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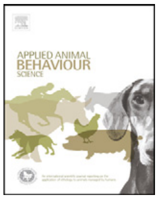

Farm characteristics in Slovene wolf habitat related to attacks on sheep

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ABSTRACT

We aimed to characterize differences between sheep farms in wolf habitat in Slovenia that either suffered from wolf attacks ($n = 30$) or not ($n = 30$) during the pasture seasons 2008–2010. Main pasture season was from April until November. Median fenced pastures were 2.7 ha and herd size was 93 sheep. The three-year period contained 288 attacks, mostly occurring in May (36), and secondly peaking in October (23). 78% of all attacks occurred at night. Significantly fewer non-attacked than attacked farms had mixed herds (17% versus 40%). Wolves killed a median of 4 sheep per attack. If herds included goats, 2 goats could be killed in addition. Sheep were driven to a night facility before dusk by 43% of non-attacked farmers, and significantly fewer attacked farms (10%). Significantly fewer attacked than non-attacked farms kept sheep in closed night barns or a separately fenced night-area (20% versus 50%). Guarding dogs (usually 2 per herd) were kept by 53% attacked and 43% non-attacked farms. Average fence height was 115 cm and did not differ between attacked or non-attacked farms. 87% non-attacked farms had wire-mesh fences (either electric or not) instead of fences with horizontal single wires, which was significantly more than at attacked farms (61%). Significantly more attacked (89%) than non-attacked farms (60%) had electric fences (mobile or fixed, fixed ones could be combined with physical fences). In spite of farmers using electric fences, annual attack number was significantly higher at farms with a history of wolf attacks than at new farms (4 versus 1). Electric fences or guarding dogs as used in the study area proved ineffective: they did not prevent wolf attacks or reduce killing rates. Adoption of mesh instead of single wires, polarity alternation of live with ground wires in electric fences, and fences higher than 145 cm seem improvements. However, potentially, improved fencing could also prevent sheep from breaking out, if wolves have found ways to enter the fenced area, and might result in surplus killing. Alternative strategies are: (1) to keep sheep in closed night barns and to move sheep there before dusk and (2) to research (a) wolf attack rates and feasibility of separating sheep and goat herds; (b) sheep and goat responses to predator attacks and methods that assist sheep and goats to avoid being attacked; (c) wolf deterring methods focused on systematic negative reinforcement of chasing and consumption of livestock.

1. Introduction

In Slovenia, 85% of the whole territory is considered less favoured area for agriculture (Rural Development

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Programme, 2007). Sustainable animal production is mainly limited to sheep and goat breeding in mountainous and hilly perennial grasslands with shallow soils of poor quality, such as in the Dinaric karst area. This Natura2000 area is an EU protected natural corridor with high biodiversity maintained by grazing small ruminants. It links the Alps in the northwest with mountainous Gorski Kotar in the southeast border with Croatia. It is also the main Slovene habitat for wolves (*Canis lupus*).

For the last decade, wolf numbers in Slovenia are 30–50 (Linnell et al., 2002), but also 60–100 is mentioned (website Large Carnivore Initiative for Europe). Slovene researchers recently mentioned 43 wolves, and 10–12 packs consisting of 4 adults on average (Krofel, 2012). The total area of Slovene wolf territories is around 4700 km^2 (Černe et al., 2010), implying a density of 1 wolf/100 km^2. Estimated total biomass of ungulates in these wolf territories is 245 kg/km^2 (Jerina, unpublished, cited by Kavčič et al., 2011). This ungulate biomass estimate represents 28% of 860 kg/km^2, found for the Italian Casentinesi forests and considered very high (Apollonio et al., 2004). Thus, wild ungulate prey is relatively abundant in Slovenia, as Slovene wolf densities are 5 times lower compared to the Casentinesi forests.

Indeed, Slovene wolves mainly predate cervides and, to some extent, young wild boars (*Sus scrofa*) (85 and 5% of consumed biomass, respectively), whereas domestic animals represent 10% of consumed biomass (Krofel and Kos, 2010). However, relations are ambiguous between prey density and prey selection in European regions with wild and domestic animals. Some researchers explain predation on domestic animals by low availability of wild ungulates (Capitani et al., 2004; Gula, 2008), but others do not find such relations or point to contradictory results (Espuno et al., 2004; Kojola et al., 2004; Mattioli et al., 2011; Meriggi and Lovari, 1996; Meriggi et al., 1996).

In spite of preferences for cervides, cervid abundance and low wolf densities, Slovene wolves have increasingly killed livestock. There were 61 cases with 218 small ruminants (90% sheep, 10% goats) killed in 2005 and 542 cases with 1931 small ruminants (85% sheep, 15% goats) killed in 2010 (ARSO, 2005-2010). Beside this livestock, cattle, donkeys and horses were killed too, but this was in 5% of cases on average. State compensation for the economic losses increased almost eleven-fold from €29,000 in 2005 to €313,000 in 2010. However, only a small number of farms had a high number of attacks each year: out of 320 known farms with wolf attacks, 25 had over 50% of all compensated damage (Černe et al., 2010). Relatively high number of attacks with a few farms seems common in Europe (Boitani, 2000) and the USA (Breck and Meier, 2004; Smallidge et al., 2008). In Switzerland, wolves return to the pastures where their hunts have been successful (Nationale Koordination Herdenschutz, 2011). Wolves' preferences for specific farms have also been found in Slovakia, where 12% of farms accounted for 79–82% of all losses. Indeed, the same farmers tended to have problems each year (Rigg et al., 2011). Gazzola et al. (2008) also reported that in Arezzo, a province in Italy, 35 attacks (14% of the total attacks) involved 44% of the total number (536) of sheep and goats killed in the whole province from 1998 to 2001.

