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Are the livestock guarding dogs where they are supposed to be?

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ABSTRACT

In many parts of the world, livestock guarding dogs (LGDs) are considered one of the most powerful prevention tools against carnivore predation on domestic animals, but how they behave when left unsupervised with their flock on pastures is mostly unknown. We monitored 29 LGDs with GPS (Global Positioning System) collars in order to investigate their space use and association with livestock. UDOI (Utilization Distribution Overlap Index) and the VI (Volume of Intersection) Index for 50% and 95% kernel isopleths were calculated to quantify the overlap and the similarity in the use of space for the core area and for the whole movement range of sheep and dogs. Linear mixed models were implemented to evaluate how dog-sheep distance was influenced by environmental (land use, percentage of trees and shrubs in the pasture, size of pasture), dog-related (sex, age), and farming-related variables (number of livestock guarding dogs associated with the flock, herd size). Finally, we tested the usefulness of GPS pet collars in managing LGDs. LGDs spent the majority of their time close to livestock, sharing the same areas but using the space in a different way. Dog-sheep distance was mostly influenced by the environmental variable land use, and the age of the dog. In fact, dogs and sheep tended to separate more in pastures with a high percentage of trees and shrubs, and less in pastures close to inhabited areas. Moreover, older dogs were more associated to the flock compared to younger individuals. GPS pet collars can be an important tool in managing LGDs, as farmers are able to check the position of their dogs and their flock at any time. This can allow producers to improve their management of LGDs, and to limit conflicts with neighbors and accidents. In this study, we demonstrated that the monitored LGDs did not leave the flock unattended when left unsupervised, although further insights into how they behave would support a full evaluation.

1. Introduction

Wolf (*Canis lupus*) populations are continuing to expand their range toward more inhabited areas across European countries following legal protection, improvement of habitat quality and exodus from rural areas (Chapron et al., 2014). Therefore, farmers have an increasing need to protect their livestock from predation.

From the late 1970s, nonlethal methods such as livestock guarding dogs (LGDs) have gained popularity among farmers and conservationists, as demonstrated by the large number of conservation projects that include their use (Rigg, 2001; Otstavel et al., 2009; Salvatori, 2014). In many parts of Europe, Asia and North America, LGDs are considered one of the most powerful prevention tools against carnivore depredation on domestic animals (Andelt, 2004; Shivik, 2006; Gehring et al., 2010; Lescureux and Linnell, 2014).

LGDs have been the subject of numerous reviews and evaluations of their use and efficacy, but few of them rigorously assessed the factors influencing effectiveness (Gehring et al., 2010). LGDs were judged effective using mainly questionnaires on farmer's perception (Marker et al., 2005), censuses of livestock losses (Andelt, 1992) and focal animal behavior sampling (Coppinger et al., 1983). Nevertheless, these studies could be biased by confounding factors that cannot be controlled by researchers, such as density of predators, experience of shepherds or LGD individuality (Gehring et al., 2010). As Landry et al. (2014) pointed out, the efficiency of LGDs should be evaluated observing the interactions between dogs and wild predators when attacks occur. However, these episodes are difficult to observe as they are unpredictable and occur mostly during the night or on heavily vegetated terrain (Landry et al., 2014). For this reason, typically indirect methods and proxies are used.

Spatial proximity between sheep and guarding dog is an essential precondition for preventing livestock depredation by predators (Gehring et al., 2011; VerCauteren et al., 2012). It is determinant also for a dog's attentiveness, one of the traits that a good guardian should show (Coppinger and Coppinger, 1980). Attentiveness implies a social bond between sheep and dog, which results in the dog constantly

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Table 1
Information on LGDs and farms involved in the study. From November 2015 to July 2016 we monitored 29 LGDs (16 males and 13 females), mostly Maremmas, at 11 farms. Each farm generally owned more than one flock and guarded by at least two LGDs (except Farm B-first sampling session). Herds were composed of "Sarda" breed dairy sheep, except in Farm B and F where herds were also composed of "Amiatina" breed meat sheep.

