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Exploring the importance of the ecological context in wolf-livestock interaction management: the case of Grosseto province

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ABSTRACT

Large carnivores, once widespread across much of Europe, between the nineteenth and twentieth centuries have suffered a dramatic decline that brought them close to extinction in many parts of Europe. Since the '70s, factors such as legal protection, improved habitats quality and mountains depopulation enabled the recovery of several predator populations. Wolf recovery in areas from which was eradicated, or was occasionally present, has been followed by an intensification of the conflict with human activities, in particular with animal husbandry. Many farmers were unprepared to deal with this new situation having abandoned over the years the use of fences, guard dogs and the practice of monitor the stock.

This research was carried out within the territory of Grosseto province, where, following the recent expansion of the wolf population, livestock activities and predator range have overlapped again leading to a situation of great conflict. The same problem occurred in different parts of the world, as demonstrated by the growing number of scientific publications on this topic.

Although wolf-livestock conflict is a complex issue, its mitigation is partially fostered by damages reduction. This research shows how the analysis of the ecological context helps in preventing livestock losses.

In recent years the use of models to predict the depredation risk has grown dramatically, suggesting how this technique will be increasingly applied to take management information to mitigate the human-carnivore conflict.

Therefore I proposed a new three-step method to predict wild canid (wolves and wolf-dog hybrids) depredation risk using presence-only data on wild canid detections and confirmed depredation events in the study area. As a first step, wild canids probability of occurrence was predict; second, I made a prediction on where depredation events were more likely to occur; third I performed an ensemble model integrating the two previous models following an ad-hoc procedure.

Models' outputs obtained from two different approaches to species distribution modeling: Maximum Entropy (Maxent), widely used, and Bayesian for Presence Only Data (BPOD), recently proposed, were compared testing their ability to predict the occurrence of events. The ecological niche factor analysis (ENFA) was used to assess the importance of each environmental variable in the description of the presence points.

Results showed that the presence of wild canids was mainly related to forests (M = 0.78). Whereas depredation events were most likely to occur close to farms (M = -0.83) where sheep densities were higher (M = 8.1) and more accessible (M = -1.46). Higher depredation risk zones were characterized by proximity to forested areas and the presence of landscape features that allowed

wild canids to reach pastures with minimum effort such as the network of smaller watercourses. Although the majority of livestock within Grosseto province graze extensively and is thus potentially available for predators, only 15% sheep farms fall within higher risk areas. This suggests that at the provincial level, depredation was facilitated by environmental conditions (e.g. closeness to the woods or steams) rather than the availability of domestic prey. Overall BPOD performed better than Maxent in terms of sensitivity, suggesting that BPOD could be a promising approach to predict probability of occurrence using presence-only data.

In many parts of the world, livestock guarding dogs (LGDs) are considered one of the most powerful prevention tools against carnivore depredation on domestic animals. As wolf populations are recovering their use is expected to increase. Although LGDs defend livestock against predators, they could negatively impact on some wild species and in some situations could be even a potential hazard to humans. Therefore how these dogs behave when left unsupervised with their flock on pastures is of utmost importance.

29 LGDs with GPS collars were monitored in order to investigate their space use and association with their livestock, analyzing two parameters: the dog-sheep distance and the overlap between dog and sheep movement ranges. The first parameter was evaluated by measuring the real distance between pairs of dog-sheep locations taken in less than five minutes apart to ensure the simultaneity of the two events. In addition linear mixed models were implemented to evaluate how dog-sheep distance was influenced by environmental, dog-related, and farming-related variables. 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. Finally the usefulness of GPS pet collars in dogs and sheep husbandry was tested.

LGDs did not leave the flock unattended when left unsupervised. They spent the majority of their time close to livestock, sharing the same areas but using the space in a different way (mean VI 95% = 0.65 ± 0.16; mean UDOI 95%= 1.31 ± 0.56). Dog-sheep distance was mostly influenced by environmental variables and the age of the dog. Dogs and sheep tended to separate more in pastures surrounded by woods ($\beta = 1.669$, $p < 2.2e^{-16}$) or located in heterogeneous agricultural areas ($\beta = 1.204$, $p = 1.33e^{-05}$), and less in pastures close to inhabited areas ($\beta = -1.730$, $p = 2.34e^{-07}$). Older dogs were more associated to the flock compared to younger individuals ($\beta = -0.438$, $p = 0.002$). Some of the variability linked to the dog-sheep distance was explained by the importance of the random components of the models, namely: the differences among individual dogs working in pastures with different extension ($p<2.2e^{-16}$); the day when the sampling was done ($p<2.2e^{-16}$); and the differences among farms ($p=4.87e^{-07}$).

The effectiveness of guarding dogs as a prevention tool is not only affected by the environmental features or by LGD's characteristics and training. In fact, to be effective, livestock guarding dogs should work in conditions that allow them to protect the entire livestock.

Comparing 79 sheep farms with at least one adult (> 1.5 years old) guarding dog, were highlighted the conditions that decrease the efficacy of these animals in reducing depredations. For each farm were measured: 1) the number of adult livestock guarding dogs; 2) the distance between the farmer's house and the night shelter; 3) night shelter permeability to predators; 4) flock size; 5) shepherd presence; 6) the number of depredation events over the last six months; 7) the depredation risk. Farms were classified on whether or not they experienced depredation over the last six months. The two groups were then compared using non-parametric tests and logistic regressions.

Depredated and non-depredated farms differed only by the night shelter-farmer's home distance value ($W = 455$, $p\text{-value} = 0.005$). The model averaging showed a significant positive correlation between damage occurrence and night shelter-farmer's home distance length ($\beta = 4.695\ e^{-04}$, $p\text{-value} = 0.0218$). These results suggest that in environmental conditions that determine a similar depredation risk, human presence is the main feature that enhances the effectiveness of guarding dogs as a tool against canid attacks on flocks.

Investigating the role of some of the ecological variables involved in depredation events helps to ensure that the wolf-livestock interactions occur in a sustainable manner. Indeed depredation risk maps could be a useful tool for farmers and manager for the timely apply prevention techniques that reduce depredation and for policymaker could be a support to allocate financial resources. Additionally conservation projects may benefit from these maps to select areas of intervention. Moreover results from this work provided some hints for farmers and conservationists to improve the use of LGDs for an effective livestock protection: some of the recommendations affected the dog management, while other the livestock husbandry practices. Finally this research introduced a new way to manage LGDs using GPS pet collars. With these devices farmers could be able to check the position of their dogs and their flock at any time, preventing wrong dog behaviors, conflicts with neighbors and accidents.

RIASSUNTO

I grandi carnivori, una volta ampiamente diffusi su gran parte del territorio europeo, tra il diciannovesimo e il ventesimo secolo hanno subito un drammatico declino che li ha portati vicini all'estinzione in molte parti d'Europa. Dagli anni '70, fattori quali la protezione legale, il miglioramento della qualità degli habitat e lo spopolamento delle montagne hanno consentito la ripresa di numerose popolazioni di predatori. Il ritorno del lupo in aree da cui era stato eradicato, o era presente occasionalmente, è stato accompagnato dall'intensificarsi del conflitto con le attività umane, in particolare con la zootecnia. Molti allevatori si sono trovati impreparati ad affrontare questa nuova situazione avendo abbandonato negli anni l'uso di recinzioni, di cani da guardiania e l'abitudine di sorvegliare il bestiame.

La presente ricerca di dottorato è stata svolta sul territorio della provincia di Grosseto dove, in seguito alla recente espansione della popolazione di lupo, attività zootecnica e presenza di predatori si sono sovrapposte nuovamente creando una situazione di grande conflitto.

La stessa problematica si è verificata in diverse parti del mondo, come testimonia il crescente numero di pubblicazioni scientifiche sull'argomento.

Negli ultimi anni l'uso di modelli per prevedere il rischio di predazione è cresciuto notevolmente, suggerendo come questa tecnica verrà sempre più applicata per trarre indicazioni gestionali in grado di mitigare il conflitto uomo-grandi carnivori.

Ho quindi proposto un nuovo metodo per prevedere il rischio di predazione che sfrutta le variabili ecologiche associate alla presenza di canidi selvatici (lupi e ibridi lupo-cane) ed eventi di predazione. Il metodo prevede tre passaggi: previsione della presenza di canidi selvatici; previsione della presenza di eventi di predazione; previsione del rischio di predazione mediante l'integrazione dei due precedenti modelli seguendo una procedura ad hoc. Per prevedere la probabilità di presenza di canidi selvatici ed eventi predatori a danno del bestiame, sono stati testati due approcci usati generalmente per modellizzare la distribuzione delle specie: Maximum Entropy (Maxent), ampiamente utilizzato, e Bayesian for Presence Only Data (BPOD), proposto di recente. La rilevanza di ciascuna variabile nel caratterizzare sia le aree occupate dai canidi selvatici che le condizioni in cui le aziende sono più vulnerabili, è stata assegnata attraverso l'ecological niche factor analysis (ENFA), considerando i valori dei parametri del coefficiente di marginalità (M), della specializzazione (S) e della tolleranza (T). Arbitrariamente è stato stabilito che i valori del coefficiente di marginalità superiori a 0.5 indicavano una preferenza per una certa variabile. Dai risultati è emerso che la presenza di canidi selvatici era principalmente associata alle zone boscate (M = 0.78). Le predazioni, invece, si sono verificate con più frequenza a poca distanza dalle aziende

zootecniche (M = -0.83) in cui la densità di pecore era elevata (M=1.08) e il bestiame raggiungibile dai predatori in breve tempo (M=-1.46). Caratteristiche ambientali quali, la vicinanza al bosco o a piccoli corsi d'acqua, sono state associate ad un rischio di predazione più alto in quanto consentono ai canidi selvatici di raggiungere il bestiame senza essere visti e di ritornare nelle zone di rifugio in poco tempo. Benché le pratiche di allevamento estensivo adottate nella provincia di Grosseto rendano disponibili le pecore ai predatori su una consistente parte del territorio, solo il 15% delle aziende è ricaduta in aree definite ad alto rischio. Questo fa supporre che su scala provinciale, gli eventi di predazione siano facilitati più dalle condizioni ambientali (es. presenza di bosco e corsi d'acqua) che dalla disponibilità delle prede domestiche. Complessivamente BPOD ha superato Maxent in termini di sensitività del modello, quantificata attraverso la stima della probability of detection (POD), dimostrando di essere un approccio promettente quando si trattano dati di sola presenza.

Per prevenire le predazioni sul bestiame domestico, l'utilizzo dei cani da guardiania è ritenuto uno dei metodi più efficaci e considerando la ripresa delle popolazioni di lupo, ci si può aspettare nei prossimi anni un aumento di questi cani sul territorio agricolo e naturale. Se da un lato i cani da guardiania sono uno strumento importante per fini gestionali (migliorando l'uso dei pascoli) e conservazionistici (mitigando il conflitto uomo-carnivori), dall'altro possono costituire una minaccia per le popolazioni di alcune specie selvatiche e in alcune situazioni anche un potenziale pericolo per l'uomo. Ad oggi l'uso dello spazio di questi cani in assenza del pastore è ancora poco noto. Studiare il comportamento dei cani da guardiania quando vengono lasciati da soli al pascolo risulta quindi di primaria importanza per verificare che il cane rimanga effettivamente vicino al gregge per poterlo difendere. A tal fine, mediante l'applicazione di collari GPS, è stata valutata l'associazione spaziale tra cani e gregge analizzando due parametri: la distanza cane-pecora e la sovrapposizione tra gli areali di movimento delle due specie oggetto di studio.

La vicinanza tra cani e gregge è stata valutata misurando la distanza reale (ovvero quella che tiene conto della topografia del territorio) tra coppie di punti di cane e pecora, presi in meno di cinque minuti l'uno dall'altro, per garantire la simultaneità dei due eventi. Il valore della distanza è stato poi messo in relazione ad alcune variabili (sesso ed età del cane, numero di cani da guardiania associati allo stesso gregge, dimensione del gregge, tipo di ambiente, tipo e dimensione dell'area di pascolo) implementando dei modelli lineari misti.

La sovrapposizione tra le aree di movimento di pecore e cani e tra quelle dei cani associati allo stesso gregge è stata calcolata attraverso il Volume of Intersection (VI) e l'Utilization Distribution Overlap Index (UDOI). Entrambi sono indici impiegati per misurare lo spazio utilizzato comune a due specie, in particolare, l'UDOI quantifica il grado di sovrapposizione e il VI quantifica la similitudine tra le stime delle aree utilizzate dalle due specie.

I risultati ottenuti hanno mostrato che cani e pecore sono rimasti vicini per la maggior parte del tempo, condividendo una larga parte dell'area di movimento ma utilizzando lo spazio in modo differente (VI medio 95%=0.65 ±0.16; UDOI medio 95%=1.31 ±0.56). Un'ipotesi è che questa differenza derivi dal fatto che i cani passano la maggior parte del tempo al riparo della vegetazione nelle aree marginali del pascolo, mentre le pecore occupano prevalentemente la parte centrale per alimentarsi. La distanza è stata principalmente influenzata da variabili ambientali, e in secondo luogo dall'età del cane. In generale, i cani si sono allontanati maggiormente dalle pecore in pascoli circondati dal bosco (β=1.669, $p<2.2e^{-16}$) o localizzati in aree agricole eterogenee (β=1.204, $p=1.33e^{-05}$), ma sono rimasti più vicini al gregge nei pascoli prossimi alle zone abitate (β= -1.730, $p=2.34e^{-07}$). Rispetto ai cani più giovani quelli più anziani si sono allontanati meno dal gregge (β= -0.438, p=0.002). I valori della distanza sono stati caratterizzati da un'alta variabilità che in parte è stata spiegata dai termini random del modello ovvero da: differenze individuali dei cani che hanno lavorato in pascoli di dimensione diversa ($p<2.2e^{-16}$); dal giorno in cui è stato effettuato il campionamento ($p<2.2e^{-16}$); e dalle differenze tra le aziende campionate ($p=4.87e^{-07}$).
I collari GPS per animali domestici utilizzati nello studio, si sono rivelati uno strumento utile agli allevatori nella gestione dei cani e del gregge offrendo la possibilità di controllare da remoto la posizione degli animali a cui erano stati applicati. Al contrario, sono risultati uno strumento meno efficace per raccogliere i dati, a causa delle loro limitazioni che hanno portato all'eliminazione di parte del dataset. L'uso dei collari GPS ha permesso tuttavia di dimostrare che i cani da guardiania rimangono associati al gregge anche quando non sono direttamente controllati dall'allevatore.

Come gli altri metodi preventivi, l'uso dei cani non garantisce l'eliminazione del 100% dei danni. Molto dipende da come i diversi sistemi di prevenzione vengono applicati e integrati tra loro. Confrontando 79 aziende zootecniche con almeno un cane da guardiania adulto (>1.5 anni), ho cercato di evidenziare le condizioni che aumentano il successo dell'uso di questi animali per ridurre le predazioni. Per ciascuna azienda campionata è stato misurato: 1) il numero di cani da guardiania adulti; 2) la distanza tra la casa dell'allevatore e la stalla; 3) la permeabilità del ricovero notturno ai predatori; 4) il numero di capi totale; 5) la presenza del pastore; 6) il numero di eventi di predazione negli ultimi sei mesi; 7) il rischio di predazione. Le aziende che avevano ricevuto almeno una predazione negli ultimi sei mesi sono state divise da quelle che non avevano avuto danni nello stesso periodo. Le caratteristiche dei due gruppi sono state confrontate utilizzando test non parametrici, e analizzate con la regressione logistica.
Non sono state osservate differenze significative tra i metodi di prevenzione delle aziende con e senza danno, localizzate in zone in cui le condizioni ambientali determinavano un rischio di predazione simile. I due gruppi differivano esclusivamente per il valore della distanza tra la casa dell'allevatore e la stalla (W=455, p-value=0.005). L'insieme dei migliori modelli ottenuti con

l'analisi di regressione ha restituito una significativa correlazione positiva (β= 4.695 e^{-04}, p-value=0.0218) tra la presenza del danno e la distanza tra la stalla e la casa dell'allevatore. Questo risultato suggerisce che a parità di rischio di predazione, la presenza dell'uomo costituisce il principale deterrente per gli attacchi dei canidi alle greggi.

Con la presente ricerca di dottorato, è stata messa in luce l'importanza di conoscere gli aspetti ecologici dell'interazione tra lupo e attività zootecnica, per proporre azioni di mitigazione della situazione di conflitto che spesso si genera quando lo spazio utilizzato dai grandi carnivori si sovrappone a quello dedicato all'allevamento estensivo di ovini. Integrando le informazioni sull'ecologia del lupo e sulle caratteristiche dell'ambiente intorno alle aziende zootecniche, è stato proposto un nuovo metodo per prevedere le aree potenzialmente più a rischio di predazione, circoscrivendo le zone in cui l'uso di metodi preventivi è prioritario. La descrizione dell'uso spaziale dei cani da guardiania in relazione al gregge ha permesso di dimostrare la loro affidabilità anche in assenza del pastore. Infine è stato riscontrato che su scala aziendale, in condizioni ambientali che determinano un rischio di predazione simile, la presenza dell'uomo rappresenta il principale fattore in grado di limitare gli attacchi al bestiame ad opera di predatori.

CHAPTER 1

INTRODUCTION

Large carnivores and humans have been sharing the landscape of Europe for millennia (Linnell and Lescureux 2015). These wild animals, once widespread in European countries, started to decline as human societies began to heavily exploit natural resource, modify the landscape and expanding farming activities. Space and food requirement of large carnivores such as wolves, led them to overlap their range to the areas occupied by humans, interfering with existing extensive livestock-raising activities (Linnell et al. 1996). Therefore intense persecutions of carnivore followed, reaching their most extreme in mid-twentieth century, when all carnivore populations experienced their smallest population sizes and range contraction (Boitani and Linnell 2015).

From the 1960s to the 1980s a shift in human attitudes towards nature led to a global revision of the environmental policies which geared to a more conservationist and protectionist vision (Linnell and Lescureux 2015). The enforcement of this renewed environmental policy, which allowed wild prey populations to increase and forests to expand, along with socioeconomic changes in European countries, enabled several wolf populations to recover (Chapron et al. 2014). However the positive trend of the wolf populations is impacting on farming activities, especially where this predator had been absent for a long time (Mech et al. 2000, Mech 2001, Fritts et al. 2003).

Although livestock depredation by wolves is an old problem for farmers, nowadays began a more complex issue as involves the whole community. This implies a clash between different values and cultures (Ciucci and Boitani 2005) originating what is called in the broadest sense human-wildlife conflict (wolf-livestock conflict in this case). On one hand wolf is supported by conservationists and many urban people, on the other hand is considered a distress by rural people, who often perceive this predator as a threat to livestock and wildlife (Fritts et al. 2003).