General recommendations to protect livestock from wolves are to keep herds within fences, and electric fences in particular, to include one or more guarding dogs in the herd, and to adopt a night enclosure (Boitani, 2000; Espuno et al., 2004; Oberle, 2010; Plan d'action national sur le loup, 2008; Reinhardt and Kluth, 2007; Štrbenac et al., 2010). However, it is not clear why some farms are frequently attacked while others in the same wolf region are not. Mech et al. (2000) compared cattle farms in Minnesota (USA) and concluded that the larger the herd and the further away from the farm, the more likely it was that the herd would be attacked. For sheep flock sizes, it was the opposite: larger flocks had fewer attacks. However, farming conditions and herd sizes differ significantly between the USA and Southern Europe. Espuno et al. (2004) did similar research in the Mercantour area, but could not confirm Mech et al.'s findings. Espuno et al. (2004) identified differences between pastures as by far the strongest determinant of attack number and of number of sheep killed. They suggested that differences between pastures concerned habitat attributes and human attendance. Besides pasture differences, Espuno et al. (2004) suggested factors such as sheep management methods, learning differences between wolf packs and local densities of wild prey. However, little research has compared farm practises in wolf habitats with regard to differences in cues that potentially appeal to wolves.

Herds in Slovenia commonly number less than 100 sheep (Udovč et al., 2011). Lambing mostly occurs throughout the year. In late autumn, a farmer moves his herd from the pasture and keeps it in a barn for some months, mostly near the farm. The pasture season is between March and December. The animals are moved between pastures or paddocks within a pasture, depending on when the grass is eaten. Pastures can have fixed fences, but paddocks mostly have mobile fences. Fences can be with or without electricity. There may be a night facility, such as a small fenced area, with or without a night barn.

Our research aimed to compare practises of sheep farms with and without problems with wolves in Slovene wolf habitat. We investigated management, pasture characteristics and potentially appealing cues that may explain differences in wolves' detection and approach.

2. Material and methods

2.1. Selection of farmers

Using a farmers' database, provided by the Department of Animal Science at the Biotechnical faculty, University of Ljubljana, we arbitrarily selected 60 farmers from regions where wolf attacks on sheep had regularly occurred for years. Thirty farmers had wolf attacks and 30 had no wolf attacks in the period between 2008 and 2010. Assessment of damage on livestock caused by wolves is regulated (Pravilnik, 2005). Farmers have to take the prescribed prevention measures, if they want to get compensation by the state for damage caused by protected wildlife. Attacks by wolves are confirmed by an authorized person from the state forest service, including numbers of sheep and other animals killed in attack. Except for two farmers, all had official confirmation proving that sheep were indeed attacked by the wolves. The two exceptions claimed wolf attacks were confirmed by hunters and other experienced farmers.

All farmers but one were located in two regions: the Notranjsko- and Obalno-kraška region with 49 farmers, and South-East Slovenia around the town Kočevje with 10 farmers. We balanced numbers of farmers with and without attacks in both regions as much as possible in order to balance possible regional differences between farms. One farmer with attacked sheep was from the Goriška region.

2.2. Questionnaire

We interviewed the selected farmers between October 2010 and February 2011. We developed a questionnaire which was the same for all farmers and covered (a) management: monthly dependent use of the pastures, breeding regime, frequency of visits to the pasture, use of night enclosures, mixing the flock of sheep with other animals, use of deterring methods, presence of conspicuous objects on the pasture and of items that smell, like sheep remains; (b) pasture characteristics: size, altitude, location, presence of fences, openness and main wind direction; (c) flock characteristics: herd size, sheep breed, behaviour of sheep, response to an attack (if applicable), and sounds by sheep or other animals present. All questions were neutrally formulated and of closed format, because we needed unbiased answers, and needed to unambiguously categorize them for statistical analysis. One trained person, familiar with sheep breeding practice, interviewed both groups of farmers. Farmers that had problems with wolves were also asked about the attacks: whether an attack was witnessed, what number of sheep and other animals were killed, and about time of the day and dates of the attacks. Most data came from files farmers had been using over the years 2008–2010 to request compensation money from the government. Not all farmers could provide information on all questions and if the farmer was in doubt, or was not able to provide an answer, the score for the particular question was a missing value. Consequently, sample size could be less than 30 per category, depending on the variable studied. Farmers that were interviewed in the last months of 2010 were contacted again in 2011 in order to finalize their dataset for 2010.

2.3. Analysis of the pasture

As a reference we used the pasture that the farmer used most, or was the most representative according to the farmer. However, whenever we interviewed a farmer that had problems with wolf attacks, we focussed on the pasture of the most recent attack, or on the pasture with attacks the farmer remembered best in the period 2008–2010. This ‘snap-shot’ approach did not allow historical analysis of changes that were made at the farm. Historical analysis was also hardly possible, because many farmers did not have detailed memory of changes, nor kept detailed time administrations of changes to farm practise. Satellite photos based on GPS coordinates taken with a GPS device (Garmin eTrex Vista h) at the spot provided an overview of the representative pasture, including forested areas. These photos of BirdsEye Imagery were generated by BaseCamp software from Garmin Ltd. The farmer indicated the boundaries of his pasture, and main wind direction in these photos. We entered the information into the satellite photo program, calculated areas, and defined whether the pasture was open (less than 50% of the surface was covered by bushes or trees) or not. For 24 farmers the BirdsEye photos were not clear enough and we used prints of Geopedia instead (an interactive online atlas and map of Slovenia developed by Sinergise d.o.o.) in combination with location codes of farmers provided by the Department of Animal Science at the Biotechnical faculty, University of Ljubljana. We transferred the information from the prints into Geopedia. Comparison of size estimations of pastures used in both programs (BaseCamp and Geopedia), showed differences between 1% and 4%.