Dog ID	Sex	Dog Breed	Age	N LGD/ flock	Flock size	Flock ID	Sampling period	Farm	
1	M	Maremma	1.5	2	200	1	Nov-15	A	
2	F	Maremma	1	2	200	1	Nov-15	A	
3	M[a]	Maremma	10m	1	50	2	Nov-15	B	
4	M	Maremma	1	5	120	3	Nov-15	C	
5	F	Maremma	1	5	120	3	Nov-15	C	
6	M	Maremma	4	5	120	3	Nov-15	C	
7	F	Mixed	3	2	120 − 70	4 and 5	Dec-15	D	
8	M	Maremma	1.5	2	70	4	Dec-15	D	
9	M	Maremma	1.5	2	120	5	Dec-15	D	
10	F	Pyrenees	3	2	150	6	Dec-15	E	
11	M	Pyrenees	8	2	150	6	Dec-15	E	
12	F	Maremma	2.5	2	70	7	Dec-15	F	
13	M	Maremma	2.5	2	70	7	Dec-15	F	
14	F	Maremma	1.5	2	180	8	Dec-15	G	
15	F	Maremma	1.5	2	180	8	Dec-15	G	
16	M	Maremma	7m	2	160	9	May-16	H	
17	M	Maremma	7m	2	160	9	May-16	H	
18	M	Maremma	1	2	300	10	May-16	I	
19	F[a]	Maremma	1	2	300	10	May-16	I	
20	F	Caucasian	1	3	450	11	May-16	E	
21	M	Caucasian	1	3	450	11	May-16	E	
22	M	Mixed	2.5	2	150	12	May-16	J	
23	F[a]	Mixed	2.5	2	150	12	May-16	J	
24	F	Pyrenees	9	5	350	13	Jul-16	E	
25	F	Caucasian	1	5	350	13	Jul-16	E	
26	M	Maremma	7m	2	150	14	Jul-16	K	
27	F	Maremma	7m	2	150	14	Jul-16	K	
28	M	Maremma	7m	3	260	15	Jul-16	A	
29	M	Maremma	1.2	2	170	15	Jul-16	B	
			2	3	191				Mean
			2	1	105				SD

[a] Neutered/spayed dogs.

maintaining contact with the flock (Coppinger et al., 1983; Coppinger and Coppinger, 2005).

As Lorenz (1989) stated, "if the dog isn't with the sheep it isn't where it's supposed to be". However, in a livestock farming system that uses fenced pastures to graze the animals, some roaming is expected as the dogs create territorial boundaries, which they maintain to help them to protect their livestock (van Bommel and Johnson, 2014). On the other hand, territorial behavior might be less important for dogs raised in a more nomadic livestock farming system where an increased closeness to the flock is expected.

A dog is an effective tool if it is not a cause of concern for the farmer and society. Indeed, some dogs do not stay with sheep and may harass people (Andelt, 2004). When a LGD roams far and wide, it is not protecting livestock and is more likely to create problems. In human-dominated landscapes, where road and human densities are high, a roaming dog can cause accidents (Gehring et al., 2010). In natural areas, roaming LGDs can chase wildlife for territoriality, for playing or as prey if they are not properly maintained (Marker et al., 2005; Potgieter et al., 2013). Moreover, wide-ranging dogs could increase the possibility of infecting wildlife with diseases (Lescureux and Linnell, 2014) and hybridizing with wolves (Kopaliani et al., 2014).

Thus, understanding the spatial behavior of these dogs in relation to the livestock to be protected is pivotal from both ecological and management points of view, especially now that the shepherding system has changed in many areas around the world. While the traditional use of LGDs was in association with a guardian or shepherd, in modern days it is becoming more difficult to have a full time shepherd, particularly where farmers strive to obtain a higher income turning to diversification. In such conditions, how dogs use the space and interact when left alone with the flock on pastures is mostly unknown.

Using GPS pet collars, we monitored LGDs on working farms in order to investigate their space use and their proximity to the flock, which, if integrated with other information, can be used as a proxy for the evaluation of appropriate dog behavior. We quantified the overlap between the movement ranges of dogs and sheep, and we evaluated how dog-sheep distance was influenced by environmental, dog-related and farming-related variables. In addition, we trialed the usefulness of GPS pet collars for LGDs and sheep husbandry.

2. Methods

2.1. Study sites

The study was performed on 11 sheep farms situated in seven municipalities of Grosseto province (Tuscany Region, Italy). We sponsored this research across 20 farms with LGDs, which were previously involved in conservation initiatives in Grosseto province. We offered them the opportunity to test GPS pet collars in dogs and sheep husbandry. The farmers could verify the location of their dogs and sheep on their electronic devices in real time (PC, smartphone, tablet), and they were alerted if an unwanted behavior occurred (e.g., roaming or staying at home). All farmers who volunteered for the study were included.