Improving knowledge and acceptance of predators in rural areas and analyzing the wild predator–livestock interactions in order to limit depredations is of paramount importance to address the situation of conflict and conserve wolf successfully (Linnell et al. 1996, Boitani 2000, Ciucci and Boitani 2005). Indeed, finding effective strategies to reduce wolf depredation on livestock is beneficial for both livestock producers and wolves (Bradley and Pletscher 2005). Nowadays new tools can be used to understand the variables associated with the depredation risk and the effectiveness of protective measures against predator attacks.

Their application can be very useful where wolf-livestock conflict poses a significant threat to both local communities and wolves. One such area is Grosseto province, located in the southern part of

Tuscany region, Italy. In this province around 200,000 sheep are raised mostly extensively in a heterogeneous landscape where wolves were recently expanded. Wolves are perceived as a threat to local economy strongly based on rural activities related to dairy products and tourism. The overlap between wolves and sheep range and the limited implementation of preventive measures due to a poor tradition in large carnivore coexistence resulted in an increased number of depredation events (Gazzola et al. 2006, Health Service Database). As a consequence the social tension escalated culminating in retaliatory killing of wolves.

Given this situation of serious conflict, some European and regional projects aimed to promote wolf-livestock coexistence have taken place in Grosseto province in recent years. Thanks to these initiatives, farmers are changing their livestock husbandry practices faster, adapting them to the predator presence in the area. A better knowledge of how the environmental features affect the depredation risk and the usefulness of preventive tools will help them in this upgrading process.

Wolf livestock conflict

Wildlife and humans compete for space and resources and when they impact negatively on each other goals conflict situations arise. Human wildlife conflict is increasing in both frequency and severity worldwide as involves a wide range of environments and species, from small rodents to elephants (Madden 2004). These conflicts may result when wildlife kill livestock and game species, damage crops and fences, spread diseases to domestic animals, threaten or kill people and when cause vehicle collisions (Manoa and Mwaura 2016). Conflicts escalate when local people feel that the needs of wildlife are given priority over their own needs (Madden 2004).

However, frequently is not only conflict between humans and wildlife, but also between people about wildlife (Madden and McQuinn 2014). Yet, in many cases the conflict with wildlife has become a symbolic manifestation of deeper social conflict between people and groups with different goals, values and wealth (Naughton-Treves et al. 2003, Madden and McQuinn 2014).

Human wildlife conflict based on livestock killed by wolves is a worldwide phenomenon with significant conservation implications as it is a concern for rural people (Muhly and Musiani 2009), and a substantial source of wolf mortality (Musiani et al. 2005, Genovesi 2005, Boitani et al. 2010). Moreover debates about wolves often involve underlying issues that reflect conflict within humans and cause social polarization (Fritts et al. 2003, Lundmark et al. 2015).

Wolf livestock conflict occurs on every continent and in every habitat where wolves and domestic animals take place together (Linnell et al. 2012). In most Italian regions, this problem is further exacerbated by the presence of free-ranging domestic dogs as wolves are often blamed for dog predation on livestock (Boitani and Fabbri 1983, Ciucci and Boitani 1998).

There are probably more than 10,000 wolves in Europe distributed across 10 populations of which two occur in Italy: the Italian peninsula population and a portion of the Alpine population. A recent estimate of the numerical presence of wolves in Italy reported 800-1300 individuals and a positive growth trend (Genovesi et al. 2014).

Until the 1970s wolves greatly declined in Italy, surviving in two small isolated subpopulations confined to the southern and central part of the Apennines. Since the late 1980s wolves have shown a spontaneous rapid recovery recolonizing all the Apennines and reaching the western Italian and French Alps (Boitani 2000, Valière et al. 2003, Marucco and McIntire 2010). In this same decade wolves steadily occurred in the eastern part of Grosseto province, namely on Mount Amiata (1738 m asl) (Boitani e Fabbri, 1983). During following years and over 1990s, wolf population rapidly expanded towards north eastern territories of the Province (Gazzola et al. 2006). A survey conducted from 2003 to 2005 (Boscagli et al. 2006) confirmed wolves presence in early 2000s also in the southern part of Grosseto Province. Since the end of 2004 wolves were sighted within the Maremma Regional Park (press release n ° 40/2004 - P.R. Maremma). More recently, it was demonstrated that the wolf population in Grosseto province included wolf-dog hybrids (Braschi and Boitani 2013; Gallo et al. 2015). For this reason hereafter I will use the term "wild canids" referring to the combination of wolves and dog-wolf hybrids.

Wolf is generally a highly adaptable specie that can persist in viable populations across a wide range of habitats as well in human dominated landscapes (Ahmadi et al. 2014, Boitani and Linnell 2015). Several mechanisms are behind this ability such as the spatiotemporal segregation between wolves and human activities (Vilà et al. 1995, Ciucci et al. 1997, Theuerkauf et al. 2003), their capacity to use different human-related sources of food (Lopez-Bao et al. 2013) or other behavioral adaptations such as den shifting (Ahmadi et al. 2014). However evidences show that wolves tend to selected hardly accessible sites, areas with low human pressure as well as forested areas where wild prey are abundant and vegetation structure provide refuges (Jedrzejewski et al. 2008, Llaneza et al. 2012). In human dominated landscapes, such as Grosseto province, factors associated with the security of wolves (refuge) can be more important than food availability that in this area is abundant (Santilli and Varuzza 2013). Indeed, although the wolf in Italy is rigorously protected by Italian (M.D. 23 July 1971, Act 157/92) and European laws (Habitat Directive 92/43/CE, Berne Convention), illegal killing is still the first cause of wolf mortality (Genovesi 2002). In Grosseto province wolves are perceived as a threat both by hunters and farmers, and poaching occurs. Although the extent of this practice is unknown, as elsewhere in Italy, a striking case was when more than ten wild canids were killed and displayed over three months between 2013 and 2014, as a protest against predator depredation on livestock.

While in many cases overall depredation costs are negligible, in some cases the economic consequences of these losses may be very significant in a local context (Young et al. 2015). Besides killing some animals, large predators can have other more subtle effects on free-ranging livestock (Breck et al. 2012, Steele et al. 2013). One contention is that livestock exposed to wolves become stressed, forage less efficiently, gain fewer weight, and may have more difficulty rebreeding and producing offspring (Howery and DeLiberto 2004, Ashcroft et al. 2010, Laporte et al. 2010). It has also been suggested that wolf presence may alter distribution or habitat-selection patterns of livestock and wild ungulates (Muhly et al. 2009). Some studies argue that predation-related stress and injuries increase livestock vulnerability to sickness and disease (Howery and DeLiberto 2004; Lehmkuhler et al. 2007; Laporte et al. 2010), which can increase producer costs for veterinary care (Ashcroft et al. 2010). Farmers in wolf country may also bear the costs for implementing preventive measures and checking animals more frequently.

Obviously if not promptly addressed, all these detriments concur to cause negative feelings toward predators in rural communities, making coexistence between human and wolf harder. Indeed, inadequate management of wolf livestock conflict undermines not only the conservation of this predator but also the livelihood of local people (Treves et al. 2011, Redpath et al. 2013).

Conflict mitigation

Approaches to solving wolf livestock conflict on long term include those mitigating the social tension among stakeholders and those reducing the negative impact of wolves on livestock farming.

A tool that is aimed both at reducing wolf depredations (Bangs et al. 2005) and mitigating social conflicts (Mech 1995) is lethal control. Although wolf removal was largely used in the past, is facing increasingly opposition in USA and Europe considering the numerous drawbacks (Treves and Karanth 2003, Ripple at al. 2014, Chapron and Treves 2016, Fernández-Gil et al. 2016). Indeed even if lethal control may provide short-term relief, other animals, potentially more numerous, will usually fill rapidly the same territories leading to even more conflicts (Robinson et al. 2008). Moreover wolves most commonly responsible for killing domestic animals are the hardest to target and thus it is likely that depredations will continue to occur (Sacks et al. 1999, Treves et al. 2004). Wolf removal can be more expensive than non-lethal methods (McManus et al. 2013) and appease only particular segments of society, typically livestock producers and hunters. General public, instead, find this killing of carnivores controversial (Treves and Naughton-Treves 2005). Thus the social benefit of lethal control might be limited.

In response to the public dislike for lethal control, translocation of selected individuals can be considered. However translocation is largely unsuccessful as a routine conflict-management tool and is discouraged (Linnell et al. 1997, Bradley et al. 2005, Linnell et al. 2012).

Since the debate on the usefulness of these two approaches is still open, lethal control and translocation will no longer be considered hereafter.

Reducing social tension

Although the field of wildlife conservation is rooted in biology, its social component should not be overlooked. Conservation conflicts often serve as proxies for conflicts over more fundamental, non-material social and psychological unmet needs (Madden and McQuinn 2014). Interested parties are polarized when it comes to their views on wolves and litigation leads to formal and inflexible rules (Lundmark et al. 2015).

Moreover there is evidence for a significant mismatch between the loss perception and reality; consequently even a small level of wildlife damage can still elicit harsh responses (Dickman 2010).

The first step to reduce social tensions should be recognizing the deep-rooted conflict among stakeholders (Peterson et al. 2013). This requires going beyond the individual depredation events promoting constructive debates among the interested parties and achieving to shared solutions. Only when the underlying unrest has been detected and addressed, promoting tolerance toward predators will be effective (Madden and McQuinn 2014).

Tolerance is usually fostered through education, awareness campaigns, compensation schemes and income from ecotourism (Marker et al. 2003, Mishra et al. 2003, Nyhus et al. 2005, Sillero-Zubiri et al. 2004, Romanach et al. 2007, Dickman et al. 2011).

Research and education can help lessen hostility toward carnivores demonstrating that these species are not as damaging as previously thought (Dickman 2010).

Compensation schemes range from indirect economic incentives to direct payment for conservation performance (Zabel and Roe 2009) and include also insurance programs (Mishra et al. 2003). Most commonly compensation forms can be: ex-post compensation, where the damage is compensated after it has occurred; or ex-ante compensation, where an estimate of the expected damaged is paid conditional on the acceptance of predators in the area (Boitani et al. 2010). The payment of compensation for livestock losses due to depredation was introduced after wolves became legally protected (Fourli 1999) and was applied in Italy since the 1970s reaching an overall cost among the highest in Europe (Boitani et al. 2010). Nevertheless despite high costs, compensation schemes do not seem to meet their original goal of increasing wolf acceptance by livestock owners (Boitani et al. 2010). Compensation is expected to fail where predator attacks occur rather regularly as where an expanding population of predator inhabits a human dominated landscape (Schwerdtner and Gruber 2007). These areas are often steadily occupied by predators and local socio-economic lifestyles do not foresee traditional husbandry methods. One such area is the province of Grosseto were conflict level is high even though the Province has contributed 37.2% of regional compensation costs (7,400,000 €) in the period of 1995–2003 (Banti et al. 2005).

Paying for wolf damages on livestock is not the only way to compensate farmers. Rural communities might receive economic benefit from the presence of wolves though ecotourism, as people are more likely to visit an area where a high charismatic species such as wolf occurs (Duffield et al. 2006). Ecotourism is an important branch of tourism, ranging from 5% to 10% of the global travel market place (Epler-Wood 2010 cited in Lu and Stepchenkova 2012), with an annual growth rate of 5% worldwide (Honey and Krantz 2007). Therefore it can be expected that wolf tourism will increasingly benefit rural communities.

Reducing wild canids depredation on livestock

Although wolves prefer wild ungulates despite the presence of livestock, they may readily kill domesticated breeds when opportunities arise (Gazzola et al. 2005, Nowak et al. 2005, Gula 2008).

In general, domestic animals express a lower incidence of anti-predator traits and behavior (Mignon-Grasteau et al. 2005). Typically they have smaller brains and less acute sense organs than do their wild ancestors (Diamond 2002). Livestock vulnerability is also enhanced by several other variables that can be related to ecological features and husbandry practices (Mech et al. 2000, Treves et al. 2004, Ciucci and Boitani 2005, Kaartinen et al. 2009).

Ecological factors that could influence the risk of depredation include: distance to forest cover (Treves et al. 2011), the vegetation type (Treves et al. 2004), percentage of vegetation cover in pastures (Fritts et al. 1992, Bradley and Pletscher 2005), elevation (van Liere et al. 2013, Behdarvand et al. 2014), topography (Behdarvand et al. 2014), distance to protected areas, human settlements, roads, and water sources (Treves et al. 2011, Behdarvand et al. 2014), wolf/livestock encounter rate (Iliopoulos et al. 2009), livestock density (Mech et al. 2000, Treves et al. 2004), closeness to rendez vous sites (Bradley and Pletscher 2005, Gula 2008), predator density (Kaartinen et al. 2009), predator home range (Graham et al. 2005), behavior and movements of predators (Kolowski and Holekamp 2006). The availability of wild pray may have opposite effects on depredation (Linnell et al. 2012). On one hand, abundant wild prey can reduce wolf predation on livestock due to prey switching (Meriggi and Lovari 1996, Peterson and Ciucci 2003). On the other hand abundant wild prey can attract wolves, leading to predation on livestock (Bradley and Pletscher 2005).

Husbandry practices define the accessibility to livestock, considered by far the most important variable in determining the extent of losses (Ciucci and Boitani 1998, Musiani et al. 2005, Gazzola et al. 2008, Iliopoulos 2009, Linnell et al. 2012). Livestock accessibility can be related to poor husbandry conditions (Ciucci and Boitani, 1998; Espuno et al., 2004, Namgail et al. 2007, Sangay and Vernes 2008) exemplified by scarce surveillance, lack of preventive measures (Kaczensky 1996), calving/lambing in forested or brushy pastures (Fritts 1992). However accessibility to domestic animals can also be fostered by some grazing conditions. In fact livestock are most vulnerable to predation when are free-range and scattered over large pastures that overlap with wild prey and predators range (Bradley and Pletscher 2005, Barnes 2015).

The combination of these variables results in a non-homogeneous distribution of depredation events that appear to affect some livestock producers more than others (Cozza et al. 1996, Ciucci and Boitani 1998, Mech et al. 2000, Gazzola et al. 2008, Rigg et al. 2011, Zarco-González et al. 2012). Besides following a spatial pattern, depredations show a recurring timing. Many studies reported that attacks peak in summer and early autumn, when livestock are left grazing on pastures and wolf pup require large food intake given their relatively high growth rate (Ciucci and Boitani 1998, Musiani et al. 2005, Gazzola et al. 2008, Iliopoulos et al. 2009, Li et al. 2013).Therefore depredation on livestock is to some extent predictable and thus preventable.

Traditionally, shepherding systems in Europe, Asia, and Africa have shepherds, often accompanied by dogs, who guard livestock while they graze during daytime, and enclose the livestock into pens or barns at night (Mertens et al. 2001; Ogada et al. 2003; Woodroffe et al. 2007).

However in areas where predators were absent for a long time farmers has shifted towards less labor intensive systems, leaving their livestock grazing extensively with poor or no supervision. Moreover in order to obtain a higher income some farmers turned to diversification (Garde 2015, Linnell and Lescureux 2015), which means that less time is available for taking care of the livestock.

Using a spatial statistical approach, known as predation risk modeling, it is possible to anticipate on a broad scale where carnivores are likely to attack livestock and to propose preventive actions in specific areas. Spatial risk models reveal locations and associated habitat features where carnivores kill livestock, providing both quantitative and visual guides for targeting conflict mitigation interventions (Marucco and McIntire 2010; Treves et al. 2011, Zarco-González et al. 2013).

At local scale, a wide range of technical approaches exist for reducing the magnitude of wildlife damage incurred (Woodroffe et al. 2007). The implementation of preventive measures such as fladry, fencing and guarding dogs, along with a conscious livestock management can keep damages at a low level.

Fladry

Fladry consists in hanging lines of flags around fields (Fritts 1982, Musiani and Visalberghi 2001) and sometimes it is also combined with electric shocks (Turbofladry). Nonetheless, evidences support that fladry has only a temporary effectiveness (60 days on average) because predators become habituated (Musiani et al. 2003, Bangs et al. 2005, Shivik 2006).

Fencing

Fences instead, have produced effective long term results (Caporioni and Teofili 2005, Linnell et al. 2012) as they provide a permanent physical barrier between livestock and predators. Of course much depends on type and material of fences. Effective fences should be robust, at least 1.75 meters high above the ground, bended outward, and partially embedded into the ground. However because of their high cost, they are mainly used in small pastures or around the night shelters. Electric fences and electric sheep nets combine the simple physical barrier with a further negative experience for the predator. They differ for number and wire disposition, support structures, power generator and ground system. Even in this case they are only appropriate for small-sized pastures (Caporioni and Teofili 2005, Reinhardt et al. 2012).

Livestock guarding dogs

An old technology to prevent depredations is the use of livestock guarding dogs (LGDs). Their effectiveness has been confirmed in several projects even though it might vary according to the socio-cultural and ecological context in which they are used (Reinhardt et al. 2012, Lescureux and Linnell 2014).

The origins of LGDs are still not clear. The most ancient co-occurrence of dogs and sheep in archaeological records only dates back to ca. 5,600 years ago (Linnell and Lescureux 2015). However there are some historical preconditions for the presence of LGDs such as large scale extensive sheep farming, the presence of sheep predators and the possibility for livestock owner to feed the dogs (Linnell and Lescureux 2015). Thus the simple association between sheep and dog is not enough to determine the origins of LGDs.

The oldest descriptions of dogs specifically used for protecting livestock from predators appear in Aristotle's *Historia Animalium* (2,356 years ago), and Varro's *Rerum rusticarum libri III* (ca. 2,100 years ago).

