Brown bear predation on domestic sheep in central Norway

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Abstract: In 1994, we studied predation on domestic sheep using mortality radiocollars in an area in central Norway inhabited by brown bears (*Ursus arctos*). The total loss among 234 radiocollared ewes in 3 herds released on summer pastures was 54, and 51 (94.4%) were due to bear predation. Among 337 radiocollared lambs, 37 were known to have died, 14 (42.4%) due to bear predation. Bears selected ewes over lambs, consistent with optimal foraging theory. Ewes with bells had a higher risk of being killed than ewes without bells. Selection of young ewes with male-dominated litters in spring and small lambs can partly be explained according to parental investment theory and selection for individuals that are last in the flock when attacked or chased by bears.

Key words: bear–human conflicts, brown bear, depredation, domestic sheep, Norway, optimal foraging, parental care, prey selection, *Ursus arctos*

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Brown bears (*Ursus arctos*) are opportunistic and prefer foods that are easily available and rich in energy. When consuming prey items with high protein (e.g., animals), bears gain weight rapidly. In Norway, where brown bears are distributed mainly along the border with Sweden (Swenson et al. 1995), such animal food may be obtained from consuming wildlife carcasses or predation on large wildlife such as reindeer (*Rangifer tarandus*) and moose (*Alces alces*), or by depredation on domestic animals such as sheep. The amount of stored body fat has major consequences for individual survival and reproductive success (Elowe and Dodge 1989).

Since the 1970s, bear depredation on sheep has occurred frequently on Norwegian summer pastures (Mysterud 1980, Kvam et al. 1993, Wabakken and Maartmann 1994, Dahle 1996). This has most likely resulted from a slowly increasing bear population on the one hand and increased use of summer pastures for sheep husbandry on the other. Due to an inability to locate carcasses quickly enough, the first studies of loss of free ranging sheep did not precisely verify the predator species involved or quantify the number of sheep succumbing to bear predation seasonally or annually. During the 1990s, mortality transmitters provided the opportunity to close this gap in knowledge.

Warren and Mysterud (1995) monitored sheep mortality in Hedmark County in southeastern Norway and found summer mortality rates from bear depredation to be 7.2% for ewes and 9.1% for lambs. Among factors predisposing lambs to depredation were sex and weight at birth—male lambs were more often killed by bears than female lambs.

In Norway, there are approximately 2.4 million free-ranging sheep, mostly without active herding, on summer pastures. In 1994, 117,000 sheep died on summer range. Known causes of mortality included diseases, accidents, and predation by red fox (*Vulpes vulpes*), dog, eagle (*Aquila chrysaetos*), bear, wolverine (*Gulo gulo*), lynx (*Lynx lynx*), and wolf (*Canis lupus*) (Norwegian Ministry of Environment 1996).

During the summer of 1994 we initiated a telemetry-based study in Lierne municipality, North Trøndelag County to document bear predation on sheep in summer pastures in a sub-alpine area. This region, close to the Swedish border, is known for its occurrence of bears and conflicts with sheep husbandry. Our objectives were to

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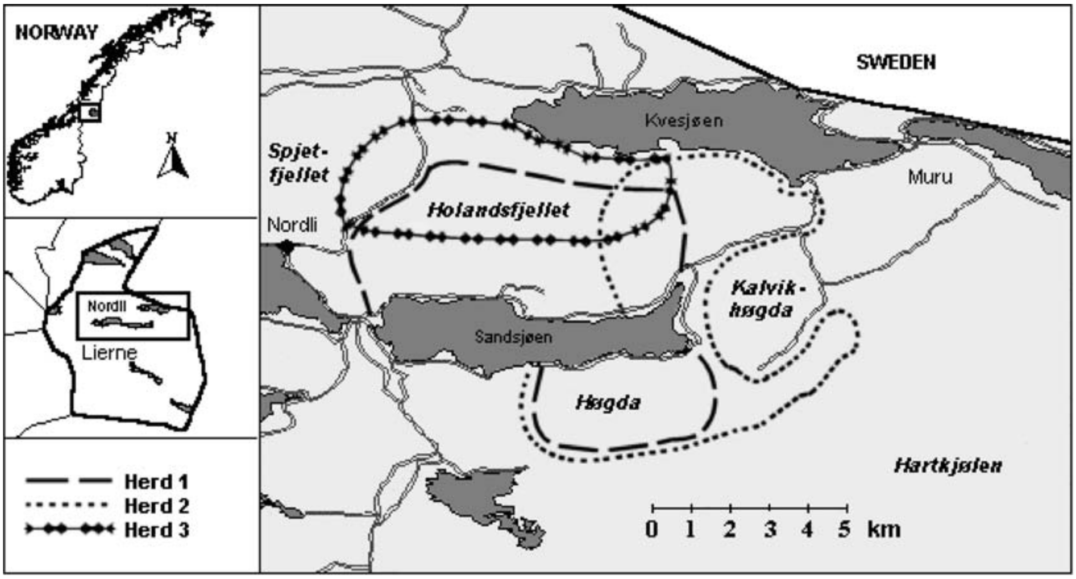