Seven farms were located in areas containing large portions of forest and four farms were located in a more open agricultural landscape. Apart from Mt. Amiata (1738 m asl) and the mountainous group of Colline Metallifere (1060 m asl) in the northern part, the Province is hilly country. Waterways are abundant.

Wolves (*Canis lupus*) and free ranging dogs (*Canis familiaris*) are the major threats to livestock in the area. Between January 2014 and mid-September 2016, 48% (N = 407) of depredation claims in Grosseto province came from the municipalities in which the study was conducted (National Health Authority database).

Table 2
Land use classes included in each land use group (Artificial, Arable, Open, Heterogeneous and Wooded). For each group we measured the hectares they occupied in the 120 m buffer around each dog-sheep distance segment, in order to obtain the variables referred to as 'land use'.

Group	Description	2013 Land use code
Artificial	Artificially surfaced areas (road and rail networks, buildings, facilities, mines, dumps)	112 – 1121 – 121 – 122 – 1221
Arable	Cultivated areas	210-221-222-2221-223
Open	Rocky areas, pastures and grasslands	231-321-332
Heterogeneous	Areas which, if fragmented for different land use, contain polygons smaller than 1 ha occupied by agricultural and natural areas	241-242-244
Forest	Deciduous and coniferous forests	311-324

Wolf presence in the area has been detected at increasing densities in the last decades, after a long period of very low density when the livestock producers had lost the habit of protecting their herds or shepherding them. Hence, herds were left alone with 1–5 LGDs without the surveillance of the shepherds for most of the time. The mean herd size was 192 ± 107 (min = 50, max = 450) and was mostly composed of "Sarda" breed dairy sheep. Flocks were kept on pastures enclosed by fences, measuring 120 centimeters in height, which were easily crossed by the dogs. The average size of the pastures where we monitored the LGDs was 4.80 ± 6.34 ha (min = 0.04 ha, max = 29.77 ha). Two farmers who participated in this study left their sheep in the pastures, 24 h/7days, while three confined their livestock in pens at night and six confined their flock in a barn at night.

2.2. Data sampling

We monitored 29 LGDs (13 females and 16 males) during 20-day sessions from November 2015 to July 2016 (Table 1).

At each farm, 1–3 LGDs and one sheep from their flock were fitted with Tractive® GPS Pet Tracking collars (Tractive GmbH, Austria). We assumed that the collared sheep would be representative of the entire flock, as the "Sarda" sheep breed flocks together very well. On seven farms, we simultaneously monitored two LGDs associated with the same flock, in order to evaluate their interactions.

GPS collars recorded one fix every 15 min when the animal was active and one fix every 60 min when the animal was resting, as originally programmed by the device producers. The accuracy of GPS devices was tested with DNRGPS software ver. 6.0.0.15 (2000–2012 Minnesota Department of Natural Resources) using 64 locations collected by one GPS collar left stationary on a tree. The CEP (Circular Error Probability) calculation, showed an accuracy of 16 m with a maximum error of 57 m.

2.3. Spatial analysis

We excluded all locations when sheep were stabled, in order to include only spatial interactions on pastures. One of the dogs (ID 7) was identified as an outlier and excluded from analyses (Please see Supplemental Fig. 1). This dog was a mixed breed, considerably smaller than the Maremma (i.e. the typical and most ancient Italian LGD), and never showed guarding behavior during our on-farm surveys for GPS collar assistance. It was in fact more a pet dog even though the farmer used it as guarding dog before the placement of two Maremma-type dogs.

For the distance analyses we retained only pairs of sheep-dog (N = 10306, 30%) and dog-dog (N = 9038, 73%) locations that were taken less than five minutes apart (average 2.5 min ± 1.5 min and 2.3 min ± 1.5 min). The five-minute interval was considered a small enough period for dogs and sheep to be considered stationary, based on visual observations and farmers' accounts. This is consistent with the findings of Gipson et al. (2012).

2.4. Distance analyses

The distance between dog and flock was approximated by the distance between dog-sheep pairs, and was measured in meters, accounting for topography. The same approach was used to quantify the distance between dog-dog pairs associated to the same flock.

