brown bear population in Sweden.

Study areas
This study was conducted in two areas in Sweden, separated by 600 km. The southern study area, hereafter named the south, was in Dalarna and Gävleborg counties in southcentral Sweden (61° N, 15° E). The rolling landscape in the south is covered with coniferous forest, dominated by Scots pine, *Pinus sylvestris*, or Norway spruce, *Picea abies*. The northern study area, hereafter named the north, was in Norrbotten County in northern Sweden (67° N, 18° E). The landscape is mountainous, with altitudes up to 2,000 m and a subalpine forest dominated by birch, *Betula pubescens*, and willows, *Salix* spp., below the timberline and a coniferous forest of Scots pine and Norway spruce below the subalpine forest. Bears are hunted in both

areas, but the northern study area was partially within national parks, where bears were protected.

Methods

We based this study on the fates of radiomarked bears. We captured and immobilized brown bears from a helicopter according to the methods described in Arnemo et al. (1996, 2011). This protocol has been approved by the Swedish Animal Welfare Agency and the Norwegian Experimental Animal Ethics Committee. The bears received either VHF or GPS telemetry units (GPS in recent years) attached to a collar and some of them received an implanted VHF transmitter. We relocated bears with VHF collars from the air or ground at intervals varying from once a week (early in the study period in the south) to a few times a year (late in the study period in the north). We obtained locations of bears with GPS units about every 30 minutes and were received remotely, either via the GSM mobile telephone network (central Sweden) or via satellite (northern Sweden). The first bear was captured and collared in 1984 in the north and in 1985 in the south. The results reported here ended with denning in late autumn 2010. The study area in the south has remained relatively stable during the study period, but the study area in the north was originally confined to the protected national parks, then expanded also to include lower-lying areas adjacent to the protected areas, and now is only outside the protected areas. The reason for this is that all radiomarked bears that had their home ranges within the protected areas are now dead.

We attempted to determine the cause of death for all bears that died while carrying a functioning radio transmitter. This was generally quite easy, but in some cases the bear was located too late to judge the cause of death. This was especially the case in the north late in the study period, when bears were located only about three times a year. We sent the bears we found dead to Sweden's National Veterinary Institute for necropsy. We found few cases of bears that definitely had been killed illegally; in some cases we found illegally killed bears without their collar, but with the implanted transmitter still functioning, or found only the functioning collar that obviously had been handled by humans (see cover photograph). We accepted all bears reported to the authorities by hunters as killed legally to be so. That means that we did not include a bear that had been killed during the hunting season using illegal methods, and reported to the authorities as killed legally. Thus, this report deals with bears that have been killed illegal and not reported to the authorities. In Sweden, all hunters are required to report killed bears to the authorities the day of kill and the carcass must be inspected by an inspector appointed and trained by the wildlife management authorities.

It was more difficult to determine the fate of bears that we lost contact with. We know that people may remove or destroy the collars on bears that they kill illegally, but telemetry units may also malfunction or young bears may emigrate from the study area. We classified a bear we lost contact with as a "suspected illegal killing" if 1) it was a resident bear with an external and internal transmitter and both quit simultaneously, 2) it was a resident bear with a new transmitter that had not shown any signs of malfunction (abnormal or weak signals) and was in an area that we searched often and/or observed snowmobile or other human-made tracks in the same area at the time of disappearance, or 3) we received an anonymous call or message that a specific bear had been killed, when we had not made the loss public. We were restrictive in our judgement of cases of "suspected illegal killing", but we recognize that we could have included some bears that actually were still alive. However, the results of an earlier study suggested that this probability was very low (Swenson and Sandegren 1999). Thus, we included these cases in our calculation of the minimum proportion and rate of illegal killing. All other bears that we lost contact with were classified as "fate unknown".