Fig. 1. The study area in Lierne municipality, Norway, and areas used by 3 sheep herds in mountains of Holand, Norway, May–June 1994. Dark areas are lakes.

clarify the extent of sheep loss to bears during the summer period, to identify relationships influencing their susceptibility to depredation (including factors such as age, weight and body condition), and to recommend ways to reduce depredation on sheep on their summer range in central Norway.

Study area

The study area was the grazing area in the mountains of Holand in Lierne Municipality, North-Trøndelag County in Norway (Fig. 1), adjacent to occupied brown bear habitat in Sweden (Swenson et al. 1994). The area covers approximately 100 km^2 and is comprised of coniferous (*Picea abies*) forest, but includes mountain birch (*Betula pubescens*) forest and some low-alpine areas. Elevations range from 300 to 750 m. Vegetative productivity is above average for the region, and large areas provide excellent grazing for free-ranging sheep. Sheep density is ~6 sheep/km^2 for the entire area, but reaches 15 sheep/km^2 in the core of the study area.

Since the mid 1970s, the brown bear population has expanded in adjacent Sweden and continues to spread into Norway (Swenson et al. 1994). Precise data on bear density over the entire Norwegian study area in Lierne and surrounding areas is lacking and may vary from year to year because the area around Lierne presently contains the westernmost population of reproductive female bears. However, from 1980 to the mid 1990s, there were increasing bear conflicts with sheep husbandry, leading to a significant reduction in the number of sheep farmers in the area.

Table 1. The 3 sheep herds containing a total of 516 ewes and 708 lambs, released in the grazing area in Lierne municipality, central Norway, May–June 1994.

	Number of sheep released		Number of radiocollared sheep	
	Adult	Juvenile	Adult	Juvenile
Herd 1	163	264	64	108
Herd 2	165	197	75	107
Herd 3	188	247	95	122
Total	516	708	234	337

Methods

Three sheep herds, primarily of the Spel breed and containing 516 ewes and 708 lambs, were released in the grazing area in mountain of Holand in May–June 1994 (Table 1). Most sheep were retrieved during early September, but a few escaped until October. The three herds were located in front-country close to human settlements (Herd 1), in the forested part of back-country and wilderness areas (Herd 2), and in more open, alpine back-country at higher elevations (Herd 3). Besides landscape differences, there were no substantial differences in herding methods (e.g., handling and releasing time in spring, retrieving during fall). Upon releasing

Table 2. Number of sheep released, found dead, and killed by bears in 3 herds released in Lierne municipality, central Norway, May–June 1994.

	Total			Radiocollared		
	Adult	Juvenile	Total	Adult	Juvenile	Total
Herd 1						
Released	163	264	427	64	108	172
Dead	52	26	78	19	12	31
Bear-killed	—	—	—	16	5	21
Herd 2						
Released	165	197	362	75	107	182
Dead	36	25	61	18	6	24
Bear-killed	—	—	—	18	6	24
Herd 3						
Released	188	247	435	95	122	217
Dead	47	39	86	17	19	36
Bear-killed	—	—	—	17	3	20

sheep on summer pastures, we systematically fitted every third individual (234 ewes and 337 lambs; Table 1) with mortality VHF (very high frequency) transmitters (Televilt, Lindesberg, Sweden). The transmitters allowed us to locate carcasses before they decayed or were consumed by scavengers and made it easier to determine cause and time of death of the sheep. Collared individuals were monitored twice daily throughout the grazing season, mainly from the ground.