We investigated the relationship between dog-sheep distance and sex and age of the dog, number of livestock guarding dogs associated with the flock, herd size, land use, percentage of trees and shrubs in the pasture and size of pasture. Dog and flock characteristics were recorded during on-farms surveys, whereas the environmental variables surrounding the pastures were quantified using a Geographic Information System (ArcGIS, ESRI, 2012).

The distance for sheep-dog and dog-dog pairs was calculated by converting Euclidean distances to real distances, using interpolation of z-values from a 10 × 10 m DTM (Digital Terrain Model) of Grosseto province (Regione Toscana, 2015).

To obtain the variables referred to as 'land use', we created a 120 m buffer around each dog-sheep distance segment, which corresponds to the mean distance between dogs and sheep. Within this buffer, we measured the area, expressed in hectares, of five different groups of land use classes (Regione Toscana, 2013): Artificial, Arable, Open, Heterogeneous and Wooded (Table 2). The percentage of trees and shrubs of pastures was determined using aerial imagery.

2.5. Movement range overlap

We calculated the Utilization Distribution Overlap Index (UDOI; Fieberg and Kochanny, 2005) and the Volume of Intersection Index (VI; Seidel, 1992) in order to characterize the degree of overlap between the movement range of 1) sheep and dogs and 2) pairs of LGDs that worked together. Both indices measure the utilization distribution (UD; i.e. the probability distribution defining the animal's use of space) shared between two species. The UDOI quantifies the degree of overlap and the VI quantifies the similarity between the estimates of the areas used by the two species (Fieberg and Kochanny, 2005). VI and UDOI indices range from 0, which indicates lack of overlap, to 1, which indicates total overlap. However, UDOI can be > 1 when the space used by two animals is non-uniformly distributed but still has a high degree of overlap.

We used a fixed kernel isopleth at 95% to define the whole area of movement, and 50% to reveal the most used areas (Powell, 2000). Bandwidth was selected with the plug-in method because it is more conservative, resulting in less smoothing than other methods (Gitzen et al., 2006). Autocorrelation was not considered a problem, as we were interested in space use rather than the size of the movement range (Swihart and Slade, 1985). In addition, areas with autocorrelated observations are often associated with important resources (Solla et al., 1999).

2.6. Statistical analysis

Distance and overlap data were non-normally distributed ($D = 0.1982$, $P < 0.0001$), therefore repeated non parametric tests were performed to test for statistical differences. Kruskall Wallis tests were used to test for significant differences in distance between dogs and between farms, and two sided Wilcoxon rank sum tests were used to test for significant differences in distance and overlap between dog

Table 3
Average distance between pairs of LGDs in each farm. The mean distance was 81 ± 110 m. However, due to the high variability in distance values we suggest that the median values are more representative of the central tendency of our data.

Farm	Mean	SD	Median	IQR
E1	61	77	41	22–75
E2	73	85	47	20–92
E3	89	96	60	26–113
F	92	118	46	22–112
G	124	135	83	38–146
H	34	37	22	11–44
I	66	70	43	17–91
J	148	176	77	29–196
K	29	36	18	10–32
Total	81	110	42	18–95

sex and distance between pairs of associated dogs. A 95% confidence level was set for all the tests.

Linear mixed models (LMMs) were used to investigate which variables influence the dog-sheep distance. LMMs can handle longitudinal and clustered data, as was our case, using random effects to model the variation within the variables (West et al., 2014).

The explanatory variables were grouped into: 1) land use, 2) dog characteristics, 3) pastures, 4) husbandry features (Table 3). Season was not included as an explanatory variable, as we sampled different animals in fall/winter than in spring/summer. We first carried out a data exploration following recommendations of Zuur et al. (2010). Since distance was not normally distributed it was log-transformed prior to analysis. Moreover, we rescaled the explanatory variables, multiplying them by a factor of 100. We fitted the models with four random effects (Dog ID nested in Pasture Areas, Dog ID nested in percentage of trees and shrubs in the Pasture Areas, Farm ID, Day of sampling) to account for variation within these variables

Analysis of variance was used to assess the importance of each variable, comparing the full best model with a second model without the variable of interest. Models were compared looking at their BIC (Bayesian Information Criterion; Schwarz, 1978) score and their weight. We opted for selecting the best model instead of model averaging as the difference (i.e. delta, Δ) between the first and the second best model was $\Delta > 5$ (Raftery, 1995). The residuals plot was used to assess the fit of the model.