We classified the documented causes of mortality into the following categories: killed by another bear, capture for research, management (including bears killed on the order of

police or wildlife management authorities or by citizens in defense of life or property), legal hunting, traffic, illegal killing, and unknown (including bears that were found dead, but a cause of death could not be accertained). Disappearances were classified as "suspected illegal" for bears where contact was lost under circumstances that gave us a strong suspicion of illegal killing, see above, and "uncertain fate" for bears where contact was lost without specifically suspecting illegal killing. We calculated the minumum proportion of nonresearch deaths due to illegal killing as the proportion of documented and suspected illegal deaths among all deaths, excluding those caused by capture during research and disappearances with uncertain fate. We calculated the maximum proportion as the proportion of documented and suspected illegal deaths and those of uncertain fate among all deaths, excluding those caused by capture during research. We excluded deaths caused by research, because this mortality factor does not occur in the unmarked population of bears, for which we were generalizing our results.

We have recently used multistate capture-recapture models to estimate cause-specific mortality rates for yearlings, subadults (2-4 years old), and adults ($\geq$5 years old) in our two study areas (Bischof et al. 2009). Causes of mortality were divided into legal hunting and other causes. This method allows the inclusion of mortalities that were not detected through radiotelemetry. Bischof et al. (2009) did not specifically report mortality rates due to other causes between areas or sexes, so we used area-specific rates for adult females presented in Bischof & Swenson (2009). Thus, to estimate the annual rate of illegal killing for adult females in each study area, we multiplied the nonhunting annual mortality rate reported by Bischof & Swenson (2009) by the minumum and maximum estimates of the proportion of this mortality that was due to illegal killing. Here we used proportions of nonhunting deaths due to illegal killing, which was different than the nonresearch deaths calculated above, to correspond with Bischof et al. (2009), who included research-caused deaths. The minimum estimate of illegal killing among nonhunting mortality was the proportion of documented and suspected illegal deaths among all deaths, excluding those caused by hunting and disappearances with uncertain fate. The maximum was the proportion of documented and suspected illegal deaths and those of uncertain fate among all deaths, excluding those caused by hunting.

We tested for differences in frequency data using χ^2 tests in SigmaStat, version 1.0. We used Yate's correction for 2x2 contingency tables.

Results

We were able to record the death or disappearance of 305 bears while they were carrying functioning radiotransmitters; 198 in the south (Table 1) and 107 in the north (Table 2). The proportion of nonresearch deaths attributable to illegal killing varied between 4.1-26.9% in the south and 44.8-58.6% in the north (Table 3), based on the criteria described in the methods. The frequency of illegal killing (known and suspected) was highly significantly higher than other causes of death (excluding research related deaths and uncertain fates) in the north (44.8%, N=67) than in the south (4.1%, N=147; χ^2_c= 51.6, df=1, p<0.0001).

The occurrence of documented and suspected illegally killed bears was evenly spread from April to August in the south (Fig. 1). In the north, however, there was a sharp peak in June and another peak in the autumn (September-November) (Fig. 1).

We know from earlier research that the mortality rate due to legal hunting has increased from 1984-1997 to 1998-2006 in the southern study area, due to increases in hunting quotas, but not in the northern study area, where hunting quotas remained stable (Bischof et al. 2009). To determine whether we could detect this change in our data, we compared the frequency of hunter-killed bears and bears that died due to all other causes of death (excluding capture for research and disappearance with uncertain fate) between these

Table 1. Causes of death of brown bears with functioning radio transmitters by age and sex category and period in the southern study area in Sweden, 1985-2010. "Management" included bears killed on the order of police or wildlife management authorities or by citizens in defense of life or property. "Unknown" included bears that were found dead, but a cause of death could not be accertained. "Suspected illegal" included bears where contact was lost under circumstances that gave us a strong suspicion of illegal killing. "Uncertain" included bears that where contact was lost without suspecting illegal killing. The total column includes 3 males of unknown age in the "uncertain fate" category from 1997 and before.