Nowadays, it is possible to recognize approximately 50 breeds of LGD which share many similar traits (Linnell and Lescureux 2015) resulted from an adaptation to the harsh conditions of transhumance, and confrontation with wild carnivores as well as a post-zygotic selection of desired behavior favored by shepherds (Coppinger and Coppinger 2005). LGDs generally weight at least 30–40 kg and reach 50– 60 cm in height (Coppinger and Schneider 1995). The coat color has been adapted to the appearance of the animals that they have to guard (e.g. white dogs with white sheep, colored dogs with colored sheep, goats or cattle) in order to increase the likelihood of livestock accepting the dogs among them and/or to allow the LGDs sneaking up on predators (Rigg 2001). Moreover white color may have been selected for helping shepherds to distinguish dogs from predators (Rigg 2001). Like other dogs LGDs are social animals, thus if they socialize with livestock at an early age they will bond with the flock/herd and will protect it. According to Coppinger and Coppinger (1980), a good LGD should be attentive, trustworthy and protective. Attentiveness, measures the social bond between dog and livestock while trustworthiness indicates the lack of play and predatory patterns of dogs towards livestock. The combination of attentiveness and trustworthiness should drive the dog to develop a protective behavior towards the flock. LGDs are not selected to chase and fight predators but rather to protect livestock by disrupting wolf predatory behavior and displaying ambiguous and context-maladapted behaviors (barking, social greeting, play, and sometimes aggression) (Lescureux and Linnell 2014). LGDs do not herd livestock and operate more or less independently of a herder (Barnes 2015). They can usually follow the flock when they are three or four months old, but they are expected to begin work and develop enough confidence to attack predators at around one year old or later (Rigg 2001). However they can take up to two years to mature, and before maturity juvenile play behavior can still interfere with effective guarding (Lorenz and Coppinger 1986; Rigg 2001). For van Bommel and Johnson (2012) dogs are fully effective in the third year and later.

It is generally advised to have several dogs for each flock/herd to defend it (Linnell and Lescureux 2015) even though there is not a general livestock\dog ratio as much depends on livestock species and local conditions. Some authors recommend one dog for 80 sheep, other one dog for 100 sheep (Reinhardt et al. 2012). Espuno et al. (2004) suggested that at least four dogs would be necessary to reduce wolf attacks in flocks with1200-1500 sheep. Tuscany Region recommends that one single dog should protect no more than 150 sheep (Banti et al. 2005).

Livestock guarding dogs will not prevent all damages, especially when facing adaptable predators like wolves (Linnell and Lescureux 2015). Landscape and livestock management context seem to affect the effectiveness of LGDs (Barnes 2015) as also the age, genetic lineage and degree of bonding to sheep (Espuno 2004). Although LGDs are prone to protect livestock due to centuries of human selection, they need to be trained in the first period of their life. If not promptly corrected, wrong behaviors in the early stages lead to low effective or even detrimental dogs for livestock farms, as they can start roaming and causing damages nearby (Tedesco and Ciucci 2005). Moreover the presence of LGDs in some context may have equivocal consequences for local conservation spreading diseases, hybridizing with wolves, killing wildlife.

All these preventive tools will be effective if properly implemented and maintained. They should be used in an integrated way and in association with husbandry practices that minimize livestock accessibility to predators. In general livestock that were closely herdered by day and stabled at night with guarding dogs and high level of human activity were less likely to be killed by wild predators (Ogada et al. 2003).

LIFE programs and wolf-livestock conflict resolution in Italy

Large carnivores (brown bears *Ursus arctos*, wolves *Canis lupus* and Eurasian lynx *Lynx lynx*) are listed in the annexes of EC Directive 92/43/EEC (Habitats Directive) as species whose conservation requires the designation of special areas of conservation (Annex II) and which need strict protection (Annex IV). All members of the European Union have to transpose and apply Habitats Directive through the development of national legislation. In order to assist the Member States in the implementation of the Habitats Directive, the European Commission has developed the LIFE program (L'Instrument Financier pour l'Environnement), a financial instrument supporting, in its Nature and Biodiversity component (http://ec.europa.eu/environment/life/about/index.htm), the development of projects aimed at conserving habitats and species.

Since 1992, when LIFE program started, the EC has provided over 17 million euros to co-fund 29 projects aimed at wolf conservation within the European borders (Salvatori 2013). Among these projects, 19 took place in Italy and have focused mainly on three aspects: habitat quality/food availability, economic conflicts (livestock damage) and negative perception. Some of these projects ('Coex' LIFE04 NAT/IT/000144, 'Ex-Tra' LIFE07 NAT/IT/000502, 'Wolfnet' LIFE08 NAT/IT/000325, 'Medwolf' LIFE11 NAT/IT000069, 'Praterie' LIFE11 NAT/IT/000234) promoted coexistence of large carnivores and livestock activities. They contributed to wolf-livestock conflict resolution showing that prevention measures can be both successful and feasible, encouraging collaboration with stakeholders, introducing new methodologies to verify livestock depredations, improving the attitude towards large carnivores and emphasizing the potential economic benefit of conserving large and charismatic predators.

Since 2010, the province of Grosseto joined two Life projects related to the implementation of wolf conservation measures: Ibriwolf (LIFE10 NAT/IT/000265) focused on the hybridization between wolves and domestic dogs, and Medwolf (LIFE11 NAT/IT000069) aimed to decrease the conflict between the wolf's presence and human activities in rural areas where cultural tradition of coexistence with predators is lost. Besides other advantages, Ibriwolf allowed to monitor the wolf population in Grosseto province and to increase the awareness on a responsible dog management in rural areas. Medwolf is promoting the correct use of preventive measures and awareness campaigns for the general public and livestock owners on the ways of coexistence between the wolf and human activities. Both the Life projects set the stage for a project implemented by Tuscany Region: "*Attuazione di interventi in materia di conservazione del lupo (Canis lupus) e prevenzione/riduzione delle predazioni in Toscana*", aimed to wolf-livestock conflict resolution. The continuing presence of this kind of initiatives is keeping the wolf-human coexistence issue in the public and farmers eye, facilitating the change in general attitude toward wolves.

Aim and objectives

Considering that most of the wolf populations in Europe are recovering (Chapron et al. 2014), the conflict with livestock activities is expected to increase. Where large carnivores have been absent for a long time, as in Grosseto province, many farmers are not prepared to face predators.

The primary goal of my research was to give new insights on how to improve damage prevention in order to mitigate wolf-livestock conflict. All preventive measures have actually limited effectiveness, thus a better understanding of the circumstances in which depredation occur can be helpful to overcame their limits (Bradley and Pletscher 2005).

More specifically my work has been developed on three objectives:

1. Predicting where depredations are likely to occur in order to provide a chance for early warning and target appropriate preventive measures into the correct areas
2. Assessing the variables that influence the spatial association between livestock guarding dogs and flock
3. Assessing the local conditions that can limit the effectiveness of using livestock guarding dogs

References

Ahmadi, M., López-Bao, J.V. and Kaboli, M., 2014. Spatial heterogeneity in human activities favors the persistence of wolves in agroecosystems. PloS one, 9(9), p.e108080.

Ashcroft, N. K., C. P. Mathis, S. T. Smallidge, J. M. Fowler, And T. T. Baker. 2010. Reestablishment of the Mexican gray wolf: the economics of depredation. Las Cruces, NM, USA: New Mexico State University, Range Improvement Task Force. Report 80. 16 p.

Bangs, E.E., Fontaine, J.A., Jimenez, M.D., Meier, T.J., Bradley, E.H., Niemeyer, C.C., Smith, D.W., Mack, C.M., Asher, V. and Oakleaf, J.K., 2005. Managing wolf-human conflict in the northwestern United States. CONSERVATION BIOLOGY SERIES-CAMBRIDGE-, 9, p.340.

Banti, P., Bartolozzi, L., Cavallini, P. 2005. La gestione del lupo in Toscana. Grandi Carnivori e Zootecnia tra conflitto e coesistenza. Biol. Cons. Fauna 115: 98-102

Barnes, B. M. 2015. Livestock Management for Coexistence with Large Carnivores , Healthy Land and Productive Ranches. Keystone Conservation Bozeman, Montana, USA.

Behdarvand, N., Kaboli, M., Ahmadi, M., Nourani, E., Mahini, A.S. and Aghbolaghi, M.A., 2014. Spatial risk model and mitigation implications for wolf–human conflict in a highly modified agroecosystem in western Iran. Biological Conservation, 177, pp.156-164.

Boitani L., Fabbri M. L. 1983. Strategia nazionale di conservazione del lupo (Canis lupus). Ric. Biol. Selv. 72: 1-31.

Boitani, L. and Linnell, J.D., 2015. Bringing large mammals back: large carnivores in Europe. In Rewilding European Landscapes (pp. 67-84). Springer International Publishing.

Boitani, L., 2000. Action plan for the conservation of wolves in Europe (Canis lupus)., (No. 18-113). Council of Europe.

Boitani, L., Ciucci, P. and Raganella-Pelliccioni, E., 2010. Ex-post compensation payments for wolf predation on livestock in Italy: a tool for conservation?. Wildlife Research, 37(8), pp.722-730.

Boscagli G., Vielmi L., Tribuzi S., Martina A., Cini N. 2006. Stima del numero minimo di lupi con il metodo dell'ululato indotto. In: Lovari S. e Sangiuliano A. 2006. Il lupo sul Monte Amiata. Progetto sui Grandi Canidi (Lupo, Cane) nel territorio dell'Amiata Grossetano e Senese. Relazione Tecnica. Ministero dell'Ambiente, Comunità Montana Amiata Grossetano.

Bradley E. H., Pletscher D. H. 2005. Assessing factors related to wolf depredation of cattle in fenced pastures in Montana and Idaho. Wildlife Society Bulletin, 33(4), 1256-1265.

Bradley, E.H., Pletscher, D.H., Bangs, E.E., Kunkel, K.E., Smith, D.W., Mack, C.M., Meier, T.J., Fontaine, J.A., Niemeyer, C.C. and Jimenez, M.D., 2005. Evaluating wolf translocation as a nonlethal method to reduce livestock conflicts in the northwestern United States. Conservation Biology, 19(5), pp.1498-1508.

Braschi C., Boitani L. 2013. Risultati delle analisi genetiche. Relazione finale. Azione A3. Progetto Life Ibriwolf (LIFE10NAT/IT/265).

Breck, S., Clark, P., Howery, L., Johnson, D., Kluever, B., Smallidge, S. and Cibils, A., 2012. A perspective on livestock–wolf interactions on western rangelands. Rangelands, 34(5), pp.6-11.

Caporioni, M. and Teofili, C.2005. Conflitti tra carnivori e zootecnia, indagine sull'utilizzo dei sistemi di prevenzione dei danni nei progetti Life. Grandi Carnivori e Zootecnia tra conflitto e coesistenza. Biol. Cons. Fauna 115: 74-88

Chapron G., Kaczensky P., Linnell J. D., Von Arx M., Huber D., Andrén H., ... & Nowak S. 2014 Recovery of large carnivores in Europe's modern human-dominated landscapes, Science, 346(6216), 1517-1519.

Chapron, G. and Treves, A., 2016. Data from: Blood does not buy goodwill: allowing culling increases poaching of a large carnivore.

Ciucci, P., Boitani, L., Francisci, F. and Andreoli, G., 1997. Home range, activity and movements of a wolf pack in central Italy. Journal of Zoology, 243(4), pp.803-819.

Ciucci P., Boitani L. 1998. Wolf and dog depredation on livestock in central Italy. Wildl. Soc. Bull. 26, 504–514.

Ciucci, P. and Boitani, L.2005. Conflitto tra lupo e zootecnia in Italia: stato delle conoscenze, ricerca e conservazione. Grandi Carnivori e Zootecnia tra conflitto e coesistenza. Biol. Cons. Fauna 115: 26-52

Coppinger, R. and Coppinger, L. 1980. Livestock-guarding dogs. Country Journal 7(4):68-77.

Coppinger, R. and Coppinger, L. 2005. Livestock Guarding Dogs: from the Transhumance to Pre-Zygotic Selection. Carnivore Damage Prevention News, 9, pp.2-8.

Coppinger, R. and Schneider, R., 1995. Evolution of working dogs. The domestic dog: Its evolution, behaviour and interactions with people, pp.21-47.

Cozza, K., Fico, R., Battistini, M.L. and Rogers, E., 1996. The damage-conservation interface illustrated by predation on domestic livestock in central Italy. Biological Conservation, 78(3), pp.329-336.

Diamond, J., 2002. Evolution, consequences and future of plant and animal domestication. Nature, 418(6898), pp.700-707.

Dickman, A.J., 2010. Complexities of conflict: the importance of considering social factors for effectively resolving human–wildlife conflict. Animal conservation, 13(5), pp.458-466.

Dickman, A.J., Macdonald, E.A. and Macdonald, D.W., 2011. A review of financial instruments to pay for predator conservation and encourage human–carnivore coexistence. Proceedings of the National Academy of Sciences, 108(34), pp.13937-13944.

Duffield, J.W., Neher, C.J. and Patterson, D.A., 2008. Wolf recovery in Yellowstone Park: Visitor attitudes, expenditures, and economic impacts. Yellowstone Science, 16(1), pp.20-25.

Espuno, N., Lequette, B., Poulle, M.L., Migot, P. and Lebreton, J.D., 2004. Heterogeneous response to preventive sheep husbandry during wolf recolonization of the French Alps. Wildlife Society Bulletin, 32(4), pp.1195-1208.

Fernández-Gil, A., Naves, J., Ordiz, A., Quevedo, M., Revilla, E. and Delibes, M., 2016. Conflict Misleads Large Carnivore Management and Conservation: Brown Bears and Wolves in Spain. PloS one, 11(3), p.e0151541.

Fritts, S. H. 1982. Wolf predation on livestock in Minnesota.United States Fish and Wildlife Service Resource Publication 145:1-11.

Fritts, S.H., Paul, W.J., Mech, L.D. and Scott, D.P., 1992. Trends and management of wolf-livestock conflicts in Minnesota (No. 181). US Fish and Wildlife Service.

Fritts, S.H., Stephenson, R.O., Hayes, R.D. and Boitani, L., 2003. Wolves and humans. Wolves: Behavior, Ecology and Conservation. The University of Chicago Press, Chicago and London.

Fourli, M., 1999. Compensations for Damage Caused by Bears and Wolves in the European Union: Experiences from LIFE-Nature Projects. Office for Official Publications of the European Communities.

Gallo O., Pagliaroli D., Zingaro M. 2015. Valutazione ex post della presenza di canidi vaganti (lupi, ibridi e cani randagi) nella Provincia di Grosseto. Azione E2. Progetto Life Ibriwolf (LIFE10NAT/IT/265).

Garde, L. 2015. Sheep farming in France: facing the return of the wolf'. Carnivore Damage Prevention News, 11, pp.17-27.

Gazzola, A., Bertelli, I., Avanzinelli, E., Tolosano, A., Bertotto, P. and Apollonio, M., 2005. Predation by wolves (Canis lupus) on wild and domestic ungulates of the western Alps, Italy. Journal of Zoology, 266(02), pp.205-213.

Gazzola A., Viviani A. (a cura di). 2006. Indagine sulla presenza storica e attuale del lupo in Toscana. Regione Toscana.

Gazzola, A., Capitani, C., Mattioli, L. and Apollonio, M., 2008. Livestock damage and wolf presence. Journal of Zoology, 274(3), pp.261-269.

Genovesi, P., 2002. Piano d'azione Nazionale per la Conservazione del Lupo (Canis lupus).

Genovesi, P. 2005. Mitigazione del conflitto e politiche di conservazione dei grandi carnivori in Italia. Grandi Carnivori e Zootecnia tra conflitto e coesistenza. Biol. Cons. Fauna 115: 21-26.

Genovesi, P., Angelini, P., Bianchi, E., Dupré, E., Ercole, S., Giacanelli, V., Ronchi, F. and Stoch, F., 2014. Specie e habitat di interesse comunitario in Italia: distribuzione, stato di conservazione e trend. ISPRA, Serie Rapporti, 194, p.2014.

Graham, K., Beckerman, A.P. and Thirgood, S., 2005. Human–predator–prey conflicts: ecological correlates, prey losses and patterns of management. Biological Conservation, 122(2), pp.159-171.

Gula, R., 2008. Wolf depredation on domestic animals in the Polish Carpathian Mountains. The Journal of wildlife management, 72(1), pp.283-289.

Honey, M. and Krantz, D., 2007. Global trends in coastal tourism. Washington DC: Center on Ecotourism and Sustainable Development.

Howery, L.D. and DeLiberto, T.J., 2004. Indirect effects of carnivores on livestock foraging behavior and production.

http://ec.europa.eu/environment/life/about/index.htm, 30 Nov. 2016.

Iliopoulos, Y., Sgardelis, S., Koutis, V. and Savaris, D., 2009. Wolf depredation on livestock in central Greece. Acta theriologica, 54(1), pp.11-22.

Jędrzejewski, W., Jędrzejewska, B., Zawadzka, B., Borowik, T., Nowak, S. and Mysłajek, R.W., 2008. Habitat suitability model for Polish wolves based on long-term national census. Animal Conservation, 11(5), pp.377-390.

Kaczensky, P., 1996. Livestock-carnivore conflicts in Europe. Munich Wildlife Society.

Kaartinen, S., Luoto, M. and Kojola, I., 2009. Carnivore-livestock conflicts: determinants of wolf (Canis lupus) depredation on sheep farms in Finland. Biodiversity and Conservation, 18(13), pp.3503-3517.

Kolowski, J.M. and Holekamp, K.E., 2006. Spatial, temporal, and physical characteristics of livestock depredations by large carnivores along a Kenyan reserve border. Biological conservation, 128(4), pp.529-541.

Laporte, I., Muhly, T.B., Pitt, J.A., Alexander, M. and Musiani, M., 2010. Effects of wolves on elk and cattle behaviors: implications for livestock production and wolf conservation. PLoS One, 5(8), p.e11954.

Lehmkuhler, J., Palmquist, G., Ruid, D., Willging, B. and Wydeven, A., 2007. Effects of wolves and other predators on farms in Wisconsin: beyond verified losses. Pub-ER-658.

Lescureux, N. and Linnell, J. D. C. 2014. Warring brothers: The complex interactions between wolves (Canis lupus) and dogs (Canis familiaris) in a conservation context. Biological Conservation. doi: 10.1016/j.biocon.2014.01.032.

Li, X., Buzzard, P., Chen, Y. and Jiang, X., 2013. Patterns of livestock predation by carnivores: human–wildlife conflict in Northwest Yunnan, China. Environmental management, 52(6), pp.1334-1340.

Linnell, J.D., Odden, J. and Mertens, A., 2012. Mitigation methods for conflicts associated with carnivore depredation on livestock. Carnivore ecology and conservation: a handbook of techniques, pp.314-332.

Linnell, J.D.C. and Lescureux, N. 2015. Livestock guarding dogs-cultural heritage icons with a new relevance for mitigating conservation conflicts. Norwegian Institute for Nature Research, Trondheim.76pp.

Linnell, J.D.C., Smith, M.E., Odden, J., Kaczensky, P. and Swenson, J.E., 1996. Strategies for the reduction of carnivore-livestock conflicts: a review. Nina Oppdragsmelding, 443(1), p.188.