Statistical and spatial analyses were performed with RStudio (RStudio Team, 2015) and ArcGIS software ver.10.1 (ESRI, 2012). Movement range overlap was calculated with the R script provided by Fieberg and Kochanny (2005).

3. Results

3.1. Distance

The average distance between LGDs and their flock was 120.0 ± 135.5 m when considering the mean value (± SD) and 70 m (IQR 35–146) when considering the median (See Supplemental Fig. 1). The average distance between pairs of LGDs was 80.8 ± 109.8 m considering the mean, and 42 (IQR 18–95) meters considering the median (Table 3). Dog-sheep distance ranged from a minimum of 0.62 m and a maximum of 990 m, while dog-dog distance ranged from 0 m to 896 m.

The distance between dog and sheep did not differ between dog sex (Wilkoxon rank sum test: $P = 0.118$) while significant differences were found between LGDs (Kruskall Wallis test: $P < 0.0001$) and farms (Kruskall Wallis test: $P < 0.0001$). For five farms, we didn't find any difference in dog-sheep distance between the two LGDs associated with the same flock, while at two farms the distance differed between paired dogs. Dissimilar dog-dog distances were found across the farms (Kruskall Wallis test: $P < 0.0001$).

The best model used to investigate the variables' influence on dog-sheep distance, included four predictors: Dog age, Artificial area, Forest, Heterogeneous area; and three random effects: Dog ID nested in Pasture Areas, Farm ID, Day of sampling. Inspection of the residuals showed a good model fit without over dispersion.

Dog-sheep distance increased with the presence of wooded ($\beta = 1.669$, $P < 0.0001$) and heterogeneous ($\beta = 1.204$, $P < 0.0001$) areas, while it decreased in the presence of artificial surfaces ($\beta = -1.730$, $P < 0.0001$). The age of dogs slightly influenced the distance ($\beta = -0.438$, $P = 0.002$), and older dogs remained closer to the flock than younger individuals.

Some of the variability linked to the dog-sheep distance was explained by the importance of the random effects of the model, that is: the differences among individual dogs working in pastures with different extension ($P < 0.0001$); the day when the sampling was done ($P < 0.0001$); and the differences among farms ($P < 0.0001$).

3.2. Overlap

The overlap of the movement range of sheep and LGDs was similar for male and female dogs for both the UDOI and VI indexes at 50% and 95% kernel isopleths (Wilkoxon rank sum test: UDOI 50% $P = 0.178$; UDOI 95%: $P = 0.341$; VI 50%: $P = 0.099$; VI 95%: $P = 0.642$). The utilization distribution for the dogs and sheep entire movement range was non-uniformly distributed, but had a high degree of overlap (Fig. 1). The VI index showed partial space-use sharing for dogs and sheep, revealing a different use of pasture areas. LGDs from the same social group shared large areas (Fig. 2).

4. Discussion

GPS collars allowed us to investigate the spatial association of LGDs with their sheep in the absence of a shepherd or guardian. Satellite data have previously been used to investigate the spatial behavior of LGDs (Gipson et al., 2012; van Bommel and Johnson, 2014; Landry et al., 2014) because, compared to focal sampling, GPS collars allow collection of spatial information at high sampling rates, including at nighttime without affecting the subject's behavior (Gipson et al., 2012; Webber et al., 2012).