Each carcass and kill site was investigated to discover primary and secondary damage. A report, including photo documentation, was prepared to assist in deducing cause of death. We described the scene and traces (such as prints) at each depredation incident. Specimens (heart, lung, liver, kidney, spleen, and scat) were collected and shipped to the Norwegian Veterinarian Laboratory for examination.

Variables and statistical analysis

We used stepwise logistic regression analyses (Hosmer and Lemeshow 1989) to examine the relationship of potential risk factors contributing to brown bear predation on ewes: spring weight (kg), age class (yearling, 2–4 years, 5–9 years), herd (1, 2, or 3), litter size (0–3), litter sex ratio, and bell presence or absence; and lambs: birth weight (kg), weight gain (g/day), spring weight (kg), sex, litter size, herd, mother's age, and mother's weight in spring (kg). The dependent variable (fate of individual) was coded 1 for a mortality and 0 otherwise. We used univariate analysis to explore variables in the data set separately.

Results

Total loss, sheep category and bear utilization of carcasses

In Herd 1, 21 (12.2%) of 172 collared sheep were killed by bears; in Herd 2, 24 (13.2%) of 182 collared sheep were killed by bears; and in Herd 3, 20 (9.2%) of 217 collared sheep succumbed to bear predation (Table 2). Among all sheep (collared and non-collared), 26.2% (135 of 516) of all ewes and 12.7% (90 of 708) of all lambs died or disappeared (Table 3). Overall for collared sheep, 23.1% (54 of 234) of ewes and 10.9% (37 of 337) of lambs died during the summer (Table 3). All radiomarked ewes and lambs were accounted for, but 14.2% of unmarked ewes and 10.6% of unmarked lambs that disappeared were not found (Table 3). For sheep in which cause of death was known, bear predation constituted 95.2% of deaths of unmarked and 96.2% of collared ewes, and 58.3% of unmarked and 42.4% of collared lambs (Table 4). Bears killed significantly more ewes than lambs ($\chi^2 = 38{,}552$, 1 df, $P < 0.001$). Bears most often consumed only the fat on the rib cage and the udder of ewes, but more often consumed most of the carcass of lambs (Fisher Test, $P = 0.004$, Table 5).

Risk factors contributing to brown bear predation on ewes

Herd 1. Of ewes killed by bears, 10 wore bells and 7 did not. Of those that survived, 9 had bells and 27 did

Table 3. Survival rate and causes of death of radiocollared and non-collared ewes and lambs released on summer pastures in Lierne municipality, central Norway, May–June 1994.

	Ewes				Lambs			
	Unmarked		Radiocollared		Unmarked		Radiocollared	
	n	%	*n*	%	*n*	%	*n*	%
Survived	201	71.3	180	77.0	316	85.6	300	89.1
Dead, known causes	41	14.5	53	22.6	12	3.3	33	9.7
Dead, unknown causes	0	0.0	1	0.4	2	0.5	4	1.2
Disappeared, not found	40	14.2	0	0.0	39	10.6	0	0
Total	282		234		369		337	100

Table 4. Known causes of death among ewes and lambs released in summer pastures in Lierne municipality, central Norway, May–June 1994.

	Ewes				Lambs			
	Unmarked		Radiomarked		Unmarked		Radiomarked	
	n	%	*n*	%	*n*	%	*n*	%
Bear	39	95.2	51	96.2	7	58.3	14	42.4
Lynx	0	0	0	0	0	0	2	6.1
Other carnivore	0	0	0	0	0	0	1	3.0
Eagle	0	0	0	0	0	0	1	3.0
Unknown bird	0	0	0	0	1	8.3	0	0
Disease	1	2.4	2	3.8	2	16.7	12	36.4
Accident	1	2.4	0	0	2	16.7	3	9.1
Total	41		53		12		33	

not. Ewes without bells had a reduced risk of bear predation by a factor 0.4 (Table 6).

Herd 2. Ewes killed by bears were significantly younger ($\bar{x} = 1.8$, $n = 24$) than those that that survived ($\bar{x} = 2.8$, $n = 51$, Table 7). Ewes in age class 1 had a 38 times higher risk of being killed by bears than ewes in age group 3. Ewes killed by bears had significantly more male lambs ($\bar{x} = 0.3$, $n = 22$) than those that survived ($\bar{x} = 0.5$, $n = 44$; Fig. 2). An increase in the sex ratio of the litter favoring female lambs reduced the risk of predation on ewes by a factor 0.2 (Table 7). No ewes in the 5–9 year age class were killed by bears.