Linnell, J.D., Aanes, R., Swenson, J.E., Odden, J. and Smith, M.E., 1997. Translocation of carnivores as a method for managing problem animals: a review. Biodiversity & Conservation, 6(9), pp.1245-1257.

Llaneza, L., López-Bao, J.V. and Sazatornil, V., 2012. Insights into wolf presence in human-dominated landscapes: the relative role of food availability, humans and landscape attributes. Diversity and Distributions, 18(5), pp.459-469.

López-Bao, J.V., Sazatornil, V., Llaneza, L. and Rodríguez, A., 2013. Indirect effects on heathland conservation and wolf persistence of contradictory policies that threaten traditional free-ranging horse husbandry. Conservation letters, 6(6), pp.448-455.

Lorenz, J. R., and Coppinger, L. 1986. Raising and Training a Livestock guarding Dog. (Oregon State University: Corvallis, OR.).

Lu, W. and Stepchenkova, S., 2012. Ecotourism experiences reported online: Classification of satisfaction attributes. Tourism Management, 33(3), pp.702-712.

Lundmark, C. and Matti, S., 2015. Exploring the prospects for deliberative practices as a conflict-reducing and legitimacy-enhancing tool: the case of Swedish carnivore management. Wildlife Biology, 21(3), pp.147-156.

Madden, F. and McQuinn, B., 2014. Conservation's blind spot: the case for conflict transformation in wildlife conservation. Biological Conservation, 178, pp.97-106.

Madden, F., 2004. Creating coexistence between humans and wildlife: global perspectives on local efforts to address human–wildlife conflict. Human Dimensions of Wildlife, 9(4), pp.247-257.

Manoa, D.O. and Mwaura, F., 2016. Predator-Proof Bomas as a Tool in Mitigating Human-Predator Conflict in Loitokitok Sub-County Amboseli Region of Kenya. Natural Resources, 7(01), p.28.

Marker, L.L., Mills, M.G.L. and Macdonald, D.W., 2003. Factors influencing perceptions of conflict and tolerance toward cheetahs on Namibian farmlands. Conservation Biology, 17(5), pp.1290-1298.

Marucco F., McIntire E. J. B. 2010. Predicting spatio-temporal recolonization of large carnivore populations and livestock depredation risk: wolves in the Italian Alps. Journal of Applied Ecology, 47(4), 789-798.

McManus, J.S., Dickman, A.J., Gaynor, D., Smuts, B.H. and Macdonald, D.W., 2015. Dead or alive? Comparing costs and benefits of lethal and non-lethal human–wildlife conflict mitigation on livestock farms. Oryx, 49(04), pp.687-695.

Mech, L.D., 1995. The challenge and opportunity of recovering wolf populations. Conservation biology, 9(2), pp.270-278.

Mech, L.D., 2001. Managing Minnesota's recovered wolves. Wildlife Society Bulletin, pp.70-77.

Mech L.D., Harper E.K., Meier T.J., Paul W.J. 2000. Assessing factors that may predispose Minnesota farms to wolf depredations on cattle. Wildl. Soc. Bull. 28, 623–629.

Meriggi, A. and Lovari, S., 1996. A review of wolf predation in southern Europe: does the wolf prefer wild prey to livestock?. Journal of applied ecology, pp.1561-1571.

Mertens, A. and Promberger, C., 2001. Economic aspects of large carnivore-livestock conflicts in Romania. Ursus, pp.173-180.

Mignon-Grasteau, S., Boissy, A., Bouix, J., Faure, J.M., Fisher, A.D., Hinch, G.N., Jensen, P., Le Neindre, P., Mormède, P., Prunet, P. and Vandeputte, M., 2005. Genetics of adaptation and domestication in livestock. Livestock Production Science, 93(1), pp.3-14.

Mishra, C., Allen, P., McCarthy, T.O.M., Madhusudan, M.D., Bayarjargal, A. and Prins, H.H., 2003. The role of incentive programs in conserving the snow leopard. Conservation Biology, 17(6), pp.1512-1520.

Muhly, T.B. and Musiani, M., 2009. Livestock depredation by wolves and the ranching economy in the Northwestern US. Ecological Economics, 68(8), pp.2439-2450.

Musiani, M. and Visalberghi, E., 2001. Effectiveness of fladry on wolves in captivity. Wildlife Society Bulletin, pp.91-98.

Musiani, M., Mamo, C., Boitani, L., Callaghan, C., Gates, C.C., Mattei, L., Visalberghi, E., Breck, S. and Volpi, G., 2003. Wolf depredation trends and the use of fladry barriers to protect livestock in western North America. Conservation Biology, 17(6), pp.1538-1547.

Musiani, M., Muhly, T., Gates, C.C., Callaghan, C., Smith, M.E. and Tosoni, E., 2005. Seasonality and reoccurrence of depredation and wolf control in western North America. Wildlife Society Bulletin, 33(3), pp.876-887.

Namgail, T., Fox, J.L. and Bhatnagar, Y.V., 2007. Carnivore-caused livestock mortality in Trans-Himalaya. Environmental Management, 39(4), pp.490-496.

Naughton-Treves, L., Grossberg, R. and Treves, A., 2003. Paying for tolerance: rural citizens' attitudes toward wolf depredation and compensation. Conservation biology, 17(6), pp.1500-1511.

Nowak, S., Mysłajek, R.W. and Jędrzejewska, B., 2005. Patterns of wolfCanis lupus predation on wild and domestic ungulates in the Western Carpathian Mountains (S Poland). Acta theriologica, 50(2), pp.263-276.

Nyhus, P.J., Osofsky, S.A., Ferraro, P., Madden, F. and Fischer, H., 2005. Bearing the costs of human-wildlife conflict: the challenges of compensation schemes. CONSERVATION BIOLOGY SERIES-CAMBRIDGE-, 9, p.107.

Ogada M.O., Woodroffe R., Oguge N.O., Frank L.G., 2003. Limiting depredation by African carnivores: the role of livestock husbandry. Conserv. Biol. 17, 1521–1530.

Peterson, R.O. and Ciucci, P., 2003. The wolf as a carnivore. Wolves: behavior, ecology, and conservation. University of Chicago Press, Chicago, pp.104-130.

Peterson, M.N., Peterson, M.J., Peterson, T.R. and Leong, K., 2013. Why transforming biodiversity conservation conflict is essential and how to begin. Pacific Conservation Biology, 19(2), pp.94-103.

Redpath, S.M., Young, J., Evely, A., Adams, W.M., Sutherland, W.J., Whitehouse, A., Amar, A., Lambert, R.A., Linnell, J.D., Watt, A. and Gutiérrez, R.J., 2013. Understanding and managing conservation conflicts. Trends in Ecology & Evolution, 28(2), pp.100-109.

Reinhardt, I., Rauer, G., Kluth, G., Kaczensky, P., Knauer, F. and Wotschikowsky, U., 2012. Livestock protection methods applicable for Germany–a Country newly recolonized by wolves. Hystrix, the Italian Journal of Mammalogy, 23(1), pp.62-72.

Rigg, R. 2001. Livestock guarding dogs: their current use worldwide', The Canid Specialist Group, (1), p. 133.

Rigg, R., Find'o, S., Wechselberger, M., Gorman, M.L., Sillero-Zubiri, C. and Macdonald, D.W., 2011. Mitigating carnivore–livestock conflict in Europe: lessons from Slovakia. Oryx, 45(02), pp.272-280.

Ripple, W.J., Estes, J.A., Beschta, R.L., Wilmers, C.C., Ritchie, E.G., Hebblewhite, M., Berger, J., Elmhagen, B., Letnic, M., Nelson, M.P. and Schmitz, O.J., 2014. Status and ecological effects of the world's largest carnivores. Science, 343(6167), p.1241484.

Robinson, H.S., Wielgus, R.B., Cooley, H.S. and Cooley, S.W., 2008. Sink populations in carnivore management: cougar demography and immigration in a hunted population. Ecological Applications, 18(4), pp.1028-1037.

Romanach, S.S., Lindsey, P.A. and Woodroffe, R., 2007. Determinants of attitudes towards predators in central Kenya and suggestions for increasing tolerance in livestock dominated landscapes. Oryx, 41(02), pp.185-195.

Sacks, B.N., Blejwas, K.M. and Jaeger, M.M., 1999. Relative vulnerability of coyotes to removal methods on a northern California ranch. The Journal of wildlife management, pp.939-949.

Salvatori, V., 2013. Large carnivore conservation and management in Europe: the contribution of EC co-funded LIFE projects. Istituto di Ecologia Applicata, Rome, Italy.

Sangay, T. and Vernes, K., 2008. Human–wildlife conflict in the Kingdom of Bhutan: patterns of livestock predation by large mammalian carnivores. Biological Conservation, 141(5), pp.1272-1282.

Santilli, F. and Varuzza, P., 2013. Factors affecting wild boar (Sus scrofa) abundance in southern Tuscany. Hystrix, the Italian Journal of Mammalogy, 24(2), pp.169-173.

Schwerdtner, K. and Gruber, B., 2007. A conceptual framework for damage compensation schemes. Biological Conservation, 134(3), pp.354-360.

Shivik, J.A., 2006. Tools for the edge: what's new for conserving carnivores. BioScience, 56(3), pp.253-259.

Sillero-Zubiri, C., Reynolds, J. and Novaro, A.J., 2004. Management and control of wild canids. The biology and conservation of wild canids, p.107.

Steele J. R., Rashford B. S., Foulke T. K., Tanaka J. A., Taylor D. T. 2013. Wolf (Canis lupus) predation impacts on livestock production: direct effects, indirect effects, and implications for compensation ratios. Rangeland Ecology and Management, 66(5), 539-544.

Tedesco, E. and Ciucci, P. 2005. Monitoraggio dell'efficienza dei cani da guardiania: applicazione preliminare sui cani dati in affidamento nell'arco alpino. Grandi Carnivori e Zootecnia tra conflitto e coesistenza. Biol. Cons. Fauna 115: 181-190

Theuerkauf, J., Jędrzejewski, W., Schmidt, K., Okarma, H., Ruczyński, I., Śniezko, S. and Gula, R., 2003. Daily patterns and duration of wolf activity in the Białowieza Forest, Poland. Journal of Mammalogy, 84(1), pp.243-253.

Treves, A. and Karanth, K.U., 2003. Human-carnivore conflict and perspectives on carnivore management worldwide. Conservation Biology, 17(6), pp.1491-1499.

Treves, A., Naughton-Treves, L., Harper, E.K., Mladenoff, D.J., Rose, R.A., Sickley, T.A. and Wydeven, A.P., 2004. Predicting human-carnivore conflict: A spatial model derived from 25 years of data on wolf predation on livestock. Conservation Biology, 18(1), pp.114-125.

Treves, A. and Naughton-Treves, L. 2005. Evaluating lethal control in the management of human-wildlife conflict. CONSERVATION BIOLOGY SERIES-CAMBRIDGE-, 9, p.86.

Treves, A., Martin, K.A., Wydeven, A.P. and Wiedenhoeft, J.E., 2011. Forecasting environmental hazards and the application of risk maps to predator attacks on livestock. BioScience, 61(6), pp.451-458.

Valière, N., Fumagalli, L., Gielly, L., Miquel, C., Lequette, B., Poulle, M.L., Weber, J.M., Arlettaz, R. and Taberlet, P., 2003. Long-distance wolf recolonization of France and Switzerland inferred from non-invasive genetic sampling over a period of 10 years. Animal Conservation, 6(1), pp.83-92.

Van Bommel, L., and Johnson, C. N. 2012. Good dog! Using livestock guardian dogs to protect livestock from predators in Australia's extensive grazing systems. Wildlife Research, 39(3), 220-229.

van Liere, D., Dwyer, C., Jordan, D., Premik-Banič, A., Valenčič, A., Kompan, D. and Siard, N., 2013. Farm characteristics in Slovene wolf habitat related to attacks on sheep. Applied Animal Behaviour Science, 144(1), pp.46-56.

Vilà, C., Urios, V. and Castroviejo, J., 1995. Observations on the daily activity patterns in the Iberian wolf. Ecology and conservation of wolves in a changing world. Occasional Publication, (35), pp.335-340.

Woodroffe R., Frank L., Lindsey P., ole Ranah S., Romañach S. 2007. Livestock husbandry as a tool for carnivore conservation in Africa's community rangelands: a case–control study. Biodivers. Conserv. 16, 1245–1260.

Young, J.K., Ma, Z., Laudati, A. and Berger, J., 2015. Human–Carnivore Interactions: Lessons Learned from Communities in the American West. Human Dimensions of Wildlife, 20(4), pp.349-366.

Zabel, A. and Roe, B., 2009. Optimal design of pro-conservation incentives. Ecological Economics, 69(1), pp.126-134.

Zarco-González M. M., Monroy-Vilchis O., Rodríguez-Soto C., Urios V. 2012. Spatial factors and management associated with livestock predations by Puma concolor in Central Mexico. Human ecology, 40(4), 631-638.

Zarco-González M. M., Monroy-Vilchis O., Alaníz J. 2013. Spatial model of livestock predation by jaguar and puma in Mexico: Conservation planning. Biological Conservation, 159, 80-87.

CHAPTER 2

ASSESSING WILD CANID DEPREDATION RISK USING A NEW THREE-STEP METHOD: THE CASE OF GROSSETO PROVINCE (TUSCANY, ITALY)*

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Abstract

The recovery of large carnivores in human dominated landscapes can cause controversy and concern for livestock producers, especially where wild predator populations and farmland overlap. This is the case in the Grosseto province, located in the southern part of Tuscany, Italy. Anticipating where predator attacks are likely to occur can help focus mitigation efforts. We suggest a three-step method to predict wild canid depredation risk using presence-only data on wild canid detections and confirmed depredation events in the study area. We obtained the probability of occurrence for canids and depredation events based on ecological variables and then performed an ensemble model following an ad-hoc procedure. We compared models' outputs obtained from two different approaches to species distribution modeling: Maximum Entropy (Maxent) and Bayesian for Presence-only Data (BPOD) testing their ability to predict the occurrence of events. The ecological niche factor analysis (ENFA) was used to assess the importance of each environmental variable in the description of the presence points. Forested areas were identified as the most important attribute predicting wild canid occurrence. Livestock predation was most likely to occur close to farms where sheep densities were higher and more accessible. Higher depredation risk zones were characterized by proximity to forested areas and the presence of landscape features that allowed wild canids to reach pastures with minimum effort such as the network of smaller watercourses. Only 15% of the total sheep farms fall within higher risk areas, indicating that depredation was facilitated by environmental conditions (e.g. closeness to the woods) rather than the availability of prey. Overall BPOD performed better than Maxent in terms of sensitivity, suggesting that BPOD could be a promising approach to predict probability of occurrence using presence-only data.

Key words: *Depredation risk, Wild canid, BPOD, Maxent, Presence-only data*

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Introduction

The wolf (*Canis lupus*) is one of the world's most widely distributed mammals, but its former range has been drastically reduced by human persecution. In recent decades, many wolf populations have been recovering, expanding close to human activities (Chapron et al. 2014). Various environmental features are known to facilitate the recolonization by wolves such as forest cover, prey availability or low density of infrastructures (Corsi et al. 1999; Gazzola et al. 2008; Llaneza et al. 2012; Lesmerises et al. 2012; Falcucci et al. 2013). Some of these features characterize the Grosseto Province, located in the southern part of the Tuscany Region in central Italy, where a permanent presence of wolves was recorded since the '80s (Boitani and Fabbri 1983; Boscagli et al. 2006; Gazzola et al. 2006). More recently the wolf population in the study area was found to include several wolf-dog hybrids (Braschi and Boitani 2013; Gallo et al. 2015); for this reason hereafter we refer to these animals as wild canids. Food requirement and wide-ranging behavior of large carnivores often bring them to kill domesticated ungulates when opportunities arise (Karanth et al. 1999; Polisar 2000). This is particularly true where wild canid populations and farming ranges overlap, as in the Grosseto Province.

Depredations compromise the economic security of local farmers, and increase negative attitude towards wolves promoting human-carnivore conflict, and thus counteracting the efforts made to promote large carnivore conservation. For this reason it is important to effectively prevent the (canid) attacks. With this aim, it is useful to predict areas in which human-carnivore conflict is likely to arise, and focus interventions in the small subset of areas that could be affected (Treves et al. 2004). Previous research identified husbandry practices, human activities, and carnivore behaviors as predictors of conflict risk (Jackson and Nowell 1996; Linnell et al. 1999). The relationship between wolf distribution and livestock losses was observed in many studies (Treves et al. 2004; Kolowski and Holekamp 2006). In addition, several other factors may affect livestock depredation including predator–prey dynamics (Treves et al. 2004; Valeix et al. 2012), the quality of livestock husbandry (Ogada et al. 2003; Woodroffe et al. 2007), the number of livestock (Gunson 1983; Ciucci and Boitani 1998), the presence of sick or pregnant animals left to roam far from humans or buildings, and the presence of carcasses left exposed (Mech et al. 2000; Bradley and Pletscher 2005). Moreover, some researchers suggested that the repetition of attacks on a few farms, disregarding farm density, indicates that the severity of depredation could be linked to the accessibility to domestic animals (Gazzola et al. 2008). To date, there is a lack of studies that assess the influence of ecological variables (EVs) on the risk of depredation in a broad sense. Understanding the EVs related to a higher risk of depredation makes it possible to forecast the spatial distribution of future depredation events, allowing to protect both local communities and large carnivores, especially in areas where the human-carnivore conflict is high (Murphy and Macdonald 2010). Previous studies on depredations conducted in Italy adopted mainly a qualitative approach in order to evaluate the level of conflict (Ciucci et al. 2005), assess the costs of environmental compensation and the losses in terms of animals killed during attacks (Ciucci and Boitani 1998; Boitani et al. 2011), and estimate the effectiveness and cost-benefit of preventive measures (Rondinini and Boitani 2007; Dalmasso et al. 2011).

In this research, we focus on livestock depredation by wild canid adopting an analytical method, investigating the main ecological features that expose a farm to depredation events. Our goal is to provide a risk map of the Grosseto Province, which can be used to anticipate the spatial location of conflict and suggest suitable preventive measures. We use presence-only data referred to wolf occurrence and confirmed depredation events in the study area to further understand the dynamics of large carnivore depredation in the Grosseto Province. How effectively depredation risk can be predicted from EVs was examined comparing two different approaches to species distribution modeling: Maximum Entropy (Phillips et al. 2006), and Bayesian for Presence-only Data (Tonini et al. 2014; Divino et al. 2015). We tested the effectiveness of these two methods in predicting the occurrence of events with different frequency distributions: the presence of wild canids, and the presence of wild canid depredation events. Finally, we developed a simple method to evaluate the predation risk based on the above-cited models' output.