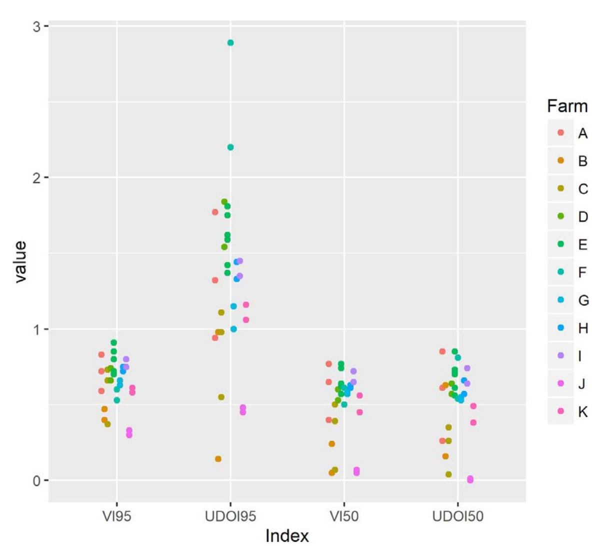

Fig. 1. UDOI and VI indexes of sheep-LGDs movement range overlap. The UDOI quantifies the degree of overlap and the VI quantifies the similarity between the estimates of the areas used by the two species. VI and UDOI indices range from 0, which indicates lack of overlap, to 1, which indicates total overlap. UDOI can be > 1 when the space used by two animals is non-uniformly distributed but still has a high degree of overlap. These two indices were calculated using a fixed kernel isopleth at 95% to define the overlap of whole area of movement, and 50% to reveal the overlap in the most used areas.

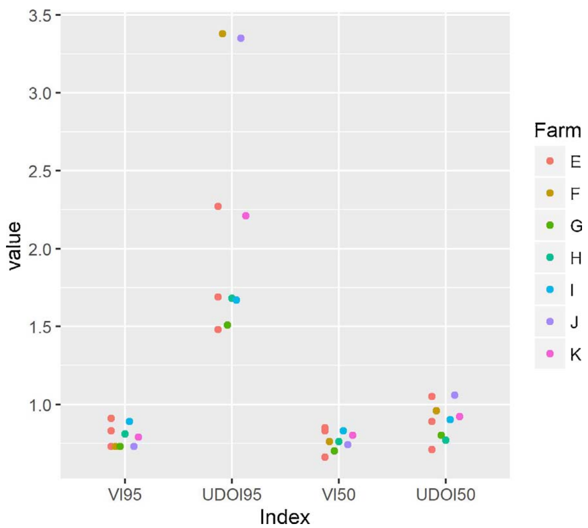

Fig. 2. UDOI and VI indexes for the overlap of movement range between LGDs of the same social group (i.e. same farm). VI and UDOI values show that LGDs from the same social group shared large areas.

Considering that a prerequisite for LGDs to be effective is that they keep at a short distance from their flock (Gehring et al., 2011; VerCauteren et al., 2012), good dogs are those that stay with livestock and successfully defend them from predators (Coppinger and Coppinger, 2005). This intuition was already stated more than 2000 years ago by the Roman scholar Varro who understood the need for LGDs to be "accustomed to follow the sheep" (Coppinger and Coppinger, 2005).

Our results confirmed the expectation that LGDs spent the majority of their time close to livestock sharing the same areas. However, they used these areas in a different way, as highlighted by the UDOI and VI index estimates, indicating that being in the same area does not always mean staying in the same spot, but at a distance that presumably allows the dog to keep the situation under control.

Occasionally dogs moved away from the flock, but there was no evidence of repeated forages outside the pasture. Patrolling around the pastures could have a significant behavioral function for LGDs, such as marking a territory from which other canids are excluded (van Bommel and Johnson, 2014). However, sometimes territorial signaling by LGDs (i.e. scent marking, barking) does not keep predators from approaching the flock, and in some cases may even attract them (Landry et al., 2014). This suggests that, in addition to territorial demarcation, the physical presence of LGDs in the area with their livestock is also important for stock protection (Gehring et al., 2010).

Although in general LGDs occupied the same area as their flocks, a high degree of variability characterized dog-sheep distance values, as confirmed by the high standard deviations and the importance of the random components of the model. We found that the average dog-sheep closeness significantly varied among dogs. Individual differences in behavior and guarding inclination may affect LGD association with the flock (Otstavel et al., 2009; Urbigkit and Urbigkit, 2010). The environment surrounding the dog also played an important role in determining dog-sheep distance length. LGDs remained closer to their flock in pastures near dwellings and wandered further from their flock if kept in pastures near forests.

We expected that pastures with a high percentage of trees and shrubs caused the sheep to flock less, and spread more during grazing, leading to a greater dog-sheep distance. However, we found that the amount of trees and shrubs in the pasture did not affect the dog-sheep closeness.