Herd 3. Ewes killed by bears in the 5–9 year age class had significantly higher weight ($\bar{x} = 67.9$ kg, $n = 17$) than those that survived ($\bar{x} = 58.9$ kg, $n = 72$), when released on pastures (Table 8). In Herd 3, a 1-kg weight gain increased the risk of depredation by a factor of 1.054 (Table 8).

Risk factors contributing to brown bear predation on lambs

Because bears killed only 14 lambs, all lambs were analysed as one group (Table 9). Although not significant, data suggests that surviving radiomarked lambs had heavier spring weights than those killed by bears ($\bar{x} = 8.8$ kg, $n = 300$ lambs versus $\bar{x} = 6.9$ kg, $n = 14$ lambs; Fig. 3). A 1-kg weight gain reduced the risk of bear predation by a factor 0.42 (Table 9).

Table 5. Proportion of sheep carcass eaten by brown bear in summer pastures in Lierne municipality, central Norway, May–June 1994. "Extreme" = fat on chest and udder was eaten. "Entire" = the entire animal was eaten.

	Ewes		Lambs	
Proportion eaten	*n*	%	*n*	%
Extreme	35	68.6	3	26.7
Entire	16	31.4	11	73.3
Total	51	100	14	100

Discussion

The extent of sheep loss to bear predation

The distribution of the 3 herds (Table 2) covered traditional pasture types from front-country near human settlements to back-country wilderness. The level of sheep was loss considerable: 22.6% ($n = 53$) of the radiocollared ewes died, as did 9.7% ($n = 33$) of the radiocollared lambs (Table 3). Moreover, bears

Table 6. Logistic regression of radiocollared ewes that were bear-killed or survived the summer season in Herd 1 in summer pastures in Lierne municipality, central Norway, May–June 1994. Variables without values were excluded from the analysis. *P* = significance level, *r* = correlation coefficient, *n* = sample size, *B* = logit coefficient, $e^{(B)}$ = odds ratio. Age class 1 = yearling, age class 2 = 2–4 years, age class 3 = 5–9 years.

	Univariate analysis			Multivariate analysis			
Variable	*P*	*r*	*n*	*B*	*P*	*r*	$e^{(B)}$
Spring weight	0.591	0.000	53		0.711	0.000	
All litter sizes	0.043	0.198	53		0.191	0.000	
Litter of 1	0.014	0.260	14		0.071	0.146	
Litter of 2	0.342	0.000	32		0.474	0.000	
Litter of 3			7				
Sex ratio	0.701	0.000	53		0.868	0.000	
All age classes	0.172	0.000	53		0.285	0.000	
Age class 1	0.156	0.013	9		0.576	0.000	
Age class 2	0.845	0.000	27		0.411	0.000	
Age class 3			17				
Bell	0.009	0.281	53	−0.074	0.014	−0.261	0.427

Table 7. Logistic regression of radiocollared ewes, bear-killed and surviving the summer season in Herd 2 at summer pastures in Lierne municipality, central Norway, May–June 1994. Variables without values were excluded from the analysis. *P* = significance level, *r* = correlation coefficient, *n* = sample size, *B* = logit coefficient, $e^{(B)}$ = odds ratio. Age class 1 = yearling, age class 2 = 2–4 years, age class 3 = 5–9 years.

	Univariate analysis			Multivariate analysis			
Variable	*P*	*r*	*n*	*B*	*P*	*r*	$e^{(B)}$
Spring weight	0.003	0.286	66		0.674	0.000	
All litter sizes	0.143	0.000	66		0.896	0.000	
Litter of 1	0.485	0.150	34		0.894	0.000	
Litter of 2	0.138	0.049	31		0.686	0.000	
Litter of 3			1				
Sex ratio	0.012	0.225	66	−1.501	0.034	−0.173	0.223
All age classes	0.001	0.329	66		0.028	0.194	
Age class 1	0.000	0.356	31	3.630	0.750	0.000	37.722
Age class 2	0.603	0.000	27	1.931	0.865	0.000	6.893
Age class 3			8				

killed 96.2% of these ewes and 42.4% of these lambs (Table 4). Bears were the main (95.2%) cause of death to loss of unmarked ewes where causes were verified (Table 4).