2.4. Statistical analysis

If variables had a skewed distribution, we used modal or median values and 25th to 75th percentile interquartile range (IQR) as descriptive parameters. Within the category of farmers with wolf problems, we analyzed frequencies of wolf attacks, numbers of animals that were killed per attack, as well as interval durations between attacks. We applied related samples Friedman non-parametric analysis or Wilcoxon signed rank tests for comparisons between years within the category of farmers with wolf attacks. We mainly applied χ^2 tests in case of comparisons between farms with and without wolf attacks, or Fisher exact tests if expected values in χ^2 tests were less than 5. In other cases we used Mann–Whitney U tests. If the variable distribution approached normal distribution, we applied t-tests. Correlations between variables were analyzed with Pearson correlation tests. PASW (SPSS) statistical package, version 18.0, was used for all analyses, except Fisher exact tests, which were calculated in a spreadsheet.

3. Results

3.1. Wolf attacks

Direct observations of wolf attacks were scarce. Out of the total of 30 farmers that had wolf attacks at their farm, 4 had witnessed an actual attack: 3 by one wolf and 1 by 7 wolves. Two farmers had witnessed wolves jumping over electric fences up to 145 cm. Three farmers described sheep running away from the wolf and 1 had seen the sheep breaking through the (mobile) electric fence. The fourth farmer had observed that the sheep that was about to be attacked did not show any reaction. Long-term effects that farmers had mentioned were (a) sheep’s reluctance to return to the pasture where the attack had taken place (2 farmers), (b) a change from distressed behaviour to no obvious reactions after experiencing, but surviving subsequent attacks (1 farmer) and (c) ewes that abort their pregnancy, one or two weeks after the attack (2 farmers).

The 30 farmers with wolf attacks on their sheep flocks had experienced 288 attacks over the three year study period: 74 attacks in 2008, 82 in 2009, and 132 in 2010.

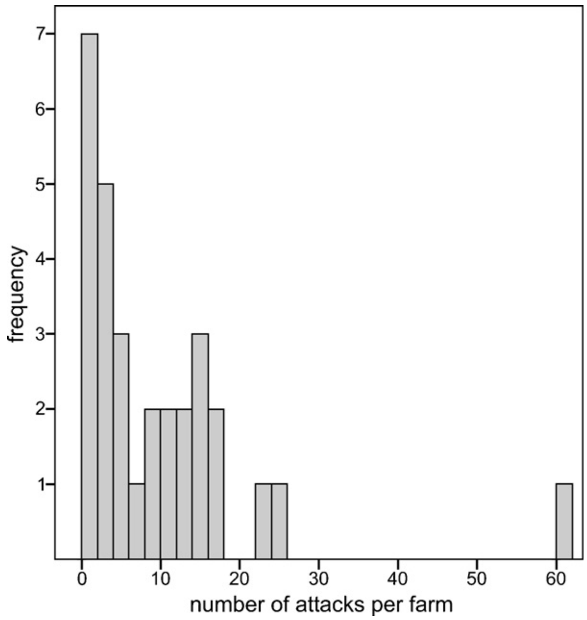

Fig. 1. Frequency distribution of number of wolf attacks in Slovenia summed per farm over the years 2008–2010.

There was no difference between years in the number of attacks (Friedman non-parametric analysis: $P = 0.13$). Median value was 6 attacks per farm (IQR 2–14; Fig. 1), so 2 attacks per year. Within a year, repeated attacks mostly occurred within 5 days of each other (median = 11 days, IQR 4–23).

Of the attacked farms, 18 had a history of attacks for 3 years (or more), whereas the other 12 experienced their first attacks around the time of the study. The 18 farms that had a history of wolf attacks, had used electric fencing throughout the observation period. The number of attacks at these farms was 5 in 2008 (median, IQR 1–6), 4 in 2009 (IQR 1–6) and 3 in 2010 (IQR 3–7), but attack numbers in 2008 did not differ from 2009, nor from 2010 (related samples Wilcoxon signed rank test: $P = 0.86$ and 0.88 respectively). Overall, farms with an attack history had a median of 4.33 attacks per year. However, the 12 farms without an attack history had 1 attack in their first year. These attack levels differed significantly (Mann–Whitney U test: $P < 0.05$, Fig. 2). The 12 first year farms did not use a fence at all (2), used a physical fence (3), or used an electric fence (7). If electric fences were applied, it was not known whether these were applied before or after the start of the attacks.

Of the 223 wolf attacks with registered dates in the period 2008–2010, a bimodal pattern could be recognized with a peak of 36 attacks in May and a second peak of 23 attacks in October. Attacks were most frequent at night (defined as the period after sunset and before sunrise; 78%), whereas 15% happened in the morning (starting at sunrise), and 7% in the afternoon (period after 12 o'clock until sunset).