Cause of death	Males						Females						Total
	≤ 1997			≥1998			≤ 1997			≥1998			
	1 yr	2-4	≥5	1 yr	2-4	≥5	1 yr	2-4	≥5	1 yr	2-4	≥5	
Other bear	1	2					4			10	2	3	22
Capture		1	1		1			1	1				5
Management	1	2	2		3	1	1					2	12
Hunting		1	2		8	16	1		2	9	20	37	96
Traffic		1				1						1	3
Unknown				1	1						4	2	8
Illegal		1				1			1	1	1	1	6
Suspected illegal													0
Uncertain fate		2	2	1	7	4	2	1	2		16	6	46
Total	**2**	**10**	**7**	**2**	**20**	**23**	**8**	**2**	**6**	**20**	**43**	**52**	**198**

Table 2. Causes of death of brown bears with functioning radio transmitters by age and sex category and period in the northern study area in Sweden, 1984-2010. "Management" included bears killed on the order of police or wildlife management authorities or by citizens in defense of life or property. "Unknown" included bears that were found dead, but a cause of death could not be accertained. "Suspected illegal" included bears where contact was lost under circumstances that gave us a strong suspicion of illegal killing. "Uncertain" included bears that where contact was lost without suspecting illegal killing. The total column includes 1 male of unknown age in the "uncertain" category from 19987 and after.

Cause of death	Males						Females						Total
	≤ 1997			≥1998			≤ 1997			≥1998			
	1 yr	2-4	≥5	1 yr	2-4	≥5	1 yr	2-4	≥5	1 yr	2-4	≥5	
Other bear	1	2										2	5
Capture								1				2	3
Management					1						2	5	8
Hunting		2	1		3	2		2			2	4	16
Traffic													
Unknown	2	1			1	1	2	1		2		4	14
Illegal					1							1	2
Suspected illegal	1	3	3	1		3	1	1	4	1	5	5	28
Uncertain	1	6	1		6	3				1	2	10	31
Total	**5**	**14**	**5**	**1**	**12**	**9**	**3**	**5**	**4**	**4**	**11**	**33**	**107**

Table 3. Causes of death of brown bears with functioning radio transmitters in the southern and northern study areas in Sweden, 1984-2010, expressed in percent. This is a summary of Tables 1 and 2. The percentages shown in bold were used to estimate the minimum and maximum proportions of illegal killing among nonresearch deaths.

Cause of death	South			North		
	All	Without capture	Without uncertain fate, or capture	All	Without capture	Without uncertain or capture
Other bear	11.1	11.4	15.0	4.7	4.8	7.5
Capture	2.5			2.8		
Management	6.1	6.2	8.2	7.5	7.7	11.9
Hunting	48.5	49.7	65.3	15.1	15.4	23.9
Traffic	1.5	1.6	2.0	0	0	0
Unknown cause	4.0	4.1	5.4	13.1	13.5	20.9
Illegal	3.0	**3.1**	**4.1**	1.9	**1.9**	**3.0**
Suspected illegal	0	**0**	**0**	26.2	**26.9**	**41.8**
Uncertain fate	23.2	**23.8**		29.0	**29.8**	
Sample size	198	193	147	107	104	67