The study lasted only one summer and does not provide a complete picture of bear–sheep relationships; however, the data clearly confirm that bears are the most important predator on sheep in the study area. In contrast, Warren and Mysterud (1995) monitored sheep mortality and bear predation during 1988–91 with a similar study in Trysil Municipality in Hedmark County, southeastern Norway. They monitored 1,399 lambs and 850 ewes that were released onto open range. Parts of their study area were adjacent to the Swedish border and a densely occupied brown bear region (Swenson et al. 1994). Total summer mortality over the 3-years was 7.2% for ewes and 9.1% for lambs. One herd grazed along the border with Sweden and was the most vulnerable to predation by bears. In this herd 12% of ewes (37 of 295 released) died from bear predation during the 3 year study.

Correlates of depredation on ewes and lambs

Ewes were preferred to lambs, consistent with previous Norwegian studies (Mysterud 1980, Kvam et al. 1994, Warren and Mysterud 1995) as well as studies of other predators of domestic sheep such as coyotes (*Canis latrans*) (Shelton 1973, Connolly et al. 1976,

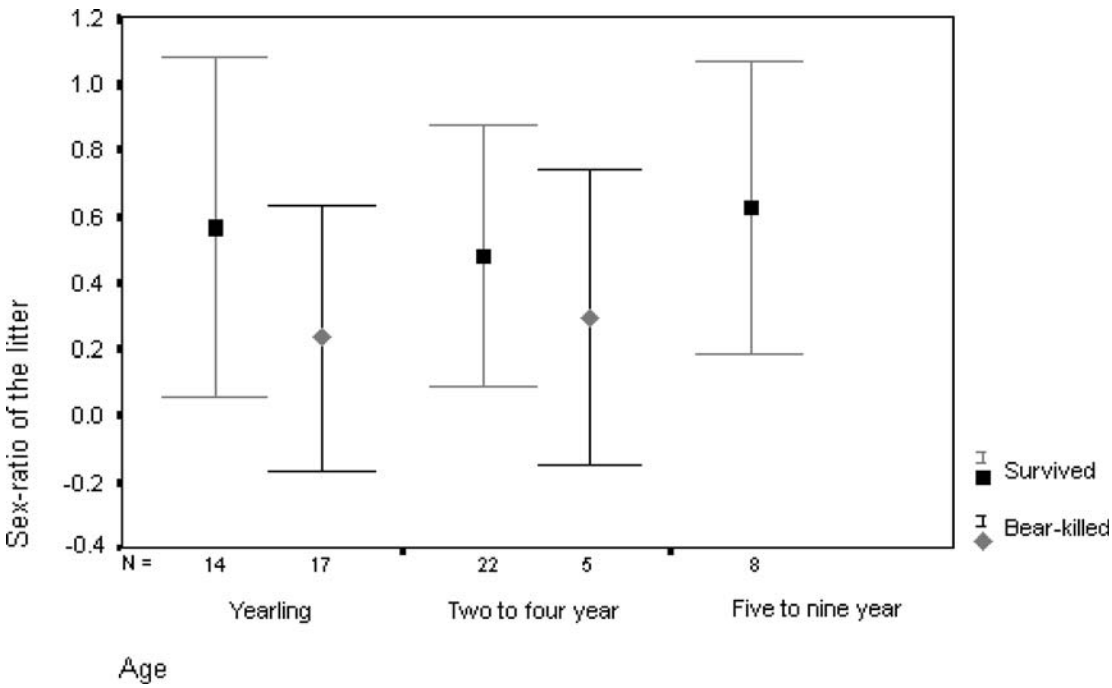

Fig. 2. Sex ratio of litter with SE for surviving ewes and bear-killed ewes by age class in Lierne municipality, central Norway, May–June 1994. Sex ratio is the number of female:male. No sheep in the 5–9 year age class were killed by bears.

Table 8. Analysis of radiocollared ewes, bear-killed and surviving in Herd 3 in the summer season in Lierne municipality, central Norway, May–June 1994. Variables without values were excluded from the analysis. *P* = significance level, *r* = correlation coefficient, *n* = sample size, *B* = logit coefficient, $e^{(B)}$ = odds ratio. Age class 1 = yearling, age class 2 = 2–4 years, age class 3 = 5–9 years. Litter of 0 = Ewe without lambs.