The age of the LGD had an effect on the dog-sheep distance, with older dogs staying closer to the flock than younger ones. Van Bommel and Johnson (2014) pointed out that dogs about eight years old and older show a reduction in mobility that could explain our findings. However, we actually monitored only two dogs older than eight years (average = 1.98 ± 2 years, max = 9 years, min = 7months, see Table 1) and the relation between dog age and proximity to the sheep might be explained, instead, by supposing that bonding between sheep and LGDs increases over time.

Dog sex did not affect the dog-sheep distance as found by Leijenaar et al. (2015). However, one female with pups often left the flock to nurse her offspring. To minimize the number of time this type of situation occurs, it might be advisable to spay all females not intended for breeding.

Coppinger et al. (1983) found that guardian dog performance was the same for small and large flocks. In our study we did not find a significant influence of flock size on dog-sheep distance.

The dog-sheep and dog-dog overlap indices suggest that most of the movement range was shared between the two species, but also highlighted a differential use of space in grazing areas; the VI index was higher between dogs than between sheep and dogs.

In Grosseto province, it is common to observe LGDs along the edges of their pastures where vegetative cover might attract the dogs for three reasons: the presence of streams, wildlife, and shade on hot days. Sheep require shelter as well, especially during summer, but they generally rest under trees scattered in the central parts of pastures where they graze. On the other hand, dogs could have preferred the margins of the pastures to better supervise the area where the flocks were grazing.

We acknowledge that several other variables that we have not considered could influence the spatial associations between sheep and LGD. For example, the behavior of the dogs toward sheep and predators is in part genetic (Coppinger et al., 1983).

Other sources of variability could be the way pups were raised and trained, and the environment surrounding them during their first weeks of life (Lorenz and Coppinger, 1986). Indeed, we found significant differences in dog-sheep distance values among farms, but in 71% of cases, there was no difference between pair of dogs of the same social group. This may confirm that the farmer's proficiency in dog management and training and the husbandry conditions of the farms have a direct impact on the general success of LGDs (Espuno et al., 2004).

Although we were unable to demonstrate any causal relationship between dog-sheep closeness and the dog's effectiveness in actively preventing depredations, we proposed a method to assess the sheep-LGD spatial association, highlighting the variables that most influenced it. This information might me valuable to check if LGDs behave as expected. A dog that constantly maintains contact with the flock is working properly and is considered attentive, a quality that is related to a reduction in predation (Coppinger et al., 1983). We observed that the monitored dogs were closely associated with their flocks and during the study period none of the farms experienced depredations. In the same period, 55% of the farms in our study area had neighbors (< 5 km) who suffered livestock depredations (National Health Authority database), although no indication of LGD presence is provided for the affected farms.

From a management perspective, GPS pet collars have proven to be an important tool in managing LGDs, as farmers were able to check the position of their dogs and their flock at any time. This opportunity would be especially useful in husbandry systems where sheep graze in pastures without a shepherd, helping to limit conflicts with neighbors and allowing intervention if dogs approach roads. In addition, GPS pet collars might be useful in dog training and behavioral corrections, showing whether the dogs are where they are supposed to be and the cause of dog's distraction. Moreover, farmers' confidence in their LGDs improved with the ability to constantly monitor them and observe what they were doing.

We actively involved farmers in our research, both to help them with the management of LGDs and to reduce the data sampling effort. The biggest drawback of this choice was data waste. We lost data when farmers did not comply with the research protocol, which stated that all

GPS units worn by the animals had to be recharged every two days simultaneously. In addition, the GPS collars we used did not allow us to program the fix rate, and therefore it was impossible to synchronize the dog's and sheep's devices in order to have concurrent locations. Nevertheless we were able to collect enough data for our analyses.

5. Conclusions

The spatial association between sheep and LGDs can be influenced by the environmental conditions surrounding the pastures. However farmer's proficiency in dog management and training still have an important role in determining the dog's attitude to remain close to the flock.

We argue that the spatial association between dog and sheep must be accounted for when evaluating a LGD, but more research is needed to assess whether this feature alone could be used as a proxy for assessing the effectiveness of the guarding dogs. GPS pet collars may help farmers to look after their dogs notably in their juvenile life, providing an important tool to improve dog training by allowing prompt correction of inappropriate roaming behavior. Whenever it is possible younger dogs should follow the sheep in open pastures not surrounded by forest when left unattended, since wooded areas are likely to distract LGDs from guarding the flock.

Conflicts of interest

The authors declare that there are no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.applanim.2017.10.002.

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