We had detailed registrations of the number of livestock killed from 18 farmers with flocks of sheep only. All but 1 had lambs in the flock during attacks. Wolves mostly killed

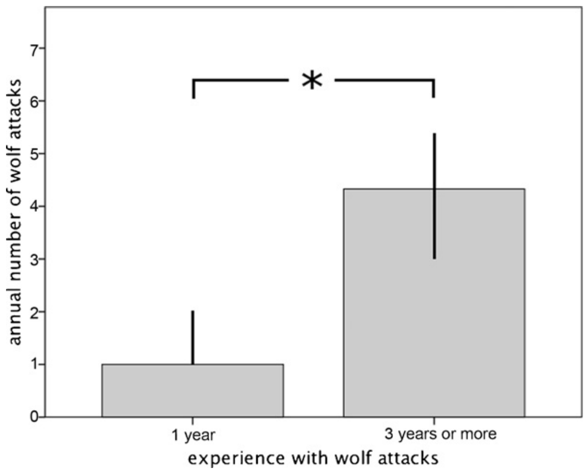

Fig. 2. Median annual number of attacks (and IQR) by wolves at Slovene sheep farms experiencing them in the first year, when electric fences may or may not have been applied, versus farms experiencing wolf attacks for 3 years or more, but always applying electric fences (*: $P < 0.05$).

1 to 2 sheep per attack (median = 4, IQR 1–5.5), with 1 adult sheep (IQR 1–2.5) and 2 lambs (IQR 0–3.5). Surplus killing (defined as a kill of 10 or more sheep) occurred in 10% of the farms and in 36 attacks (12.5% of all attacks).

3.2. *Comparison between farms*

3.2.1. *Husbandry*

Table 1 provides a summary of the most significant comparisons in this study.

The start or ending month of the pasture season did not differ between farmers with attacks and those without ($\chi^2_{(2)} = 0.3$; $P = 0.86$ and $\chi^2_{(2)} = 1.5$; $P = 0.47$ respectively). 46 farmers had a regular grazing season and 31 of them started the season in April, but by May all farmers had herds in the pasture. 36 ended the grazing season in November, 3 in October and 7 in December. The other (14) farmers had variable seasons, depending on the end and start of snow cover in their pasture.

For each category of farms (with and without wolf attacks) 16 farms had sheep breed JSR (Improved Jezersko Solčava) only, 7 had JS sheep (Jezersko Solčava), and the remaining 7 had other breeds or a mix of breeds. Lambs were present during the pasture season in almost all farms (Table 1). Median area of a fenced pasture was 2.7 ha and median herd size was 93 sheep. Median density was 23.3 sheep per ha. There was no statistical difference between farmers with or without problems with wolves in the size of fenced area, herd size or density (Mann–Whitney *U* test: $P = 0.50$, $P = 0.10$ and $P = 0.67$, respectively). Average number of attacks per year on a farm did not correlate with herd size ($r_s = 0.28$; $P = 0.18$; $n = 25$) nor with sheep density ($r_s = 0.34$; $P = 0.11$; $n = 23$). Number of sheep killed per attack, however, tended to correlate positively with herd size ($r_s = 0.40$; $P = 0.05$; $n = 25$), and with density of sheep ($r_s = 0.37$; $P = 0.08$; $n = 23$).

Seventeen out of 60 farmers kept other livestock (goats, horses or cattle) amongst the sheep (Table 1). Five of them (4 with goats) had no problems with wolves, but 12 suffered

Table 1
Characteristics of the Slovene sheep farms investigated ($n = 60$) showing representative observations where there were no differences between farms (middle column; IQR is used together with median values, sd with averages), and χ^2 comparisons of numbers of farms without and with wolf attacks: ns: not significant; (*): $0.1 < P \leq 0.05$; *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$. If χ^2 is significant, it applies to the adjacent 2×2 or 3×2 counts.

	Variable	Class	Representative observations for all 60 farms	Number of farms without wolf attacks	Number of farms with wolf attacks	χ^2 value (df) and significance
Management	pasture season starting month		April			
	pasture season ending month		November			
	sheep breed		JSR and JS			
	lambs present during pasture season			26	28	0.7 (1) ns
	herd composition	only sheep		25	18	4.0 (1) *
		mixed herds		5	12	
	area of fenced pasture		2.7 ha (IQR 1.5–7.3)			
	herd size		93 sheep (IQR 55–140)			
	density		23.3 sheep/ha (IQR 11.0–57.5)			
	night facilities	open barn or no night facilities at all		15	24	5.9 (1) *
		closed barn or separately fenced area		15	6	
	time of driving sheep for the night	driving at dusk or no driving		17	27	8.5 (1) **
		driving before dusk		13	3	
	time of driving sheep from night enclosure back to the pasture		after sunrise			
Deterrents	guarding dogs			16	13	0.6 (1) ns
	guarding donkeys			3	4	0.2 (1) ns
	visiting	visiting twice a day		16	17	0.1 (2) ns
	acoustic, visual, chemical or olfactory deterrents	none used		25	17	7.1 (2) *
		indicating potential human presence		1	8	
		not indicating human presence		4	5	
	openings in fence			16	14	0.3 (1) ns
	type of fence wiring	horizontal single wires		4	11	5.1 (1) *
		wire-mesh		26	17	
	fence height		115 cm (sd 17)			
	type of fence	electric		10	24	16.6 (2) ***
		physical		12	3	
		electric combined with physical		8	1	
Potentially appealing cues	predominantly white sheep			26	26	0 (1) ns
	no synchronizing lamb delivery			23	26	1.0 (1) ns
	no disposal of placenta			22	20	0.3 (1) ns
	slaughter remains not to hygiene service			10	12	0.3 (1) ns
	sheep at night	reported noisy		17	9	3.9 (1) *
		not reported noisy		13	21	
	sheep during shearing	reported noisy		14	4	7.1 (1) **
		not reported noisy		16	26	
Pasture types	altitude		538 m (sd 107)			
	open pastures			12	7	1.9 (1) ns
	immediately bordering woods			27	26	0.2 (1) ns
	main wind direction towards woods	yes		11	14	3.2 (1) (*)
		no		16	7	