Materials and Methods

Study area

The Grosseto Province is located in the southern part of the Tuscany Region, Italy, with an area of 4,504 km^2. With only five residents per square kilometer, Grosseto is among the Italian provinces with the smallest population densities. Apart from Mt. Amiata (1,738m asl) and the mountainous group of Colline Metallifere (1,060m asl) in the northern part, the Province is hilly country. The climate of the region is mainly Mediterranean, with continental traits on reliefs. The landscape is a mosaic of extensive cultivation, shrubs, fallows, pastures; woods dominated by holm oak (*Quercus ilex*), cork oak (*Quercus suber*), and beech (*Fagus sylvatica*) in mountainous areas (Selvi 2010). Wolf wild prey include abundant populations of wild boar (*Sus scrofa*), roe deer (*Capreolus capreolus*), and fallow deer (*Dama dama*).

Husbandry practices and human-predator conflict

The Grosseto Province has been shaped by agriculture and farming which play an important role in the local economy mainly related to dairy products and tourism. The most recent census (2014) reports 1,150 sheep farms (please see Supplemental Figure S1) with 19,4422 sheep (data BDN, national livestock database). 95% of sheep and goat farms raise flocks outdoors or extensively on pastures (data BDN, national livestock database). Often these grazing areas are bordered by fences about one meter high that are not able to protect livestock from depredation because predators can cross them easily. At night, the animals are returned to the stables, or in other enclosures in the proximity of the farm except during the summer months, when it is too hot to leave them out in the sun during the day. In recent years more and more breeders are adopting guarding dogs as a defense against attacks of wild canid species.

Wild canid presence data

Locations of wild canid presence were collected as part of the project Life Ibriwolf (LIFE 10/NAT/IT/265), using two complementary techniques: camera trapping, and genetic sampling (Manghi et al. 2012; Braschi and Boitani 2013; Gallo et al. 2015). Between June 30 and October 31, 2014, a survey was carried out using infrared camera traps (Multipir, IR and IR plus BF 110°). 34 trapping sites out of 49 revealed the presence of wolves or wolf-dog hybrids and thus were selected for this study. The genetic sampling of wolves/hybrids was made analyzing the DNA found in scats collected on defined circuits throughout the entire territory of the Grosseto province between June 1 and October 31, 2014. 39 genetic samples assigned genetically to wolves and wolf-dog hybrid populations were used to build the wild canid presence model. Overall, 73 presence-only data were used for wild canid distribution model.

Depredation data

Locations of depredation events were obtained from 140 surveys in farms which had claimed an attack by predators between May 2014 and March 2015. Depredations were verified applying a specific protocol (Argenio 2014), by trained veterinarians commissioned by the province of Grosseto as part of the project Life Medwolf (LIFE 11/NAT/IT/069). In the model, depredations from canids, even in those where distinctions between dogs and wolves could be misleading, were included. Indeed, the aim was to highlight the ecological characteristics that increase the vulnerability of farms with respect to canid attacks. Overall, 71 predations attributed to wolf or dogs were included in the depredation occurrence model.

Ecological Variables

We considered a set of variables potentially important in determining the distribution of wolves and livestock depredation events in a human-dominated hilly countryside landscape like the Grosseto Province (Tab. 1). In order to quantify the ecological variables associated with depredation sites and wild canid localizations, we overlapped the study area with a grid, utilizing both 12.56 km^2 and 3.14 km^2 rectangular cells. We chose the dimension of the cells considering the wolves' perception of the environment on a landscape-wide scale (Falcucci et al. 2013). The choice of two different cell sizes in the early steps of analysis allowed us to evaluate the most appropriate measure of the grid to use without losing too much detail or significance in predictions. The grid with cells 3.14 km^2 wide was considered the best option looking at the Probability of Detection (POD) score, expressed by the percentage of correctly predicted occurrences in the sample. Larger cell sizes would include in several cells a relatively large number of observed presence, leading to a consistent loss of information.

We considered three classes of variables to fit the wild canid distribution model and estimate the probability of occurrence: land use, anthropogenic factors, and waterways. The density of wild prey was not considered, as it was assumed to be even within the study area by referring to some previous surveys (AA.VV. 2012; Santilli and Varuzza 2013). Since the Grosseto province is mostly flat with gentle hills, the topography should not influence considerably wolves' movements, thus it was not taken into account. We obtained land cover, with a 50 m resolution, from Corine Land Cover database (Corine Land Cover 2012). Land use classes were grouped into six categories considered influential for the ecology of the wolf in a human dominated landscape (Tab. 1). To account for anthropogenic factors, we considered the distance from the infrastructures, and the road density within the cells. The map of the road networks was supplied by the Province of Grosseto, while to account for waterways, we obtained the drainage network from the regional cartography produced by the Province of Grosseto.

We predicted where depredation events were more likely to occur, considering four classes of variables: canopy, anthropogenic factors, domestic prey availability, and accessibility to livestock. To account for canopy we considered the distance to nearest forest edges and waterways. Forests were extracted from land cover. To account for anthropogenic factors, we considered paved and gravel road density for each cell. We obtained domestic prey availability from the national livestock census data (BDN 2014). We also considered the distance to the closest sheep farm, and the sheep density in each cell. To account for accessibility to livestock we evaluated the cost distance to reach the nearest predation point. Since the fencing system commonly used in the study area cannot be considered a real barrier for wolves, which can easily cross them, we supposed that some environmental features, such as land cover or roadways may play, instead, a primary role in orienteering wolf movements toward available domestic prey (Llaneza et al. 2012; Valeix et al. 2012; Ahmadi et al. 2014). We created a layer of the cost distance values for all cells, scoring different landscape variables for their expected relation with wolf movements. Based on the published literature we assigned each cell a value from 1 to 10, indicating increasing impediment to cross the cell. To define the value of this cost, we used three variables: land cover type, watercourses (primary, secondary and higher orders) and paved roads (primary, secondary and tertiary). For each cell, we summed the values for each variable. We assumed that all variables had the same relative importance in determining the cost distance (equal weights).

All variables were quantified at cell level on the chosen grid covering the whole area. In detail, the density values refer to the whole cell area, while the distance values refer to the centroid of the cell. Land cover has been assessed as a percentage of each group of land use type within the cell. ArcGIS v. 10.0 (ESRI 2010) was used for all spatially explicit data manipulation and visualization.

[Table 1]

Modeling approach

In order to predict the probability of presence of both canids, and livestock depredation events, two modeling approaches were considered: Maximum Entropy (Phillips et al. 2006) and Bayesian for Presence Only Data (Tonini et al 2014; Divino et al. 2015). Furthermore, the ecological niche factor analysis (Hirzel et al. 2002) was used to assess the importance of each environmental variable in the description of the presence points.

As a first step, before implementing our new three steps method, we performed a depredation risk model using both Maximum Entropy (Maxent) and Bayesian for Presence Only Data (BPOD). We included as a variable the wild canid probability of occurrence along with the ecological variables used to predict the occurrence of depredation events. Through this approach we obtained low and homogenous depredation risk values and a negative correlation between the occurrence of depredation and the canid presence which is not realistic and therefore was rejected. Hence, we used a new method to assign to the study area a probability of predation risk, adopting a three-step procedure. In the first two steps we obtained the probability of occurrence for canids and depredation events using only the EVs and then we performed an ensemble model using both Maxent and BPOD approaches, starting from the definition of risk as the product of hazard and vulnerability. The depredation risk was quantified using the following procedure: first we assigned a priori a risk equal to zero to all the cells with very little sheep density and areas with an estimated probability of wild canid occurrence too small; then in the remaining cells we multiplied the values of canid probability of occurrence (hazard) with the values of depredation probability (vulnerability). Specifically a risk equal to zero was assigned to a cell 1) when the sheep density was lower than 1/km^2 and the depredation probability of occurrence was below the threshold (0.3 for Maxent and 0.47 for BPOD), or 2) when the canid probability of occurrence was below the threshold (0.3 for Maxent and 0.6 for BPOD) and the depredation probability of occurrence was above the aforementioned threshold.

Thresholds have been chosen on the basis of the obtained probability distributions (described by their histograms) of depredation events and canid occurrences in order to get their prevalence in the study area comparable between the BPOD and Maxent estimated maps. However, different thresholds are possible if we consider separately the two approaches (Maxent or BPOD). We performed a sensitivity analysis, first to compare the two approaches and define which was the most suitable for the final risk map; second to assess how the results change according to threshold setting criteria.

Maximum entropy approach

Maxent is a way to model species distributions from presence-only data (Phillips et al. 2006). It is based on machine learning concepts, although it can be viewed as the model that, using the Bayes' rule, minimizes the relative entropy between two probability densities: one estimated from the presence data, and one from the landscape. Its implementation involves the choices of several quantities such as the prevalence of the occurrences (the proportion of occupied sites by the species) and the number of background samples. We fixed the first at 0.5 as we had no prior knowledge of the "true" value, and the second at 10,000, the default choice in the software. Among the available outputs we chose the logistic one, since it can be interpreted as probability of presence (Merow et al. 2013). The Maxent models were run in Maximum Entropy Species Distribution Modeling version 3.3.3k.

Bayesian for Presence-only Data approach

The Bayesian Presence-only Data model proposed in Divino et al. (2015) and applied in Tonini et al. (2014) was built introducing a specific correction into a logistic model, similarly to what is proposed in Ward et al. (2009). The latter carried an estimation under a likelihood approach while Divino et al. (2015) adopts a Bayesian approach.

As mentioned, the key point in the BPOD method is the introduction of a specific correction accounting for the peculiar characteristic of presence-only data. In this kind of dataset some occurrence of the species can also be included in the background sample.

This implies that the traditional logistic regression approach, where the response variable Y = 0 marks the absence of an attribute of interest in the population, while Y = 1 denotes the presence of the same attribute, may be misleading. In fact, when presence-only data are considered we do not observe Y, but instead are able to assess information on a naive approximation Z of Y. If Z = 0, then the location is collected from the whole reference population where the observed value is an unknown number that can be 0 (absence), or 1 (presence). If Z = 1, then the location is collected from the sub-population of presence so that Y = 1. In BPOD the introduction of this “stratum” variable Z, allows to define a linear logistic regression, adjusted for presence-only data (Tonini et al. 2014; Divino et al. 2015). The main advantage of the model is that it does not require the a priori knowledge of the occurrences prevalence.

Its estimation requires the use of Monte Carlo Markov Chains algorithm that demands the user to set several quantities, the number of iterations (15,000), the burn-in (10,000), and how many simulated samples to discard to reduce autocorrelation (thinning 5). These values are chosen after inspection of the model’s parameter traces, and an evaluation of their autocorrelation before and after thinning, so to ensure good inferential performances. In the Bayesian setting the choice of prior distributions for model parameters are often highly influential; in this case, all priors are chosen to ensure proper posterior distributions and, at the same time, to guarantee the highest learning from the data. Then priors are all weakly informative distributions as suggested in Divino et al. (2015). The implementation of this model is currently made in C++ and R and is available from the authors upon request.

Ecological Niche Factor Analysis approach

The Ecological Niche Factor Analysis (ENFA) algorithm encompasses species preference for habitat types in two different indices: marginality and specialization. The overall marginality (M) values range from 0 to 1, with large numbers indicating species preference for a particular habitat in relation to the reference set (Hirzel et al. 2002). For each variable, a ‘marginality coefficient’ is also calculated and identifies species preferences for particular environmental features (Hirzel et al. 2002). We set a threshold value (0.5) in order to assess if a variable is strongly preferred (Abade et al. 2014). The overall specialization (S) measures species’ niche extent, with values over 1 indicating some kind of specialization. Moreover, ENFA provides an index of overall species tolerance (T) which ranges from 0 to 1, with values close to 1 indicating that the species tolerates large variations from its optimum conditions (Simard et al. 2009).

Modeling evaluation

Model performance was evaluated following two criteria: prediction accuracy of presence data (sensitivity) using the POD index and ecological realism. We compared the parameter estimates with expected values derived from literature, ecological theory and knowledge of the study area. The comparison across models was made on the basis of POD scores since Maxent model structure differs from BPOD, hence accuracy of fit criteria as AIC or AICc cannot be used (Tonini et al. 2014). Other traditional statistical evaluation metrics such as Cohen's Kappa (Cohen 1960) or the area under the receiver operating characteristic curve (AUC, Hanley and Mcneil 1982) are commonly used with presence-absence (or pseudo-absence) data. However, in this case we do not make any assumption of pseudo-absence for background data. We used ENFA to explore the contributions of the variables in characterizing the locations of observed presence. To assess the importance of the environmental variables in the models we considered the results of jackknife tests in Maxent, while for BPOD we used the significance level of model's parameters, discharging all variables that were not significant at a confidence level of 0.05.

Results

Wild canids distribution model

Relying on POD values, the best performing models included different sets of variables for BPOD and Maxent. For BPOD we considered the percentage of agricultural areas; heterogeneous agricultural areas; forests. For Maxent many more variables were included: paved and gravel road density; distance from primary and secondary watercourses; x and y coordinates; the percentage of open areas, agricultural areas, heterogeneous agricultural areas, forests, shrubs, artificial areas, and wetlands.

Two groups of variables influenced the distribution of wild canids in the opposite way: as expected, the elements related to human settlements have, overall, a negative influence, while features associated to natural environment contribute to increase the habitat suitability. Wetlands do not appear to be part of the ecological niche of wolves and hybrids. Although ENFA showed (please see also Supplemental Table S1) a connection between wild canids' presence and some of the variables, specialization was non relevant (S = 0.86), meaning that wild canids could live in a broad range of different environmental conditions, and could be widely distributed in the area. Wild canids avoid agricultural areas (M = -0.77) and roads (M = -0.70), instead they prefer forest-covered areas (M = 0.78), open areas such as pastures or grasslands (M = 0.71), and places far from primary watercourses (M=0.68). Both BPOD and Maxent, estimated high probability of wild canid occurrence in wooded areas and away from cultivated areas, or areas with an extended primary road network (Fig. 1).

The sensitivity of the best model run with BPOD (POD = 0.76) was greater than that obtained with Maxent approach (POD = 0.66), considering for both a threshold probability of 0.5.

[Figure 1]

Depredation events

The best model for both Maxent and BPOD approach included the following variables: distance from nearest forest edge; farm and sheep density; paved and gravel road density; distance from primary; secondary and tertiary watercourses; accessibility to livestock.

Maxent and BPOD concurred in suggesting that sheep density, accessibility, distance to small rivers, and gravel roads density, are the ecological variables that were more informative on the probability of livestock depredation occurrences. ENFA reveals (please see also Supplemental Table S1) that most of the predation points were located close to farms (M = -0.83) where both sheep density (M=1.08), and sheep and goat farms density (M = 1) are higher. Flocks that were easy to approach, considering vegetation cover and presence of anthropogenic and natural barriers, were selected (M = -1.46). Using these three modeling approaches we can infer that attacks will take places close to small rivers where farms are spread out, the sheep density is high and flocks are reachable with little effort (Fig. 2).

Compared to the wild canid distribution models' results, the prediction for potential livestock depredation areas in relation to specific environmental variables was less precise. The set of environmental variables that plays a role on detecting where livestock predations may occur was rather wide, as showed in ENFA (global marginality=1.39, S = 0.43).

Maxent had a better performance (POD = 0.62) assuming a threshold probability of 0.5, compared to BPOD (POD = 0.51) with a threshold probability of 0.47.

[Figure 2]

Depredation risk

Examining the distributions of canid occurrence in cells with sheep density and probability of livestock depredation events above the limits (Fig. 3), it is clear that Maxent estimated highly variable and very small probability values showing a clear tendency to underestimate the probability of canid occurrences. In comparison, BPOD estimated larger probability values with a more concentrated distribution; it never assigns probability zero of canid occurrence to grid cells verifying the above-mentioned conditions. This model is maybe slightly over estimating the probability of canid presence, however its results are more sensitive to variables included in the model, and more sensible in terms of ecological considerations.

[Figure 3]

The sensitivity of the BPOD model suggested for the final depredation risk map was the highest (POD=0.85) both in comparison to Maxent models, and among the BPOD models with other threshold setting criteria (Tab. 2). Hence, it has been preferred in the building of the depredation risk estimation (but see also Supplemental Figure S2 for the risk map estimated using Maxent).

[Table 2]

Using this model we can predict that some areas located in the central-southern part of the Province and a portion of northern sector, are exposed to higher predation risk (Fig. 4). These areas are characterized by proximity to forested areas and the presence of landscape features that allow wild canids to reach pastures with minimum effort (e.g. small watercourses and absence of paved roads). Only a limited percentage (15%) of the total sheep farms (1,150) fall within higher risk area, suggesting that depredation is facilitated by environmental conditions, rather than by the availability of domestic prey alone.

[Figure 4]

Discussion

According to our results, wild canids are widely distributed in the Grosseto Province. Compared to brown bears and lynx, wolves and wolf-dog hybrids are better adapted to human-dominated landscapes and can persist in areas where mean human density is relatively high (36.7 ±95.5 inhabitants/km^2) (Chapron et al. 2014). Nevertheless, BPOD, Maxent, and ENFA identified forested areas as the most important attribute promoting the wild canid occurrence. Dense vegetation serves as shelter, offers wild prey, and provides security from humans (Llaneza et al. 2012). We also found that wild canids positively select zones that include open areas, where indeed, both wild and domestic ungulates graze.

The human attitude toward wolves is, however, probably one of the most important factors determining wolf distribution (Boitani and Ciucci 1993), but it is a complex variable and its distribution is hard to be mapped (Corsi et al. 1999). Contrary to the suggestion by some authors

(Mladenoff et al. 1995; Corsi et al. 1999), we did not assume human disturbance being density dependent for two reasons: the Grosseto Province has the smallest human population density among the Italian provinces, and secondly, poaching is the primary cause of death for wolves in Italy (Genovesi 2002), occurring mainly in rural areas with fewer people. Therefore, we chose road density, artificial areas, and arable lands as a proxy to anthropic factors, assuming that wild canids simply avoid areas where they could come across humans more easily. Our results may validate this hypothesis showing that these variables were negatively selected. We did not consider wild prey as a significant variable because they are abundant in the study area (Mattioli et al. 2004; Santilli e Varuzza 2013). Moreover, in human-dominated landscapes, factors associated with the security of wolves (refuge) become more important, and food availability is likely to play a secondary role. (Llaneza et al. 2012).