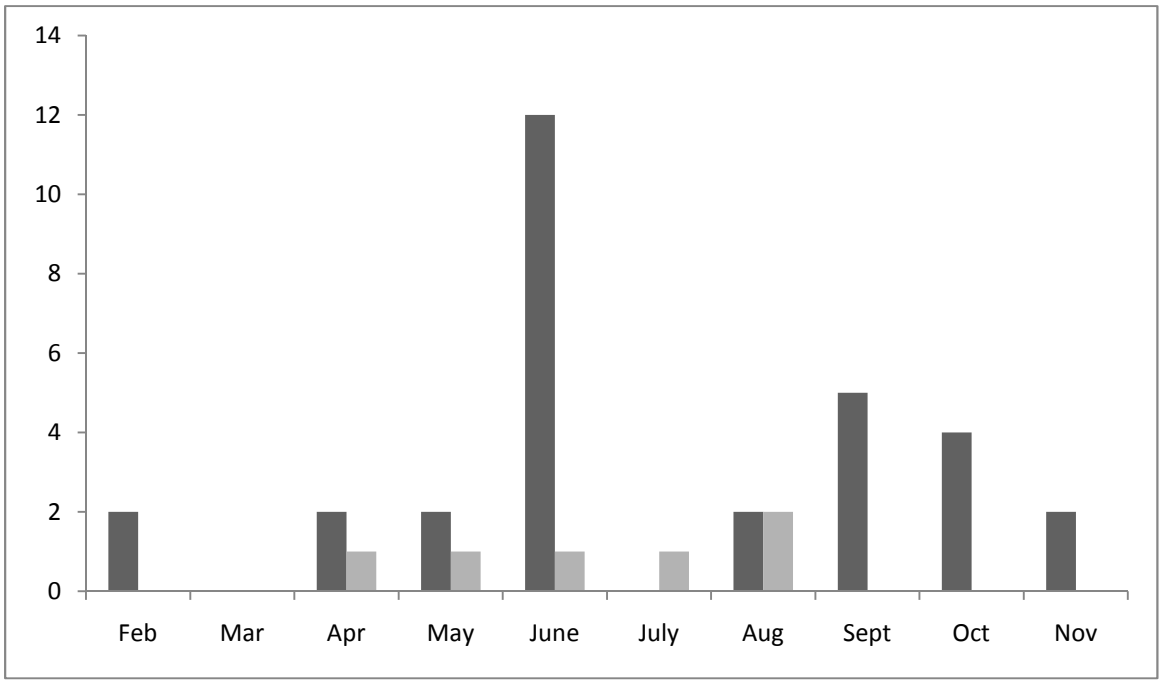

Fig. 1. Month that a brown bear was documented or suspected killed illegally in the northern (black) and southern (gray) study areas in Sweden and Norway. Especially for suspected illegal killing, the event may have occurred somewhat earlier than shown here.

two periods. As expected, based on the results of Bischof et al. (2009), we found a significant difference in the frequency of hunting deaths in the south between 1985-1997 (27%, N=22) and 1998-2010 (72%, N=125, χ^2_c= 14.6, df=1, p=0.0001). Also as expected, based on the results of Bischof et al. (2009), there was no significant difference in the frequency of hunting

deaths in the north between 1984-1997 (18%, N=27) and 1998-2010 (14%, N=80, χ^2_c= 0.60, df=1, p=0.81).

We then compared the frequency of illegally killed bears (documented and suspected) with that of bears that died due to all other causes of death (excluding hunting, capture for research, and disappearance with uncertain fate) between the two periods. We found no significant difference in the frequency of illegal deaths in the north between 1984-1997 (59%, N=22) and 1998-2010 (49%, N=35, χ^2_c= 0.25, df=1, p=0.62). We found the same result in the south, comparing 1985-1997 (12%, N=16) with 1998-2010 (11%, N=35, Fisher's exact test, p=1.00). We therefore conclude that the rate of illegal killing has not changed between these two periods in either study area.

Based on the results of this test, we combined the data from both periods and compared the frequency of illegally killed bears (documented and suspected) with that of bears that died due to all other causes of death (excluding hunting, capture for research, and disappearance with uncertain fate) between the sexes. We found no differences between the proportion of illegally killed bears among males (57%, N=21) and females (50%, N=36) either in the north (χ^2_c= 0.060, df=1, p=0.81) or the south (males 11%, N=18; females (12%, N=33; Fisher's exact test, P=1.00). Therefore we combined the sexes to test for age differences. We did not find age differences in the frequency of illegally killed bears in either the north (yearlings, 36%, N=11; subadults, 56%, N=18; adults, 57%, N=28; χ^2= 1.46, df=2, p=0.48) or the south (yearlings, 5%, N=19; subadults, 12%, N=17; adults, 20%; χ^2= 1.75, df=2, p=0.42).