from wolf attacks (9 with goats). Thus, herds with mixed species were significantly associated with wolf attacks. The 9 farmers with mixed flocks of sheep and goats had a total of 94 attacks in the period 2008–2010. In 28% of these attacks not only sheep, but also goats were killed. In such an attack, wolves killed 2 goats (median; IQR 1–3), 2.5 adult sheep (IQR 2–4) and 2 lambs (IQR 1–3). These numbers of adult sheep kills and lamb kills were similar to those from attacks without goat kills at the same farms (related samples Wilcoxon signed rank test: $P = 0.94$ and $P = 0.13$, respectively).

Farms with wolf attacks more often used open night barns or no night enclosure at all than farmers without attacks (Table 1). Moreover, the timing of driving sheep to night facilities differed between farmers with and without wolf attacks: farmers without attacks were significantly more likely to drive their sheep before dusk (period of around two hours after sunset when objects are still distinguishable to the naked human eye) to the night enclosure (Table 1). Sheep were driven back to the pasture the following day after sunrise.

3.2.2. Deterrents

Farmers with guarding dogs mostly had 2 dogs together with sheep. These were all guarding breeds (mostly Pyrenean mountain dog, Hungarian Kuvasz or Tornjak). All dogs had been raised from 2 months of age together with sheep. There was no difference between farmers with or without wolf problems in the use of dogs: in both categories about half of the farmers used guarding dogs (Table 1). Of the 30 farmers with wolf attacks, there was no difference between farmers with dogs and those without dogs in the number of animals killed per attack (median number of animals killed (IQR): 2 with dogs (1–8), $n = 13$ farms; 4 without dogs (3–5.5), $n = 17$ farms; Mann–Whitney U test: $P = 0.74$). Furthermore, 4 farmers with wolf attacks and 3 farmers without attacks had guarding donkeys. Presence of donkeys did not affect the number of sheep killed per attack (Mann–Whitney U test: $P = 0.39$).

Besides having dogs or donkeys with the herd, farmers could also frequently visit the pasture or apply deterrents against wolves. However, visits categorized as 'not visiting or once a day', 'visiting twice a day' and 'visiting 3 times a day or daily spending at the least 4 h with the herd' did not differ between farms with or without attacks and majority visited twice a day (Table 1). Eighteen farmers used (forms of) deterrents. Deterring against wolves involved applying radios, flash lights, chemicals against deer or wild boar, gas canons and fire spots, or human hair, meat in cans, noisy cans or CD's attached to the fence, as well as checking the pasture during the night by car or tractor. We categorized these measures in those clearly indicating potential human presence (checks in the night by car, radio playing, human hair attached to the fence) and those that did not. It showed that farmers with wolf problems more often used deterrents indicating human presence than other deterrents (Table 1) and that the application of deterrents did not differ between farmers that visited the pasture twice daily or more, and those that visited the pasture less ($\chi^2_{(2)} = 0.71$; $P = 0.70$). Five out of 8 farmers with wolf problems using deterrents indicating human presence mentioned that attacks occurred at locations just out of reach of sounds or lights of these deterrents, or occurred shortly after these applications had stopped.

All farmers used fences around the area where the sheep grazed, except for 2 (who had wolf attacks). The average height of the fence surrounding the representative pasture or paddock was 115 cm (sd 17) and did not differ between farms with or without wolf attacks (t-test, $t = 0.05$; $P = 0.96$). However, farmers differed in the type of fences they used (Table 1): most farmers having wolf problems had electric fences, whereas most farmers without wolf problems used physical fences or a combination of electric and physical fences. Farmers stated that they applied standard equipment, like from the Gallagher company, and a voltage of at least 3500 V to their electric fence, as was recommended (Vidrih and Vidrih, 2009). Five of 10 non-attacked farms and 10 of 24 attacked farms ($\chi^2_{(1)} = 0.2$; $P = 0.66$) using electric fences, applied mobile electric fences. The wiring of the fences (regardless of use of electricity) differed (Table 1): farmers without wolf attacks strongly preferred wire-mesh compared to farmers with wolf attacks and hardly used fences with single horizontal wires. Nevertheless, at around half of the farms in both categories, openings were present in and under fences that could provide wolves opportunity to get past them (Table 1).

3.2.3. Presence of appealing cues

We checked for presence of fence sounds, sound devices attached to sheep or other livestock, such as bells, and the farmer's judgement of whether or not sheep would emit sounds when the farmer arrived or drove the sheep, whether he had noisy barking dogs or braying donkeys. Both categories of farms did not differ in the presence of noisy objects or animals. However, farmers without attacks reported significantly more that sheep were noisy during the night than farmers with attacks (Table 1). Farmers without attacks also reported significantly more that sheep could be noisy during shearing (Table 1).

There were no differences between farmers with regard to presence of potential visual attractants. This applied to colour of the sheep, which was predominantly white (in 52 farms), yellow ear tags (in 55 farms), lights that had been applied to the fences or near the flock (14 farms) or cisterns in contrasting colours, like white or blue (24 farms).