In predicting where sheep farms are more exposed to wild canid depredations, we found that livestock depredations occur close to farms, where sheep are located with higher densities. Larger flocks, in fact, could increase the probability of predation success (Bradley and Pletscher 2005). Nevertheless, livestock accessibility, in line with Ciucci and Boitani's (1998) observations, was the key factor in determining the extent of depredation events. In accordance with our best BPOD model, grazing areas easily reachable by wild canids are more vulnerable, considering that in almost all cases, the fencing system adopted in the study area is inadequate to protect livestock. The structure of wild canid packs within the study area could be an important variable to forecast predation risk (Marucco and McIntire 2010). It can be supposed that stable family groups could have different impacts on livestock depredation compared to wandering dispersers or loners, but we didn't have data to account for this variable.

Several studies quantified the severity of depredation on livestock referring to unconfirmed claims made by livestock producers (Gusset et al 2009; Dar et al. 2009), thus depredation events are frequently overestimated (Zarco-Gonzalez et al. 2012). Only in-field verified data by trained veterinarians were used to build our model of probability of depredation, in order to avoid additional bias. The outputs derived from BPOD probability models of wild canids and depredation occurrence were used to map the spatial distribution of risk: this is helpful to anticipate the locations of human-carnivore conflict and focus interventions in this smaller set of areas. Unlike other studies (Zarco-Gonzalez 2013; Abade et al. 2014) that proposed a risk map based only on the environmental features of the sites where predation on livestock is present, we suggest a risk map considering both the environmental conditions associated with sheep farm vulnerability and the probability of wild canid occurrence. High-risk zones denote areas where vulnerable farms overlap wild canid range. In the Grosseto Province, we found that few sheep farms are located in high risk areas (15%). In these portions of territory a high level of conflict is likely to arise but only a small percentage of farms is usually involved (Gazzola et al. 2008; Rosas-Rosas et al. 2008; Zarco-Gonzalez et al. 2012).Treves et al. (2004) predicted human-carnivore conflict areas, identifying the intersection of human and carnivore activities in space or consistent landscape features associated with these areas. Contrary to what suggested by Abade et al. (2014), in the Grosseto Province, habitat suitability of wild canids cannot be used alone as a predictive parameter for depredation risk. As we highlighted, wooded areas are preferred by wild canids but are unsuitable for livestock farming. However, higher percentage of vegetation cover close to farms facilitates depredations (Treves at al. 2004; Bradley and Pletscher 2005), firstly because it can be used by wild canids for movements across pasture patches, and because it provides a refuge where they can hide. We can argue, then, that depredation risk results from the ease with which a predator approaches and kills domestic prey, and the speed at which it can reach the shelter area, especially in a human dominated landscape like the Italian setting. In order to reduce human-carnivore conflict, efforts should be focused on reducing the accessibility to trophic resources and adopting adequate measures to protect livestock efficiently, even if this increases management costs for livestock producers (Steele et al. 2013), and might sometimes be difficult to accept (Ciucci and Boitani 1998).

Overall, considering that just presence-only data were available in our study area, BPOD performed better than Maxent in terms of sensitivity. Maxent estimated high probability values only around cells with observed presence, as it is clear examining the distributions of canid occurrence in cells with sheep density and probability of livestock depredation events above the chosen threshold. We choose BPOD and Maxent modeling approach because of their high predictive power and reliability of results (Phillips et al. 2006; Elith et al. 2011; Abade et al. 2014; Tonini et al. 2014). Nevertheless Maxent, even though widely used to predict probability of presence, relies on strong assumptions that have been criticized (Merow et al. 2012). BPOD, on the other hand, is a model recently proposed and not yet widely applied. Our conclusions, according to the results reported in Tonini et al. (2014), suggest that BPOD could be a promising approach to predict probability of presence using presence-only data, particularly since it was able to discriminate better than Maxent regardless the fact that many landscape attributes of the observed presence points were similar to the rest of the Grosseto Province. For what concerns Maxent, the choice of default settings may have been a limiting factor of its performance. However, these become mandatory when little a priori knowledge is available on the occurrences in the given area (Merow et al. 2013).

To evaluate the models and make comparisons between the two approaches, we did not use AUC because it can produce misleading measures of fit, as suggested in several reviews for cases similar to our study (Lobo et al. 2008; Elith et al. 2011; Merow at al. 2013). Instead, we use POD, a metric based on sensitivity (percentage of correctly predicted presences), as recommended also by Merow et al. (2013).

The small scale of the study area allows limited generalizations. However, the approaches proposed here can be widely applicable to many other studies that deal with presence-only data. Our risk map allows proposing preventive actions in specific areas to reduce both the impact of wild canids on humans, and the political controversy over these predators (Treves et al. 2004; Zarco-González et al. 2013). Wolves along with other larger carnivores are necessary for the maintenance of biodiversity and balanced ecosystem functioning (Ritchie et al. 2012; Ripple et al. 2014), and can be preserved only mitigating the level of human-carnivore conflict.

References

AA.VV. 2012. Piano faunistico venatorio 2012-2017. Relazione. Provincia di Grosseto.

Abade L., Macdonald D. W., Dickman A. J. 2014. Assessing the relative importance of landscape and husbandry factors in determining large carnivore depredation risk in Tanzania's Ruaha landscape. Biological Conservation, 180, 241-248.

Ahmadi M., López-Bao J. V., Kaboli M. 2014. Spatial Heterogeneity in Human Activities Favors the Persistence of Wolves in Agroecosystems.

Argenio A. 2014. Protocollo operativo per la raccolta dati presso le aziende zootecniche che hanno subito danni da canidi. Provincia di Grosseto. Life Medwolf

Boitani L., Fabbri M. L. 1983. Strategia nazionale di conservazione del lupo (Canis lupus). Ric. Biol. Selv. 72: 1-31.

Boitani L., Ciucci P. 1993. Wolves in Italy: critical issues for their conservation. Wolves in Europe-status and persepectives. WGM, Oberammergau. 136pp, 74-90.

Boitani L., Ciucci P., Raganella-Pelliccioni E. 2011. Ex-post compensation payments for wolf predation on livestock in Italy: a tool for conservation?. Wildlife Research, 37(8), 722-730.

Boscagli G., Vielmi L., Tribuzi S., Martina A., Cini N. 2006. Stima del numero minimo di lupi con il metodo dell'ululato indotto. In: Lovari S. e Sangiuliano A. 2006. Il lupo sul Monte Amiata. Progetto sui Grandi Canidi (Lupo, Cane) nel territorio dell'Amiata Grossetano e Senese. Relazione Tecnica. Ministero dell'Ambiente, Comunità Montana Amiata Grossetano.

Bradley E. H., Pletscher D. H. 2005. Assessing factors related to wolf depredation of cattle in fenced pastures in Montana and Idaho. Wildlife Society Bulletin, 33(4), 1256-1265.

Braschi C., Boitani L. 2013. Risultati delle analisi genetiche. Relazione finale. Azione A3. Progetto Life Ibriwolf (LIFE10NAT/IT/265).

Chapron G., Kaczensky P., Linnell J. D., Von Arx M., Huber D., Andrén H., ... & Nowak S. 2014. Recovery of large carnivores in Europe's modern human-dominated landscapes. Science, 346(6216), 1517-1519.

Ciucci P., Teofili C., Boitani L. 2005. Grandi Carnivori e Zootecnia tra conflitto e coesistenza. Istituto nazionale per la fauna selvatica" Alessandro Ghigi".

Ciucci P., Boitani L. 1998. Wolf and dog depredation on livestock in central Italy. Wildl. Soc. Bull. 26, 504–514.

Cohen J. 1960. A coefficient of agreement for nominal scales. Educ. Psychol. Meas. 20: 37–46.

Corine Land Cover 2012. Available from: http://www.sinanet.isprambiente.it/it/sia-ispra/download-mais/corine-land-cover [24 November 2015]

Corsi F., Dupré E., Boitani L., 1999. A large scale model of wolf distribution in Italy for conservation planning. Conserv. Biol. 13, 150–159.

Dalmasso S., Vesco U., Orlando L., Tropini A., Passalacqua C. 2011. An integrated program to prevent, mitigate and compensate wolf (Canis lupus) damage in Piedmont region (northern Italy). Hystrix, the Italian Journal of Mammalogy, 23(1), 54-61.

Dar N. I., Minhas R. A., Zaman Q., Linkie M. 2009. Predicting the patterns, perceptions and causes of human–carnivore conflict in and around Machiara National Park, Pakistan. Biological Conservation, 142(10), 2076-2082.

Divino F., Golini N., Lasinio G. J., Penttinen A. 2015. Bayesian logistic regression for presence-only data. Stochastic Environmental Research and Risk Assessment, 1-16.

Elith J., Phillips S. J., Hastie T., Dudík M., Chee Y. E., Yates C. J. 2011. A statistical explanation of MaxEnt for ecologists. Diversity and Distributions, 17(1), 43-57.

Falcucci A., Maiorano L., Tempio G., Boitani L., Ciucci, P. 2013. Modeling the potential distribution for a range-expanding species: Wolf recolonization of the Alpine range. Biological conservation, 158, 63-72.

Gallo O., Pagliaroli D., Zingaro M. 2015. Valutazione ex post della presenza di canidi vaganti (lupi, ibridi e cani randagi) nella Provincia di Grosseto. Azione E2. Progetto Life Ibriwolf (LIFE10NAT/IT/265).

Gazzola A., Viviani A. (a cura di). 2006. Indagine sulla presenza storica e attuale del lupo in Toscana. Regione Toscana.

Gazzola A., Capitani C., Mattioli L., Apollonio M. 2008. Livestock damage and wolf presence. Journal of Zoology, 274(3), 261-269.

Genovesi P. 2002. Piano d'azione nazionale per la conservazione del Lupo (Canis lupus).

Graham H. 2003. The ecology and conservation of lions: human-wildlife conflict in semi-arid Botswana, University of Oxford, Oxford. p. 194.

Gunson J.R. 1983. Wolf predation on livestock in Western Canada. In Wolves in Canada and Alaska: 102–105. Carbin L.N. (Ed.). Chicago: Canadian Wildlife Service, Report Series 45.

Gusset M., Swarner M. J. Mponwane L., Keletile K., & McNutt J. W. 2009. Human–wildlife conflict in northern Botswana: livestock predation by Endangered African wild dog Lycaon pictus and other carnivores. Oryx, 43(01), 67-72.

Hanley J. A., McNeil. B.J. 1982. The meaning and use of the area under a receiver operating characteristic (ROC) curve. Radiol. 143: 29-36.

Hirzel A. H., Hausser J., Chessel D., Perrin, N. 2002. Ecological-niche factor analysis: how to compute habitat-suitability maps without absence data?. Ecology, 83(7), 2027-2036.

Jackson P., Nowell, K. 1996. Problems and possible solutions in management of felid predators. Journal of Wildlife Research, 1, 304-314.

Llaneza L., López-Bao J. V., Sazatornil V. 2012. Insights into wolf presence in human-dominated landscapes: the relative role of food availability, humans and landscape attributes. Diversity and Distributions, 18(5), 459-469.

Lesmerises F., Dussault C., St-Laurent M. H. 2012. Wolf habitat selection is shaped by human activities in a highly managed boreal forest. Forest ecology and management, 276, 125-131.

Linnell J. D., Odden J., Smith M. E., Aanes R., Swenson J. E. 1999. Large carnivores that kill livestock: do" problem individuals" really exist?. Wildlife Society Bulletin, 698-705.

Lobo J. M., Jiménez-Valverde A., & Real R. 2008. AUC: a misleading measure of the performance of predictive distribution models. Global ecology and Biogeography, 17(2), 145-151.

Manghi L., Tosoni E., Masi M. 2012. Azioni A3 e A4. Relazione Tecnica, progetto Ibriwolf LIFE10NAT/IT/265.

Marucco F., McIntire E. J. B. 2010. Predicting spatio-temporal recolonization of large carnivore populations and livestock depredation risk: wolves in the Italian Alps. Journal of Applied Ecology, 47(4), 789-798.

Mattioli L., Capitani C., Avanzinelli E., Bertelli I., Gazzola A., Apollonio, M. 2004. Predation by wolves (Canis lupus) on roe deer (Capreolus capreolus) in north-eastern Apennine, Italy. Journal of Zoology, 264(3), 249-258.

Mladenoff D. J., Sickley T. A., Haight R. G., Wydeven A. P. 1995. A regional landscape analysis and prediction of favorable gray wolf habitat in the northern Great Lakes region. Conservation Biology, 9(2), 279-294.

Mech L.D., Harper E.K., Meier T.J., Paul W.J. 2000. Assessing factors that may predispose Minnesota farms to wolf depredations on cattle. Wildl. Soc. Bull. 28, 623–629.

Merow C., Smith M. J., Silander, J. A. 2013. A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter. Ecography, 36(10), 1058-1069.

Murphy T., Macdonald D.W., 2010. Pumas and people: lessons in a landscape of tolerance from a widely distributed felid. In: Macdonald, D.W., Loveridge, A. (Eds.), Biology and Conservation of Wild Felids. Oxford University Press, Oxford, UK, pp. 431–452.

Karanth K. U., Sunquist M. E., Chinnappa K. M. 1999. Long-term monitoring of tigers: lessons from Nagarahole. Riding the tiger: tiger conservation in human-dominated landscapes. Cambridge University Press, Cambridge, United Kingdom, 114-122.

Kolowski J. M., Holekamp K. E. 2006. Spatial, temporal, and physical characteristics of livestock depredations by large carnivores along a Kenyan reserve border. Biological conservation, 128(4), 529-541.

Ogada M.O., Woodroffe R., Oguge N.O., Frank L.G., 2003. Limiting depredation by African carnivores: the role of livestock husbandry. Conserv. Biol. 17, 1521–1530.

Phillips S. J., Anderson R. P., Schapire R. E. 2006. Maximum entropy modeling of species geographic distributions. Ecol. Model. 190: 231-259.

Phillips S.J., Dudı´k M. 2008. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. Ecography, 31, 161–175.

Polisar J. 2000. Jaguars, pumas, their prey base, and cattle ranching: ecological perspectives of a management issue (Doctoral dissertation, University of Florida).

Ripple W. J., Estes J. A., Beschta R. L., Wilmers C. C., Ritchie E. G., Hebblewhite M., ... & Wirsing A. J. 2014. Status and ecological effects of the world's largest carnivores. Science, 343(6167), 1241484.

Ritchie E. G., Elmhagen B., Glen A. S., Letnic M., Ludwig G., McDonald R. A. 2012. Ecosystem restoration with teeth: what role for predators?. Trends in Ecology & Evolution, 27(5), 265-271.

Rondinini C., Boitani, L. 2007. Systematic conservation planning and the cost of tackling conservation conflicts with large carnivores in Italy. Conservation biology, 21(6), 1455-1462.

Rosas-Rosas O. C., Bender L. C., Valdez R. 2008. Jaguar and puma predation on cattle calves in northeastern Sonora, Mexico. Rangeland Ecology & Management, 61(5), 554-560.

Santilli F., Varuzza P. 2013. Factors affecting wild boar (Sus scrofa) abundance in southern Tuscany. Hystrix, the Italian Journal of Mammalogy, 24(2), 169-173.

Simard F., Ayala D., Kamdem G., Pombi M., Etouna J., Ose K., Fotsing J.-M., Fontenille D., Besansky N., Costantini C. 2009. Ecological niche partitioning between Anopheles gambiae molecular forms in Cameroon: the ecological side of speciation. BMC Ecol. 9, 17.

Selvi F. 2010. A critical checklist of the vascular flora of Tuscan Maremma (Grosseto province, Italy). — Fl. Medit. 20: 47-139. — ISSN 1120-4052.

Steele J. R., Rashford B. S., Foulke T. K., Tanaka J. A., Taylor D. T. 2013. Wolf (Canis lupus) predation impacts on livestock production: direct effects, indirect effects, and implications for compensation ratios. Rangeland Ecology and Management, 66(5), 539-544.

Tonini F., Divino F., Lasinio G. J., Hochmair H. H., Scheffrahn R. H. 2014. Predicting the geographical distribution of two invasive termite species from occurrence data. Environmental Entomology, 43(5), 1135-1144.

Treves A., Naughton-Treves L., Harper E. K., Mladenoff D. J., Rose R. A., Sickley T. A., Wydeven A. P. 2004. Predicting human-carnivore conflict: A spatial model derived from 25 years of data on wolf predation on livestock. Conservation Biology, 18(1), 114-125.

Valeix M., Hemson G., Loveridge A. J., Mills G., Macdonald D. W. 2012. Behavioural adjustments of a large carnivore to access secondary prey in a human-dominated landscape. Journal of Applied Ecology, 49(1), 73-81.

Ward G., Hastie T., Barry S., Elith J., Leathwick, J. R. 2009. Presence-only data and the EM algorithm. Biometrics, 65(2), 554-563.

Woodroffe R., Frank L., Lindsey P., ole Ranah S., Romañach S. 2007. Livestock husbandry as a tool for carnivore conservation in Africa's community rangelands: a case–control study. Biodivers. Conserv. 16, 1245–1260.

Zarco-González M. M., Monroy-Vilchis O., Rodríguez-Soto C., Urios V. 2012. Spatial factors and management associated with livestock predations by Puma concolor in Central Mexico. Human ecology, 40(4), 631-638.

Zarco-González M. M., Monroy-Vilchis O., Alaníz J. 2013. Spatial model of livestock predation by jaguar and puma in Mexico: Conservation planning. Biological Conservation, 159, 80-87.

Zuur, A. F., Ieno, E. N. and Elphick, C. S. (2010) 'A protocol for data exploration to avoid common statistical problems', Methods in Ecology and Evolution, 1(1), pp. 3–14. doi: 10.1111/j.2041-210X.2009.00001.x.

Table 1. Ecological variables considered for wild canid presence and depredation events occurrence.

Model	Groups of variables	Ecological variables	Hypothesis of potential impact
Wild canid occurrence	Land Use	Artificial surfaces	Avoided by wolf
		Forested areas	Used as shelter
		Agricultural areas	Avoided by wolf
		Heterogeneous agricultural areas	Low potential shelter
		Shrubs	Used as shelter
		Open areas	Livestock grazing areas
	Anthropogenic factors	Primary road density	Dangerous and difficult to cross
		Secondary road density	Disturbing feature
	Waterways	Distance to primary waterways	Mainly exposed areas and difficult to cross
		Distance to secondary waterways	Used as shelter and for movements
		Distance to tertiary waterways	Used as shelter
Depredation Events	Canopy	Distance to forest	Used as shelter
		Distance to primary waterways	Mainly exposed areas and difficult to cross
		Distance to secondary waterways	Used as shelter and for movements
		Distance to tertiary waterways	Used as shelter
	Anthropogenic factors	Paved road density	Disturbing feature
		Gravel road density	Disturbing feature
	Domestic prey availability	Sheep density	Trophic resource
		Distance to closest sheep farm	Trophic resource but with humane impact
	Accessibility to livestock	Cost distance to depredation point	Trophic resource

Table 2. Results of sensitivity analysis. POD measure the sensitivity at different threshold probability.