	Univariate analysis			Multivariate analysis			
Variable	*P*	*r*	*n*	*B*	*P*	*r*	$e^{(B)}$
Spring weight	0.014	0.221	84	0.049	0.019	0.208	1.054
All litter sizes	0.086	0.085	84		0.405	0.000	
Litter of 0			1				
Litter of 1	0.511	0.000	48		0.407	0.000	
Litter of 2	0.111	0.083	31		0.501	0.000	
Litter of 3	0.357	0.000	4		0.612	0.000	
Sex ratio	0.606	0.000	83		0.942	0.000	
All age classes	0.017	0.226	84		0.168	0.000	
Age class 1	0.005	0.268	30		0.116	0.075	
Age class 2	0.364	0.000	26		0.974	0.000	
Age class 3			28				

Table 9. Analysis of bear-killed (*n* = 14) and surviving lambs (*n* = 300) in the summer season in Lierne municipality, central Norway, May–June 1994. Variables without values were excluded from the analysis. *P* = significance level, *r* = correlation coefficient, *n* = sample size, *B* = logit coefficient, $e^{(B)}$ = odds ratio.

	Univariate analysis			Multivariate analysis			
Variable	*P*	*r*	*n*	*B*	*P*	*r*	$e^{(B)}$
Birth weight	0.159	0.000	314		0.540	0.000	
Weight gain	0.002	0.255	314		0.349	0.000	
Spring weight	0.000	0.311	314	−0.863	0.000	−0.303	0.422
All litter sizes	0.770	0.000	314		0.861	0.000	
Litter of 1	0.589	0.000	86		0.587	0.000	
Litter of 2	0.718	0.000	181		0.925	0.000	
Litter of 3			47			0.000	
Sex	0.436	0.000	314		0.429	0.000	
Age of mother	0.952	0.000	314		0.376	0.000	
Weight of mother	0.985	0.000	314		0.223	0.000	
All herds	0.179	0.000	314		0.625	0.000	
Herd 1	0.216	0.000	98		0.375	0.000	
Herd 2	0.068	0.108	102		0.468	0.000	
Herd 3			114			0.000	

O'Gara 1978). According to optimal foraging theory, bears should eat the prey, or parts of prey, that provide the greatest energy benefit for survival and reproductive success (MacArthur and Pianka 1966, Pyke et al. 1977). Ewes should provide most benefit in terms of energy; indeed, bears ate only chest or udder fat on most ewes (Table 5). However, this eating pattern is expected when the supply of prey is high; it is beneficial to eat the most energetically valuable part of the prey (Sih 1980). Hence, we propose that sheep density in our study area represents a kind of prey availability that bears respond to by functional predatory behavior.

Other patterns in bear predation were detected. Ewes without bells in Herd 1 had a reduced risk of bear predation (Table 6), and ewes killed by bears in Herd 2 were in the younger category and had more male lambs (Table 7). Ewes killed by bears in Herd 3 had higher weights when released on summer pasture than those who survived (Table 8). We believe that bears in some way associate the sound of the bells with chasing and food possibilities. That young ewes in Herd 2 were vulnerable to predation can be connected to their male-dominated litters. Studies elsewhere in related species indicate that increasing number of male lambs in the litter increases the risk of predation, which may be due to the greater cost of raising male offspring compared with female offspring, as shown for example in red deer (*Cervus elaphus*) (Flook 1970, Clutton-Brock et al. 1982), and wild reindeer (Skogland 1986). Alternatively the risk of predation among those young ewes may also be explained by the observation that male offspring are more daring and less connected to their mother, an effect that can be more pronounced when the mother is young. This has been shown for sheep (Hewson and Verkaik 1981, O'Connor et al. 1985, Warren and Mysterud 1995), red deer (Clutton-Brock et al. 1982, Mech and McRoberts 1990), and domesticated reindeer (Bjärvall et al. 1990). When danger occurs it may take a longer time for younger ewes with male lambs to gather their offspring and escape. Finally, that ewes killed by bear in Herd 3 were older and had higher weights when released on summer pasture than those that survived seems counter-intuitive, in particular because these older, heavier ewes did not tend to have large litter size or male-dominated litters. Had they been wild animals, we would have expected heavier individuals to be less, rather than more, susceptible to predation. However, we speculate that in domesticated animals such as sheep, high weights are an artifact of domestication not necessarily correlate with health and thus may lead to higher predation. We postulate that heavier ewes are maladapted to wild environments, and due to their high weight (and perhaps relatively