There were also no differences in olfactory cues related to farming practises between farms without or with wolf attacks. Most farms did not synchronize delivery of lambs and had pregnant ewes during the pasture season (Table 1). After birth, the ewe's placenta remained on the pasture in most farms, but 18 farmers located the placenta and disposed of it. There was also no difference between farms with or without wolf attacks in the disposal of slaughtered sheep: most (38) provided the remains to a hygiene service (Table 1). The remains could also be buried, fed to the dogs, or left outside (which could also be the pasture).

3.2.4. Pasture types

Pasture altitude averaged 538 m above sea level and did not differ between farms (t-test, $t = 0.93$; $P = 0.36$). Farms with or without attacks also did not differ in openness: one third of all 60 farms had open pastures (Table 1).

However, farms with mixed herds with goats that had wolf attacks, more often had non-open pastures than open pastures (9 versus 0), which tended to differ from those with only sheep (11 versus 6; Fisher exact probability test: $P = 0.05$). Distance to woods did not differ between farms (Mann–Whitney U test: $P = 0.71$): woods were in all but 7 cases immediately bordering pastures. Attacked farms were more likely to have wind directions towards adjacent woods than non-attacked farms (Table 1). Of 21 farmers with wolf attacks that had indicated main wind directions, all 6 farms that had sheep-goat herds, had pastures with the main wind towards woods. In 15 attacked farms with herds only of sheep this applied to 8 farms (Fisher exact probability test: $P = 0.06$).

4. Discussion

Farms with sheep in closed night barns or a separately fenced night-area have less risk of attacks by wolves, as shown in this study. We have also shown that chances of attacks are reduced if sheep are moved to these night facilities before dusk. Protected housing of sheep during the night is important, as in this study 78% of wolf attacks were at night-time. These findings correspond with the general view that wolves are active during the night (Kusak et al., 2005; Okarma, 1997; Stahler et al., 2006) and the recommendation to adopt night enclosures (Boitani, 2000; Espuno et al., 2004; Oberle, 2010; Plan d'action national sur le loup, 2008; Reinhardt and Kluth, 2007; Štrbenac et al., 2010).

However, we could not find evidence with Slovene sheep farmers that electric fences were also effective, although this measure is recommended in general (Boitani, 2000; Espuno et al., 2004; Oberle, 2010; Plan d'action national sur le loup, 2008; Reinhardt and Kluth, 2007; Štrbenac et al., 2010) as in Slovenia (Vidrih and Vidrih, 2009). Slovene authorities recommend farmers apply electric fencing, otherwise they will not be compensated for their losses. Not surprisingly therefore, we found that most farmers with wolf attacks applied electric fences. This also applied for 18 out of 22 farmers that had experience with wolf attacks for more than 3 years and had electric fences during our observation period. However, in contrast to what would be expected, electric fences did not reduce attack rates when wolf attacks were persistently recurring at farms. Moreover, farms that were newly confronted with wolf attacks (whether or not they had electric fences) had low annual killing rates compared to rates at farms that had electric fences and wolf attacks for more than 3 years. Electric fences as used in our study area are therefore ineffective measures against repeated wolf attacks. Moreover, low annual killing rates at new farms need not relate to electric fences, but may relate to wolves generally avoiding unfamiliar sites and returning to familiar farms (Boitani, 2000; Černe et al., 2010; Gazzola et al., 2008; Nationale Koordination Herdenschutz, 2011; Rigg et al., 2011).

Several reasons may explain why electric fences were not found to be effective in the Slovene practise, even if they are used several years. Average fence height of 115 cm, as we found, is well below minimum height of 140 cm of fixed electric fences that were tested to protect against depredation (Acorn and Dorrance, 1994; Gates et al., 1978; Linhart et al., 1982; Thompson, 1979). Although these studies concerned coyotes and fixed fences, the features of these fences are adopted and recommended to protect against wolves too (Haviernick, 1998; Paul and Gipson, 1994; Shivik, 2004; Vidrih, 2002). Indeed, some farmers in our research saw wolves jump over fences of 145 cm. So even 140 cm is not high enough for wolves in all cases. Wam (2004a, 2004b) found traditional fixed fences of mesh wire, 100 cm high, more effective against wolves if improved by applying electricity and a height up to 160 cm. Mertens et al. (2002) and Cortés (2007) found that mobile electric fences of 150 cm were effective against wolves. Although it is assumed that wolves crawl under fences, we did not find that attacked pastures provided more crawling opportunities, as half of the farms, both in attacked and in non-attacked farms, had openings in fences that wolves could use to crawl through. Coyotes can also jump between wires or climb fence corners, using horizontal corner braces as toe-holds, instead of crawling under or jumping over (Acorn and Dorrance, 1994; Gates et al., 1978; Linhart et al., 1982; Thompson, 1979). There is no detailed research into how wolves pass fences and therefore it is not known to what extent wolves also jump between wires or climb electric fences. If they do, wolves in the Slovene situation are likely not receiving any shock. The reason is that live wires in our research were never alternated with grounded wires. Live and ground wire alternation was applied by Gates et al. (1978), one of the first in establishing effectiveness of electric fences. Such alternation is recommended in Slovenia to guarantee closing of the electrical circuit when the animal touches the fence, and the dry soil is not conducting well (Vidrih and Vidrih, 2009). Indeed, the karst area is particularly known for dry perennial grasslands (Rural Development Programme, 2007). Therefore, fences with the same polarity at the electric wires will not shock a wolf, if it would jump between these wires. A wolf may not even get a shock at all in dry conditions. Similar features would apply for wolves climbing a fence. In particular, mobile fences can only be partly stretched, for instance on uneven, rough terrains as in the karst, and, again, all electric wires have the same polarity. Wolves may learn to jump onto these fences, use the wires as toe-holds, and climb over without being shocked. Furthermore, it is generally emphasized that electric fences require regular maintenance and this requirement may not have been met. However, we have no data about fence maintenance. In conclusion, electric fences in this study did not provide a noteworthy physical threshold, whereas polarity of their live wires was not alternating, and electric grounding was difficult in the dry karst, which likely did not produce a systematic aversive experience by shocks to wolves. Thereby, we assume that after novelty of putting up a fence had faded, electric fences became ineffective tools. In order to improve fences and application of electricity, comparative research needs to be done of what wolves actually do at typical entry points e.g. with stealth and infrared cameras.