CRITERION	**BPOD**	**Maxent**	
	POD (0.15)	**POD (0.06)**	**POD (0.02)**
Mean value	0.27	0.31	0.35
1 Quartile	0.69	0.42	0.73
2 Quartile	0.4	0.42	0.65
3 Quartile	0.56	0.24	0.29
Comparable with the other approach	0.85	0.1	0.16

Figure 1. Distribution of wild canid probability of occurrence Maxent model using (A) and BPOD model (B). Darker areas show were wolves are more likely to occur.

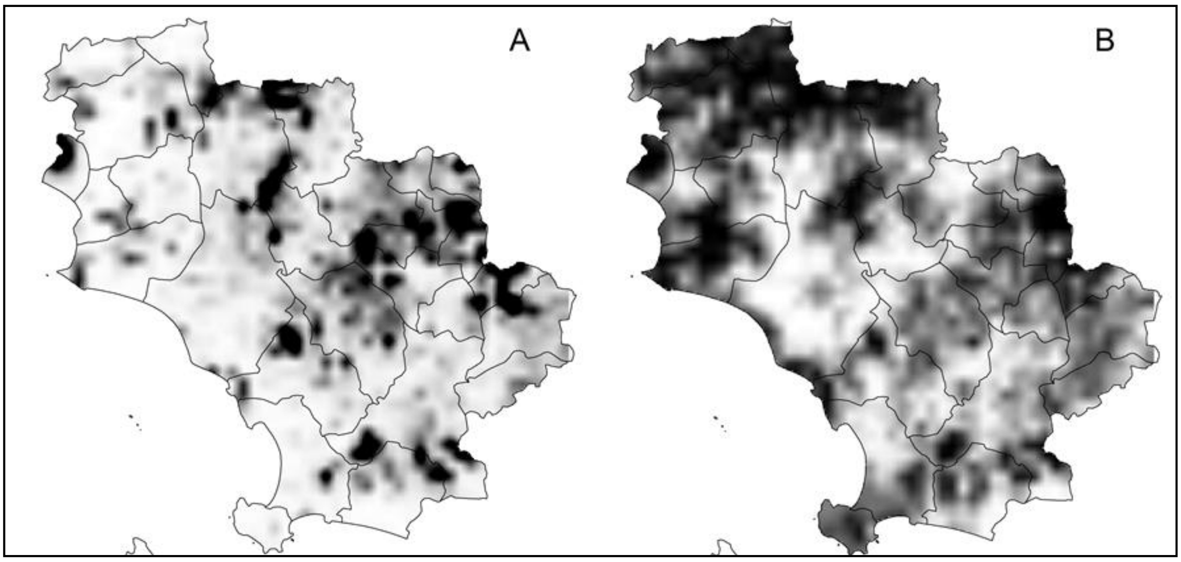


Figure 2. Maxent model (A) and BPOD model (B) of depredation event probability. Areas with higher probability of depredation are darker.

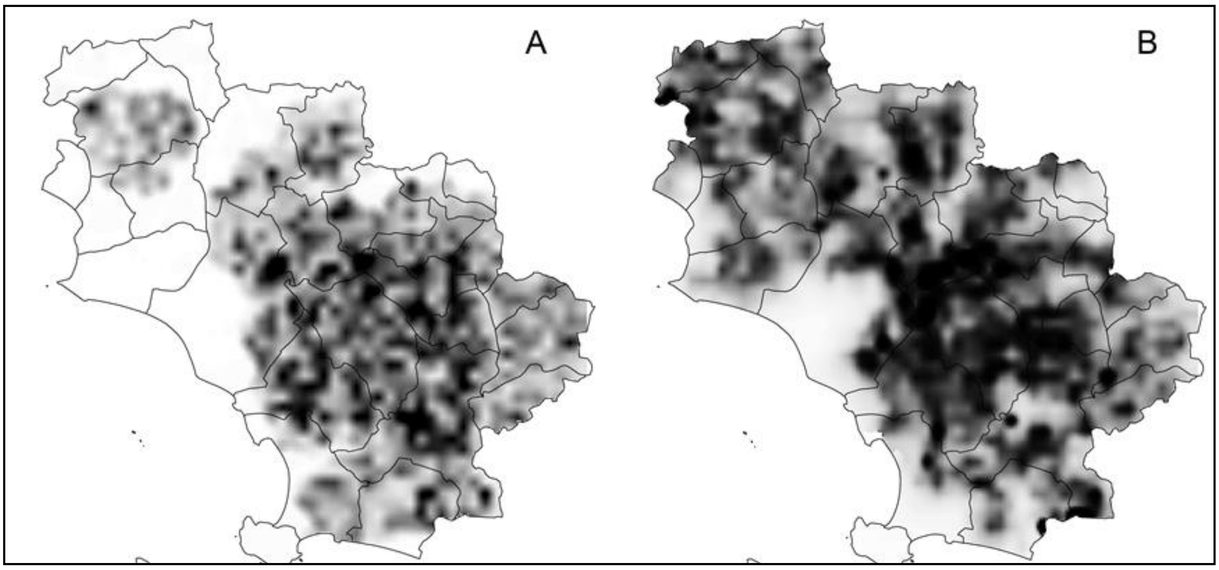


Figure 3. Distribution of probability of wild canid occurrence in cells with sheep density and probability of livestock depredation events above the threshold.

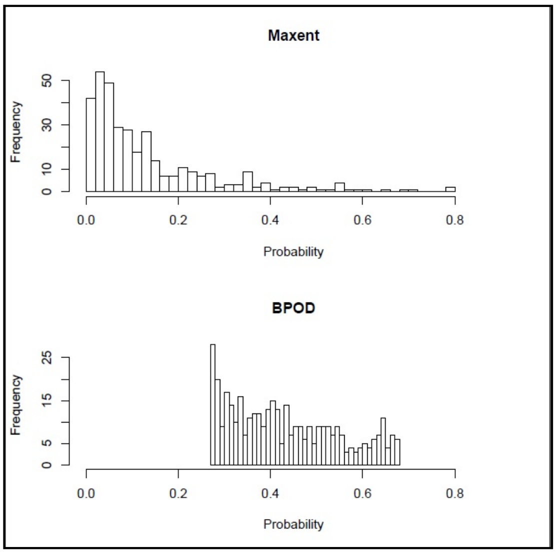
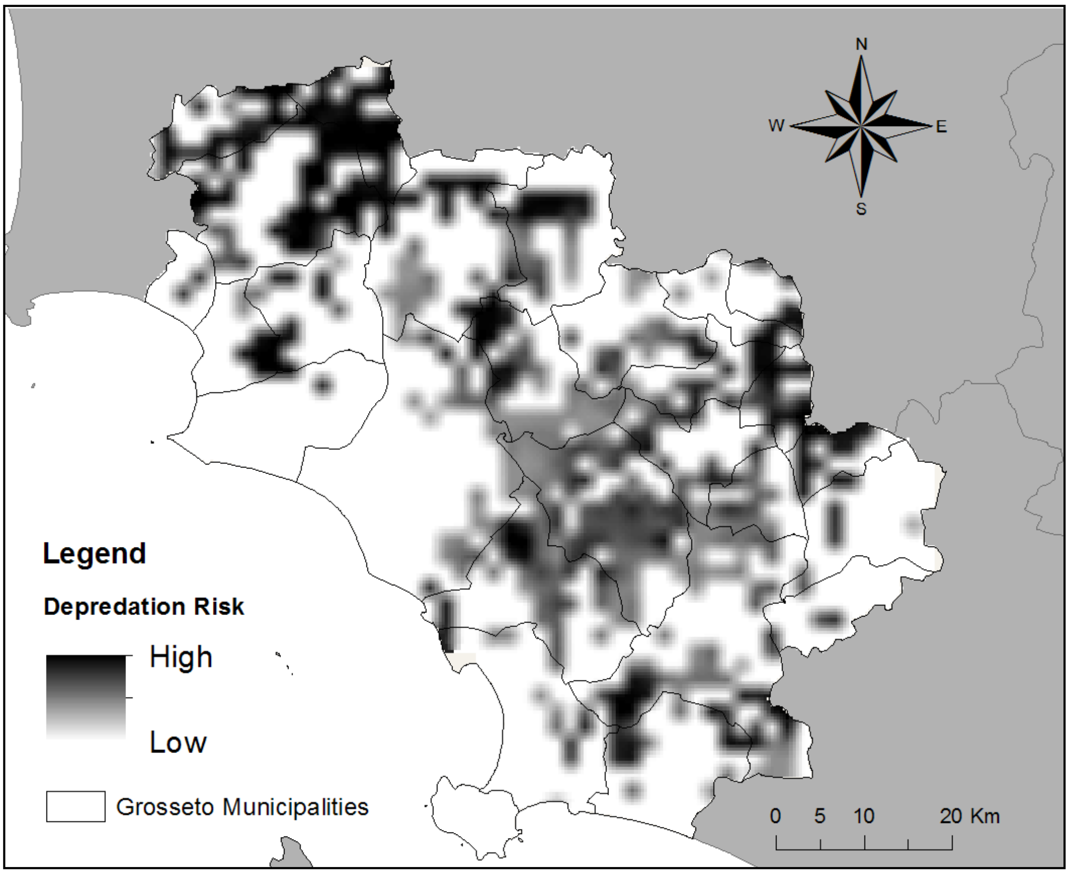


Figure 4. Predictive map of livestock depredation risk by wild canids in the Grosseto Province. Darker color indicates the areas with higher depredation risk.



Supplemental information

Table 3. S1. Result of ENFA analysis. Marginality score for all the variables is reported.

Wild canid		Depredation event	
Variable	**Marginality**	**Variable**	**Marginality**
Artificial surfaces	-0.28	Distance to forest	0.3
Forested areas	0.78	Distance to primary waterways	0.07
Agricultural areas	-0.77	Distance to secondary waterways	-0.16
Heterogeneous agricultural areas	-0.39	Distance to tertiary waterways	-0.03
Shrubs	-0.06	Paved road density	-0.18
Open areas	0.71	Gravel road density	-0.23
Primary road density	-0.7	Sheep density	1.08
Secondary road density	0.02	Distance to closest sheep farm	-0.83
Distance to primary waterways	0.68	Cost distance to depredation point	-1.46
Distance to secondary waterways	0.42	Global	1.39
Distance to tertiary waterways	-0.21		
Global	0.94		

Figure 5. S1. Distribution of sheep farms, waterways and forests within the study area.

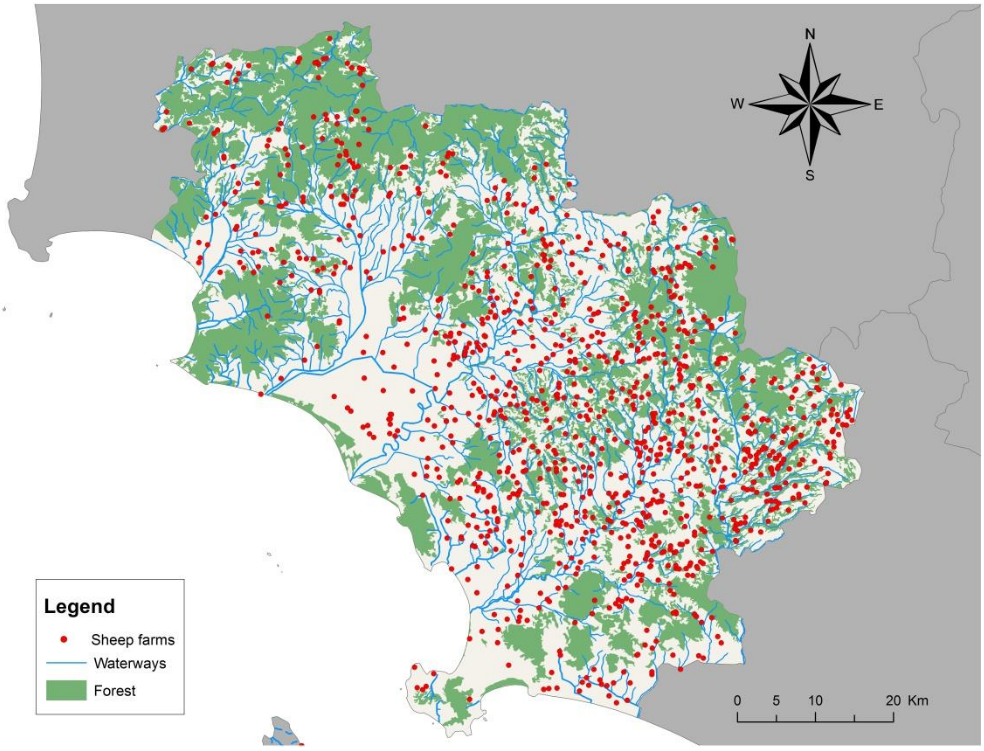
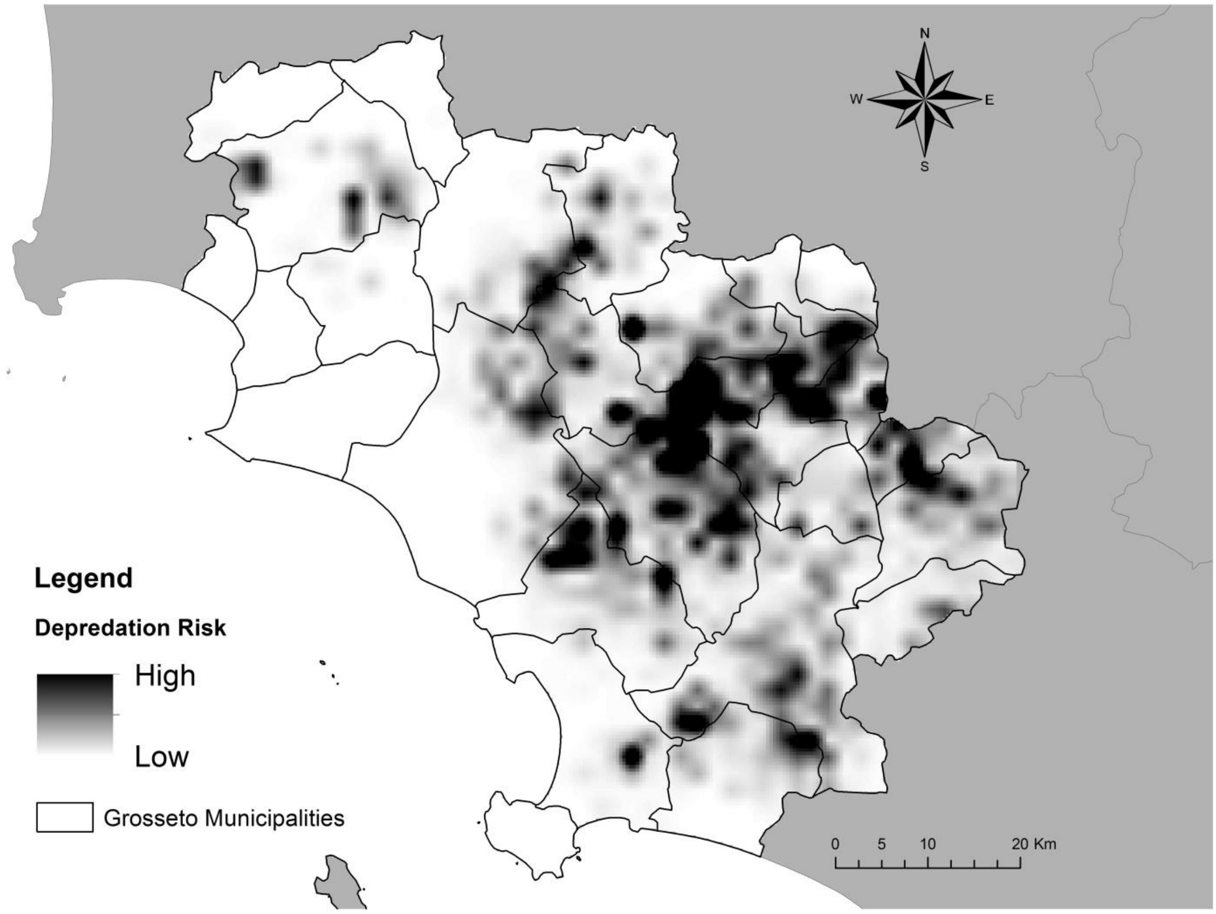


Figure 6. S2. Predictive map of livestock depredation risk by wild canids in the Grosseto Province using Maxent. Darker color indicates the areas with higher depredation risk. Compared to BPOD, high risk areas are reduced and are mostly distributed around observed presence locations.



CHAPTER 3

ARE THE LIVESTOCK GUARDING DOGS WHERE THEY ARE SUPPOSED TO BE?

Abstract

In many parts of the world, livestock guarding dogs (LGDs) are considered one of the most powerful prevention tools against carnivore depredation on domestic animals, but how they behave when left unsupervised with their flock on pastures is mostly unknown. We monitored 29 LGDs with GPS collars in order to investigate their space use and association with their 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, dog-related, and farming-related variables. Finally we tested the usefulness of GPS pet collars in dogs and sheep husbandry. 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 environmental variables and the age of the dog. 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. 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 LGDs do not leave the flock unattended when left unsupervised.

Key words: *LGD, GPS collars, utilization distribution, distance, sheep-dog association.*

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 ’70, 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 the use of LGDs (Rigg, 2001, Ostavel 2009, Salvatori 2014). In many parts of the world (Europe, Asia, USA), 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 (Gering 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 dog’s attentiveness, one of the traits that a good guarding should show (Coppinger and Coppinger 1980). Attentiveness implies a social bond between sheep and dog which results in the dog constantly 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 the society. Indeed, some dogs do not stay with sheep or harass people (Andelt 2004). When an LGD roams far and wide, it is not protecting livestock and is more likely to create problems. In human-dominated landscapes, where road and people 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 and or for hunger if they are not properly kept (Marker et al. 2005, Potgieter et al. 2013). Moreover wide ranging dogs could increase the possibility of affecting 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 under both an 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 these dogs 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 these animals use the space and interact when left alone with the flock on pastures is mostly unknown.

Using GPS pet collars, we monitored 29 LGDs on 11 different 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.