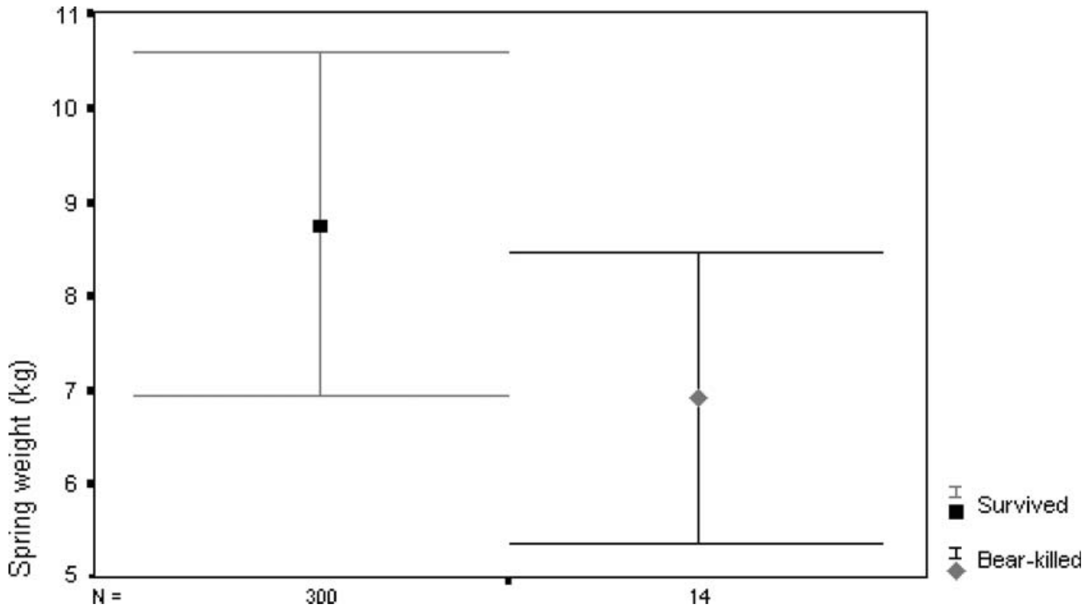

Fig. 3. Average spring weight with SE for surviving lambs and lambs killed by bears in Lierne municipality, central Norway, May–June 1994.

older age) have slower escape speeds than younger, lighter individuals. Further, older ewes generally have a tendency to protect their lambs against threats (Hewson and Verkaik 1981, Festa-Bianchet 1988, Warren and Mysterud 1995), which may lead to higher exposure to predators. In addition we suggest that if the general preference for ewes over lambs suggests selection on the part of bears for availability of fat or protein-rich body parts, predation on the larger ewes should be expected.

We found no association between sex of the lamb, litter size, age of mother, or spring weight of the mother, and risk of being killed by a bear. Although not statistically significant, radiomarked lambs that survived had heavier spring weights than those killed (Table 9, Fig. 3). This is in accord with studies in which birth weight and growth rate during spring correlated with postnatal mortality (Purser and Young 1964). We believe that lower weight may reflect less vigilance and endurance and that lambs in the lower weight class could not maintain the same speed as the other sheep when chased and so became the first prey. This impression is strengthened by predation events that we categorized as surplus killing, in which the bear left prey without consuming it and started chasing the herd again. In this type of predation, smaller individuals with the lowest weights are the first to be depredated.

Conclusions and management recommendations

We suggest searching for possibilities to reduce the proportion of older ewes within the herd. Moreover, we suggest keeping ewes with male-dominated litters to the farmhouse and not releasing them to remote summer pastures at all. However, bears may shift predation to other age classes, so close monitoring must continue. Wearing bells seems to have an increased risk of predation. Thus, substitutes for bells should be considered. Lambs in the lower weight category may be more vulnerable to predation. Lambs weighing >9 kg before being released on summer pastures probably have best chances to survive predation.

An ideal solution may be that pastures for sheep are separated from brown bear areas. However, this raises practical and economical questions. The main management tactic has been to offer farmers in this area the opportunity to change from sheep husbandry to cattle farming. After 1994, cattle raising increased and sheep farming decreased in the farming society studied in this work.

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