It is also generally assumed that a guarding dog protects the herd from wolf attacks (Boitani, 2000; Mettler, 2005; Reinhardt and Kluth, 2007; Rigg et al., 2011; Štrbenac et al., 2010). However, we did not find a protective effect of guarding dogs, as there was no difference between farms with or without wolf attacks in the number of farms that had guarding dogs. Moreover, presence of guarding dogs did not reduce the number of sheep killed in an attack. Gehring et al. (2010) stated in their review that suggested effectiveness of livestock protecting dogs was based on testimonial evidence, producer-based reporting or limited captive trials. They concluded there is a lack of experimental research on the effectiveness of such dogs, especially against wolf predation of livestock. Indeed, wolves can even be attracted to guarding dogs, socially interact and fight in a ritualized way with them without injuries (Coppinger et al., 1988). Wolves may also actively seek and kill dogs (Kojola et al., 2004; Okarma, 1997) and prey more on dogs than on sheep (Gula, 2008). Prevention of wolf attacks by dogs is therefore not evident. Moreover, the number of dogs was two in most farms, whereas Espuno et al. (2004) showed that reduced wolf attack rates associated only with 4 or more dogs.

Flock size did not correlate with annual number of attacks, which is similar to findings in Poland of Nowak et al. (2005) who found the same attack numbers for flocks of 40 sheep or more, and fewer than 40 sheep, as well as Rigg et al. (2011) who studied wolf predation of flock sizes of 100–2000 sheep in Slovakia. However, Kaartinen et al. (2009) found larger herds more likely to be attacked in Finland, with flock sizes of 100 sheep or less in 91% of the farms. The number of sheep in a flock may relate positively with chances that resident wolves detect sheep, but several other features discussed in the present study may affect a simple correlation. These features were only partially covered in the mentioned references. Therefore, we cannot meaningfully compare these studies further regarding relation between flock size and annual attack rate. However, we did find that in case of an attack, the number of animals killed tended to correlate positively with flock size and sheep density. This also corresponds with Nowak et al. (2005) who found that 6.5 sheep were killed on average in an attack at large flocks, but 3.6 animals were killed in small flocks. Also Ciucci and Boitani (1998) and Gula (2008) found higher number of sheep lost at pastures with relatively high sheep density, compared to those with low densities. Breck and Meier (2004) suggested that concentration of sheep facilitates surplus killing. Indeed, wolves may be more successful in chasing and biting, thus killing sheep, in case sheep density is high compared to low sheep density. This may apply especially when sheep are in a fenced area where an effective escape from the predator is almost impossible, unless sheep break out, as witnessed by one farmer. It will therefore be necessary to test whether killing rates are still density dependent and surplus killing still occurs in pastures where sheep can effectively respond to a predator. It is not known what kind of response or hiding facilities are effective to reduce surplus killing. For instance, whether fleeing or immobilizing at a wolf threat results in different killing rates remains to be researched.

Farmers with mixed herds had a higher risk of wolf attacks than farmers with herds only of sheep. Mixed herds were in 76% of all cases herds with goats. Moreover, total losses of livestock to predatory wolves were higher in herds of sheep and goats compared to herds with only sheep. These rates of sheep killed in a wolf attack are similar to rates found by Ciucci and Boitani (1998) and Gazzola et al. (2008) in Tuscany, Italy, and Černe et al. (2010) in Slovenia. However, these authors do not mention goat kill rates. Differences between sheep and goats have been studied particularly with regard to their diet selection. Goats forage on trees and shrubs more than sheep, which prefer grasses (Bartolomé et al., 1998; Jáuregui et al., 2009; Yiakoulaki et al., 2009). Pakhretia and Pirta (2010) observed that goats wander around alone, but also explore more frequently than sheep. These observations suggest that herds with goats are more likely to enter woods by goats foraging for shrubs and trees, than herds with sheep only. Indeed, in the current research area, mixed herds with sheep and goats were more often on pastures covered with trees and shrubs, than herds of sheep only.