We multiplied estimates of the proportion of nonhunting deaths attributable to illegal killing (10.7-51.0% in the south and 50.0-67.1% in the north; Table 4) by the annual nonhunting mortality rates for adult females during 1998-2007 in the south (1.2%, 95% confidence intervals = 0.3-3.0%) and in the north (4.6%, 2.5-7.1%) reported in Bischof & Swenson (2009). From this, we estimated annual rates of illegal mortality among adult females to be 0.1-0.6% in the south and 2.3-3.1% in the north.

Table 4. Causes of death of brown bears with functioning radio transmitters in the southern and northern study areas in Sweden, 1984-2010, expressed in percent. This is a summary of Tables 1 and 2. The percentages shown in bold were used to estimate the minimum and maximum proportions of illegal killing among nonhunting deaths for calculation of the mortality rates due to illegal killing.

Cause of death	South			North		
	All	Without hunting	Without uncertain fate, or hunting	All	Without hunting	Without uncertain fate, or hunting
Other bear	11.1	21.6	39.3	4.7	5.5	8.3
Capture	2.5	4.9	8.9	2.8	3.3	5.0
Management	6.1	11.8	21.4	7.5	8.8	13.3
Hunting	48.5			15.1		
Traffic	1.5	2.9	5.4	0	0	0
Unknown cause	4.0	7.8	14.3	13.1	15.4	23.3
Illegal	3.0	**5.9**	**10.7**	1.9	**2.2**	**3.3**
Suspected illegal	0	**0**	**0**	26.2	**30.8**	**46.7**
Uncertain fate	23.2	**45.1**		29.0	**34.1**	
Sample size	198	102	56	107	91	60

Discussion

We did not find any statistically significant differences in frequency of illegally killed bears compared to other causes of mortality based on age class, sex, or study period. There was, however, a highly significant difference between study areas. We estimated that the proportion of nonresearch deaths attributable to illegal killing was between 4.1-26.9% in the south and 44.8-58.6% in the north. We calculated the rate of illegal killing for adult females to assess its impact on the population (Sæther et al. 1998). The estimated annual rate of illegal mortality among adult females was minimal in the south, 0.1-0.6%, but much higher in the north, 2.3-3.1%. These results were supported by findings of Bischof et al. (2009) that the recapture probability of newly dead bears without functioning transmitters was higher in the south than in the north and that their second-best model showed that the mortality rate due to factors other than legal hunting was slightly lower in the south. In an analysis of causes of brown bear mortality in Scandinavia from 1984-1998, Swenson and Sandegren (1999) found that the annual rate of illegal mortality was 4-5 times higher in the north than in the south. This difference is still evident. Andrén et al. (2006) found the highest illegal mortality among radiomarked Eurasian lynx in four study areas in Scandinavia to be in the same northern study area. Similarly, Persson et al. (2009) found a substantial rate of illegal mortality among wolverines in this same area. There seems to be no question that the illegal killing of large carnivores is high in this specific area, but it is difficult for us to determine how widespread the phenomenon is for bears.

There was also a difference in the seasonal pattern of illegal deaths between the south and north. Whereas there was no obvious pattern in the south, there was a sharp peak in June in the north. The June peak includes bears that we could not relocate in June and we suspected had been killed illegally. Some of these may have been killed in May. Especially May is an important period of bear predation on reindeer calves and most suspected illegally killed bears were last located on reindeer calving grounds. The peak in the autumn corresponds with the hunting season.

Although the rate of illegal killing was higher in the north, it did not seem to occur at a level that was causing a general population decline. Bischof & Swenson (2009) reported that the population in the southern study area could sustain an annual female hunting mortality of 11.2% (95% CI: 8.2% - 13.5%), compared with 12.7% (95% CI: 10.4% - 14.5%) in the northern study area, when accounting for nonhunting mortality. The present harvest rate is far below that in the northern study area, but not in the south (Bischof & Swenson 2009). In addition, the brown bear population in Sweden as a whole has been growing at an average instantaneous rate of 0.045 during 1998-2007 (Kindberg et al. 2011) and densities of brown bears are increasing in many areas with formerly lower densities, both in the north and south (Kindberg 2010). Only two Swedish counties have not shown significant rates of growth in this period; Dalarna, where our southern study area is located, and Västerbotten, which is in northern Sweden, but south of our study area (Kindberg et al. 2011). Thus, we conclude that illegal killing is generally not a limiting factor for the brown bear population in Sweden, but that it can be an important factor locally, such as in the northern study area.