Higher vulnerability of livestock near or within forested areas is generally found (Bangs and Shivik, 2001; Kaartinen et al., 2009; Nowak et al., 2005; Rigg et al., 2011) and wolves inhabiting woods may detect livestock more easily when goats enter the woods. However, a mixed herd as such may also be attractive regardless of the coverage of the pasture. Goats smell differently than sheep, and a goat's smell may be specifically attracting. Goats also produce more low pitched sounds compared to sheep (Pakhretia and Pirta, 2010). Low pitched sounds may travel further than high pitched sounds. Detection of sound and smell will be dependent on wind direction. Indeed, farms with wolf attacks tended to have main wind directions across the pasture towards the woods, and we found this was particularly the case when they had goats in the herds. Thus, wolf attacks seem to relate in particular to herds with sheep and goats at a pasture where the wind blows towards the neighbouring woods. Indeed, Espuno et al. (2004) identified differences between pastures as by far the strongest determinant of attack rates and suggested habitat attributes in particular. However, at this point, we cannot compare non-mixed herds with mixed herds in pastures where the wind blows towards the neighbouring woods. Therefore, we cannot differentiate between the relative importance of pasture features, in particular wind direction, and the mixing of herds to the attractiveness of a herd to wolves. Further research is needed, also to estimate the detection range of herd sounds and smells, for instance through work with dogs that are trained to recognize sheep and goat sounds or smells. Moreover, it is also necessary to compare behaviour and sound production of sheep in a single species herd with a sheep-goat herd. If noise production is enhanced due to mixing of herds, then this could be another potential attractant to wolves.

Espuno et al. (2004) also suggested differences between pastures concerned human attendance. However, we could not find differences between farms with and without wolf attacks in the number of daily visits by the farmer. Nevertheless, farmers that have had sheep killed by wolves, often use deterrents at the pasture that indicate human presence. Wolves would be fearful of humans and avoid human confrontation (Štrbenac et al., 2010) and farmers experiencing attacks may have applied such deterrents more than farmers without problems. However, in 5 out of 8 farms, attacks did happen in pastures nearby or shortly after the application of such deterrents had stopped. Opposite to the assumption that wolves avoid humans, are the observations that wolves develop a tolerance to humans and use their resources. Kusak et al. (2005) for instance describe wolves using garbage dumps in Italy and Romania, wolves that live in open oat fields in Spain, and wolves that mainly feed on garbage and slaughter-house dumps in Dalmatia. Cues that indicate human presence may therefore be counterproductive and motivate exploring wolves to revisit the pasture. Attacks can then occur as soon as the pasture no longer indicates that humans are nearby.

Several sources make it plausible that resident wolves explore in a repetitive way. Firstly, travels by wolves in general are characterized by repeated use of specific routes (Mech and Boitani, 2006). Secondly, repeated visits to certain herds are also commonly found (Boitani, 2000; Gazzola et al., 2008; Nationale Koordination Herdenschutz, 2011; Rigg et al., 2011), and can be seen as part of a repeated foraging route. Thirdly, studies by Jędrzejewski et al. (2001) have shown that in spring and summer daily ranges of individual wolves overlapped to one third. Compared to day 1, this level of overlap could remain the same on following days and only decline after day 4. In winter, they discovered that wolves changed their daily range every day, but returned to the same part of their territory in 6 days. In the present study, we found repeated attacks on farms, mostly within 5 days. If it is true that 'deterrents' of sheep pastures indicating human presence attract wolves to revisit these pastures, then daily ranges of local wolves are expected to overlap more compared to areas where other or no deterrents are used.

Statements that sheep are noisy in the night and during shearing differed between farmers with herds that wolves had attacked and farmers without attacked herds. Herds having experienced wolf attacks were less noisy. Although the statements were subjective reports and sound intensity measurements had not been done, we see no reason for a biased answer in either group of farmers. There was no difference in breeds between the two categories of farmers, and, therefore, no difference in genetic predisposition. Rather, reduced sound production could be part of an immobility response seen in stressed sheep (Dwyer and Bornett, 2004), and induced by experiences with wolf attacks, as also observed by one farmer. Dwyer (2004, 2009) explains, on the basis of different sources, that sheep readily learn to associate unpleasant experiences with places or auditory stimuli, and that they show long-term avoidance of these places and stimuli. Research is therefore needed to verify reduction in sounds, responsiveness and presence of chronic stress in sheep after survival of wolf attacks.

5. Conclusion

The use of electric fencing or of 2 guarding dogs was not effective in reducing the annual wolf attack numbers in Slovene sheep farms. Regarding fences, it seems an improvement to adopt mesh wire instead of single wires, whether or not electricity is applied to the fences. Alternation of polarity of live with ground wires in electric fences may improve reliability to deliver shocks to wolves that touch the fence. Moreover, it seems that fences have to be higher than 145 cm, as wolves are seen to jump over 145 cm ones. However, potentially, improved fencing could also prevent sheep from breaking out during an attack, if wolves still find ways to enter the fenced area, and might result in high levels of surplus killing. In addition, costs, weight and size of high fences (especially in case of mobile fences) can be problematic for farmers. Regarding 2 guarding dogs, Espuno et al. (2004) already suggested that 2 dogs would not be effective, and that at the least 4 dogs would be necessary to reduce wolf attacks. However, costs of the dogs and the fact that guarding dogs, raised together with sheep, are potentially dangerous to humans (Mettler, 2005) pose management problems.

The relatively poor effectiveness of current methods of wolf control suggests alternative strategies: (1) to keep sheep in closed night barns and to move sheep there before dusk; (2) to research separation of goats and sheep with regard to wolf attack rates, practical feasibility and maintenance of perennial grasslands, as in the Dinaric karst area; (3) to research sheep and goat responses to predator attacks and to develop methods that assist sheep and goats to avoid being chased and bitten; (4) to develop new (automatic) deterring methods, which from a wolf's perspective, are meaningful and systematically negatively reinforce chasing livestock and consumption of livestock.

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