Bischof et al. (2009) did not report area-specific rates of nonhunting mortality for adult males, because their models indicated that there was no significant difference. Nevertheless, earlier studies have suggested a reduced occurrence of adult males in the northern study area, presumably due to a higher rate of illegal killing there, compared with the southern study area (Swenson et al. 2001). This appears to have had life-history effects on the population, with higher rates of sexually selected infanticide in the south (Swenson et al. 2001) and a higher reproductive success among younger males in the north than in the south (Zedrosser et al. 2007). Presumably due to the lack of older males in the north, estrous females there selected the larger young males for mating, whereas in the south, they chose

older males (Bellemain et al. 2006). Thus, illegal killing may impact the life-history traits and not just the size or trends of a brown bear population.

We did not find a difference in the frequency of illegally killed bears and other nonresearch and nonhunting mortality causes when comparing the periods ≤1997 and ≥1998 in either study area. A comparison of the frequency of hunter-killed bears did show a difference between periods for the south, but not for the north, similar to what Bischof et al. (2009) found in a more sophisticated analysis based primarily on the same data. We conclude that the rate of illegal killing has not changed over the study period and that it was not related to the mortality rate due to legal hunting. Andrén et al. (2006) also found that there was not a simple inverse relationship between rate of legal harvest and poaching for Eurasian lynx in Scandinavia, although this relationship commonly is expected. However, we do not know if future changes in the way management deals with bears that depredate reindeer will affect the rate of illegal killing.

Bischof et al. (2009) concluded that hunting mortality was additive to other forms of mortality in Scandinavian brown bears. The apparent lack of relationship between harvest rate and illegal killing suggests that this might also hold for illegal killing. Thus, when managers set hunting quotas, they must be aware that illegal killing may come in addition to the legal mortality. This may be especially important in areas where managers suspect the rate of illegal mortality to be high.

We found strong evidence of a spatial difference in rates of illegal killing of brown bears within Sweden. The rate of illegal killing was high in our northern study area, but the bear population is increasing and expanding in many areas in northern Sweden. It is therefore important to identify the areas where illegal killing is common. This is probably not easy to do. However, one possible method to evaluate this would be to examine the changes in distribution of hunter-killed females over time. Given that the population has been increasing generally, one might suspect a higher rate of illegal killing in areas where the occurrence of hunter-killed females has declined over time, unless other reasonable factors could explain it. One could compare changes in the distribution of hunter-killed females between mountainous and forested areas within the reindeer raising area, for example. Another possible method might be to use mark-capture-recapture techniques, based on the individually-identified bears in the scat-based population estimates, to estimate total mortality rates in areas where two scat surveys have been conducted. Such data are now available for Västerbotten and Norway, and may soon be available from other Swedish counties.

It is very difficult to document illegal killing, primarily because it is illegal. We believe that our minimum and maximum estimates have bracketed the true values of the proportion and rate of illegal killing. Nevertheless, there are several sources of bias beyond documenting the deaths. For example, the fact that people know that animals are radiomarked in an area may reduce illegal mortality, to avoid being caught or alerting the authorities of this activity. However, it may also increase illegal mortality, if the poachers have access to equipment that helps them locate radioed animals. They might destroy the transmitter(s) after killing the animal, or report it as legally killed, if killed during the hunting season. In the latter case, they would not be included in our estimates. Our study area has remained quite stable during the study period in the south. In the north, however, the distribution of radiomarked animals has moved from the protected areas to now almost completely outside them, due partially to documented and suspected illegal killing within the protected areas. Thus, we did not estimate illegal killing within the same areas during the two time periods, which also could be a source of bias.

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