Materials and Methods

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 stay at home). All the 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 agricultural landscape. Apart from Mt. Amiata (1,738 m asl) and the mountainous group of

Colline Metallifere (1060 m asl) in the northern part, the Province is hilly country. Waterways were 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 conduct (Health Authority database).

The use of guardian dogs is only recently widespread in the area, indeed in the last few years an increasing number of sheep producers are adopting these dogs as a defense against predation. All the farmers in this study stated that predation decreased after they integrated LGDs, and during the study period none of these farms experienced depredations. However, 55% of the farms in this research had neighbors (<5km) where livestock depredations occurred in this time period (Health Authority database).

Wolf presence in the area has been detected at increasing densities from 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 by “Sarda” breed sheep. Flocks were raised on pastures demarcated 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). Eighteen percent of farmers (N=2) who participated in this study left their sheep in the pastures, 24hours/-7days, 27% (N=3) confined their livestock in pens at night and 55% (N=6) confined their flock in a barn at night.

Data sampling

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

In 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 this one 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 minutes when the animal was active and one fix every 60 minutes when the animal was resting. This was the default schedule of the GPS devices, and cannot be modified. 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 meters with a maximum error of 57 meters.

[Table 1]

Spatial analysis

We excluded all the locations during the time when the sheep were stabled, in order to only include spatial interactions on pastures. One of the dogs (ID 7) was identified as an outlier and left out from the analyses (Fig.1). This dog was a mixed breed, considerably smaller than Maremma dog, which never showed a guarding behavior during our on farm surveys for GPS collar assistance. It could be considered more a pet dog even though the farmers stated to use it as guarding dog before the placement of two Maremmas.

[Figure 1]

For the distance analyses we retained only pairs of sheep-dog (N=10,306, 30%) and dog-dog (N=9,038, 73%) locations that were taken less than five minutes apart (average 2.5 min ±1.5min and 2.3min ±1.5min). The five-minute interval was considered a small enough time frame 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).

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 three and shrubs in the pasture and size of pasture. Dogs and flock characteristics were recorded during on-farms surveys, whereas the environmental variables surrounding the pastures were quantified using 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 10X10m DTM (Digital Terrain Model) of Grosseto province (Regione Toscana 2015).

To obtain the variables referred 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 (Tab. 2). The percentage of trees and shrubs of pastures was determined using aerial imagery.

[Table 2]

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 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 plug in method because 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).

Statistical analysis

Distance and overlap data were non-normally distributed (D= 0.1982, p-value < 2.2e-16), 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 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 in: 1) land use, 2) dog characteristics, 3) pastures, 4) husbandry features (Tab.3). Season was not included as an explanatory variable, as we sampled different animals in fall/winter then in spring/summer. We first carried out a data exploration following Zuur et al. (2010)'s recommendations. Since distance was not normally distributed 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 (Tab.3).

[Table 3]

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).

Results

Distance

The mean distance between LGDs and their flock was 120.0 ±135.5 meters and between pairs of LGDs it was 80.8±109.8 meters. Dog-sheep distance ranged from a minimum of 0.62 meters and a maximum of 990 meters, while dog-dog distance ranged from 0 meters to 896 meters. The distance between dog and sheep did not differ between dog sex (W=11797000, p=0.1175) while significant differences were found between LGDs (χ^2=2608, df=27, p<2.2e^{-16}) and farms (χ^2=2848, df=10, p<2.2e^{-16}). For five farms we didn't find any difference in dog-sheep distance between the two LGDs associated with the same flock, while in 2 farms the distance differed between paired dogs (Tab. 4). Dissimilar dog-dog distances were found across the farms (χ2=532.52, df=6, p<2.2e^{-16}).

[Table 4]

The best model used to investigate which variables influence the dog-sheep distance, included four predictors: Dog age, Artificial area, Forest, Heterogeneous area (Tab. 5); 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.

[Table 5]

Dog-sheep distance increased with the presence of wooded (β=1.669, p<2.2e^{-16}) and heterogeneous (β=1.204, p=1.33e^{-05}) areas, while it decreased in the presence of artificial surfaces (β= -1.730, p=2.34e^{-07}). The age of the dogs slightly influenced the distance length (β= -0.438, p=0.002), with older dogs remained closer to the flock than younger individuals.

Some of the variability linked to the dog-sheep distance length 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<2.2e^{-16}); the day when the sampling was done (p<2.2e^{-16}); and the differences among farms (p=4.87e^{-07}).

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 (UDOI 50% W=123 p=0.178; UDOI 95%: W=117 p=0.341; VI 50%: W=132 p=0.099; VI 95%: W=107 p=0.642). The utilization distribution for the dogs and sheep entire movement range was nonuniformly distributed, but had a high degree of overlap (Tab.6). The VI index showed partial space-use sharing for dogs and sheep, revealing a different use of pastures areas. LGDs from the same social group shared large areas (Tab.7).

[Table 6]

[Table 7]

Discussion

GPS collars allowed us to investigate the spatial association of LGDs with their sheep in absence of a shepherd or guardian. Satellite data were already 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).

Considering that a prerequisite for LGDs to be effective is that they keep at short distance from their flock (Gehring et al. 2011, VerCauteren et al. 2012), good dogs are those that stick 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 not always means staying in the same spot, but at a distance that presumably allows the dog to have the situation under control.

Occasionally the 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 the LGDs occupied the same area of 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 an LGD association with the flock (Ostavel et al. 2009, Urbigkit and Urbigkit 2010). The environment surrounding the dog played also 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 nearby the forests.

We expected that pastures with a high percentage of trees and shrubs inside caused the sheep to flock less, and spread more during grazing, leading to a grater 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 Tab.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 left the flock often to nurse her offspring. To prevent this behavior, 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 also 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 the trees scattered in the central parts of the 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 the pup 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 maintain contact with the flock is working properly and is considered attentive, a quality that is related to a reduction in predation (Coppinger at al. 1983). We observed that the monitored dogs were closely associated with their flock 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 (<5km) who suffered livestock depredations (National Health Authority database), although no indication of LGD presence is provided for the affected farms.

We argue that the spatial association between dog and sheep must be accounted for when evaluating an 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.

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 shepherd, helping in limiting conflicts with neighbors, and allowing intervention if the 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 improved the confidence in their LGDs being able to constantly monitor them and observing 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 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 an appropriate amount of data for our analyses.

References

Andelt, W. F. (1992) 'Effectiveness of livestock guarding dogs for reducing predation on domestic sheep', Wildlife Society Bulletin, 20(1), pp. 55–62.

Andelt, W. F. (2004). 'Use of livestock guardian animals to reduce predation on sheep and livestock'. Sheep and Goat Research Journal 19: 72–75.

Chapron G., Kaczensky P., Linnell J. D., Von Arx M., Huber D., Andrén H., ... & Nowak S. (2014) 'Recovery of large carnivores in Europe's modern human-dominated landscapes', Science, 346(6216), 1517-1519.

Coppinger, R., Coppinger, L., (1980), 'Livestock-guarding dogs'. Country Journal 7(4):68-77.

Coppinger, R., Lorenz, J., Glendinning, J. and Pinardi, P. (1983) 'Attentiveness of guarding dogs for reducing predation on domestic sheep in the United States, Italy.', Journal of Range Management Archives, 36(3), pp. 275–279. doi: 10.2307/3898468.

Coppinger, R., Coppinger, L., (2005), 'Livestock Guarding Dogs: from the Transhumance to Pre-Zygotic Selection', Carnivore Damage Prevention News, 9, pp.2-8.

Espuno, N., Lequette, B., Poulle, M.-L., Migot, P., and Lebreton, J.-D. (2004) 'Heterogeneous response to preventive sheep husbandry during wolf recolonizaiton of the French Alps', Wildlife Society Bulletin, 53(9), pp. 1689–1699. doi: 10.1017/CBO9781107415324.004.

ESRI (2012) 'ArcGIS Desktop: Release 10.1', Redlands, CA: Environmental Systems Research Institute.

Fieberg, J. and Kochanny, C. O. (2005) 'Quanitfying home-range overlap: the importance of the utilization distribution', Journal of Wildlife Management, 69(4), p. 1346. doi: 10.2193/0022-541X(2005)69.

Gehring, T. M., Vercauteren, K. C., Landry, J.-M., Gehring, T. M. ; and Vercauteren, K. C. ; (2010) 'Livestock Protection Dogs in the 21st Century: Is an Ancient Tool Relevant to Modern Conservation Challenges?', BioScience, 60(299). Available at: http://digitalcommons.unl.edu/icwdm_usdanwrc.

Gehring, T. M., Vercauteren, K. C., Cellar, A. C. and Vercauteren, K. C. (2011) 'Good fences make good neighbors: implementation of electric fencing for establishing effective livestock-protection dogs' Human–Wildlife Interactions, 5(1), pp. 106–111. Available at: http://digitalcommons.unl.edu/icwdm_usdanwrc.

Gipson, T. a., Sahlu, T., Villaquiran, M., Hart, S. P., Joseph, J., Merkel, R. C. and Goetsch, a. L. (2012) 'Use of global positioning system collars to monitor spatial-temporal movements of co-grazing goats and sheep and their common guardian dog', Journal of Applied Animal Research, 40(4), pp. 354–369. doi: 10.1080/09712119.2012.692475.

Gitzen, R. A., Millspaugh, J. J. and Kernohan, B. J. (2006) 'Bandwidth Selection for Fixed-Kernel Analysis of Animal Utilization Distributions', Journal of Wildlife Management, 70(5), pp. 1334–1344. doi: 10.2193/0022-541X(2006)70[1334:BSFFAO]2.0.CO;2.

Kopaliani, N., Shakarashvili, M., Gurielidze, Z., Qurkhuli, T. and Tarkhnishvili, D. (2014) 'Gene flow between wolf and shepherd dog populations in georgia (caucasus)', Journal of Heredity. doi: 10.1093/jhered/esu014.

Landry J.-M., Millischer G., Borelli J.-L., Lyon G. (2014) 'The CanOvis Project : Studying internal and external factors that may influence livestock guarding dogs' efficiency against wolf predation', Carnivore Damage Prevention News 10 : 21-30.

Leijenaar, S.-L., Cilliers, D. and Whitehouse-Tedd, K. (2015) 'Reduction in Livestock Losses following placement of Livestock Guarding Dogs and the impact of herd species and dog sex', Journal of Agriculture and Biodiversity Research, 4(1), pp. 9–15.

Lescureux, N. and Linnell, J. D. C. (2014) 'Warring brothers: The complex interactions between wolves (Canis lupus) and dogs (Canis familiaris) in a conservation context', Biological Conservation. doi: 10.1016/j.biocon.2014.01.032.

Lorenz, J. R., & Coppinger, L. (1986). 'Raising and Training a Livestock guarding Dog'. (Oregon State University: Corvallis, OR.).

Lorenz, J. R. (1989). 'Introducing livestock-guarding dogs'. Corvallis, Or.: Extension Service, Oregon State University.

Marker, L. L., Dickman, A. J. and Macdonald, D. W. (2005) 'Perceived Effectiveness of Livestock-Guarding Dogs Placed on Namibian Farms', Rangeland Ecology and Management, 58(4).

Minnesota Department of Natural Resources (2012) 'DNRGPS', Copyright (c) 2000-2012 (www.mndnr.gov).

Otstavel, T., Vuori, K. A., Sims, D. E., Valros, A., Vainio, O. and Saloniemi, H. (2009) 'The first experience of livestock guarding dogs preventing large carnivore damages in Finland', Estonian Journal of Ecology, 58(3), pp. 216–224. doi: 10.3176/eco.2009.3.06.

Potgieter, G. C., Marker, L. L., Avenant, N. L. and Kerley, G. I. H. (2013) 'Why Namibian Farmers Are Satisfied With the Performance of Their Livestock Guarding Dogs', Human Dimensions of Wildlife, 18(6), pp. 403–415. doi: 10.1080/10871209.2013.803211.

Powell, R. A. (2000) 'Animal home ranges and territories and home range estimators', Research techniques in animal ecology: controversies and consequences, 442.
Raftery, A. E. (1995) 'Bayesian model selection in social research', Sociological methodology, 111-163.
Regione Toscana (2013) 'Cartografia Ucs2013', www.geografia.toscana.it .
Regione Toscana (2015) '10X10 m Grosseto Province DEM', (http://dati.toscana.it/dataset/dem10mt/resource/4288aa6f-e2ec-4f68-bce0-6408fec6cda0).
Rigg, R. (2001) 'Livestock guarding dogs: their current use worldwide', The Canid Specialist Group, (1), p. 133.
RStudio Team (2015) 'RStudio: Integrated Development for R', RStudio, Inc., Boston, MA URL http://www.rstudio.com/ .
Salvatori, V. (2014) 'Medwolf: a new project to decrease man-wolf conflicts in Mediterranean-type areas', CDPnews. Issue 10.
Seidel, K. S. (1992) 'Statistical properties and applications of a new measure of joint space use for wildlife' Thesis, University of Washington, Seattle, USA.
Shivik, J. a. (2006) 'Tools for the Edge: What's New for Conserving Carnivores', BioScience, 56(3), p. 253. doi: 10.1641/0006-3568(2006)056[0253:TFTEWN]2.0.CO;2.
Schwarz, G.E. (1978) 'Estimating the dimension of a model', Annals of Statistics, 6 (2): 461–464, doi:10.1214/aos/1176344136, MR 468014.
Solla, D.E., Shane, R., Bonduriansky, R. and Brooks, R.J. (1999) 'Eliminating autocorrelation reduces biological relevance of home range estimates', Journal of Animal Ecology, 68(2), pp.221-234.
Swihart, R. K., and N. Slade. (1985) 'Testing for independence of observations in animal movements', Ecology 66:1176–1184.
Urbigkit, C. and Urbigkit, J. (2010) 'A Review: The Use of Livestock Protection Dogs in Association with Large Carnivores in the Rocky Mountains', Sheep & Goat Research Journal, 25, pp. 1–8.
van Bommel, L. and Johnson, C. N. (2014) 'Where do livestock guardian dogs go? Movement patterns of free-ranging Maremma sheepdogs', PLoS ONE, 9(10), pp. 1–12. doi: 10.1371/journal.pone.0111444.
VerCauteren, K. C., Lavelle, M. J., Gehring, T. M., & Landry, J. M. (2012). Cow dogs: use of livestock protection dogs for reducing predation and transmission of pathogens from wildlife to cattle. Applied Animal Behaviour Science, 140(3), 128-136.
Webber, B. L., Weber, K. T., Clark, P. E., Moffet, C. A., Ames, D. P., Taylor, J. T., ... & Kie, J. G. (2012) 'Movements of Domestic Sheep in the Presence of Livestock Guardian Dogs', Review at the Journal of Rangeland Ecology and Management. Manuscript Number REM-S-12-00018.
West, B. T., Welch, K. B., & Galecki, A. T. (2014). 'Linear mixed models: a practical guide using statistical software'. CRC Press.
Zuur, A. F., Ieno, E. N. and Elphick, C. S. (2010) 'A protocol for data exploration to avoid common statistical problems', Methods in Ecology and Evolution, 1(1), pp. 3–14. doi: 10.1111/j.2041 210X.2009.00001.x

Figure 1. Boxplot of sheep-dog distance

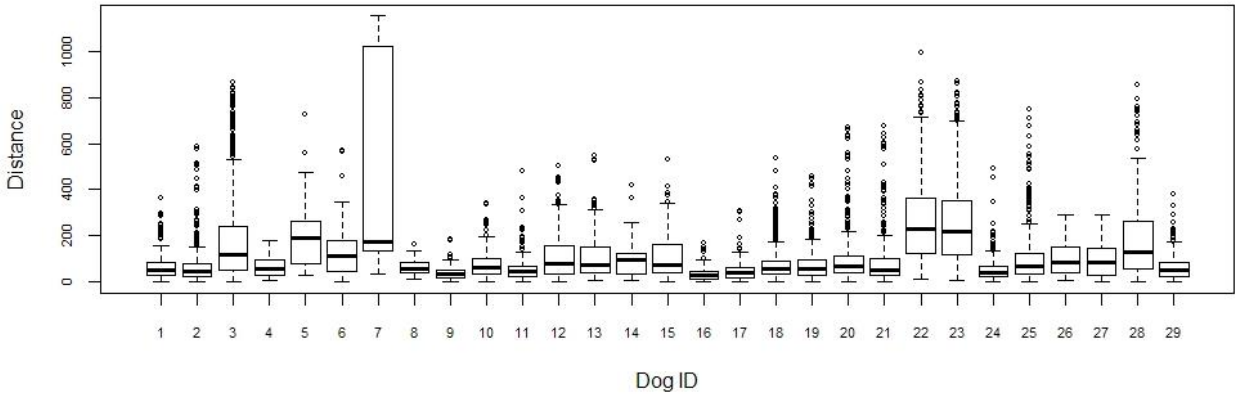


Table 1. Information on LGDs and farms involved in the study.

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*	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*	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*	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

*Neutered dogs

Table 2. Land use classes included in each land use group.

Group	Description	2013 Land use code
Artificial	Artificially surfaced areas	112-1121-121-122-1221
Arable	Cultivated areas	210-221-222-2221-223
Open	Rocky areas, pastures and grasslands	231-321-332
Heterogeneous	Agricultural areas interspersed with significant natural areas	241-242-244
Forest	Deciduous and coniferous forests	311-324

Table 3. Fixed and random effects fitted in the linear mixed models.

	Groups of variables	Variables	Measuring units
Fixed effects	Dog	Dog age	Months
		Dog sex	Sex class (M,F)
	Pasture	Pasture type	% of trees and shrubs in the pasture
		Pasture area	Ha
	Land use	Agricultural areas	Ha
		Artificial surfaces	Ha
		Heterogeneous areas	Ha
		Forest	Ha
	Husbandry	N associated LGDs	Number of dogs
		Flock size	Number of sheep
		Flock size class	small<200sheep, large≥200 sheep
Random effects		Dog nested in pasture area	DogID, Ha
		Dog nested in pasture type	DogID, % of trees and shrubs in the pasture
		Day of sampling	Date
		Farm	FarmID

Table.4. Results of Wilcoxon rank sum test to detect differences in distance between pair of LGDs from the same social group.

Farm	W	p-value
E1	22628	$5.2e^{-05}$
E2	105980	0.002
E3	79962	$2.2e^{-16}$
F	48007	0.944
G	2344	0.910
H	9913	0.019
I	325660	0.425
J	293310	0.365
K	3553	0.776

Table 5. Selected models with delta<10. Art= Artificial area, For= Forest, Het= Heterogeneous area, FlS=Flock size, FlSCl=Flock size class (small<200sheep, large≥200 sheep).

Model	(Int)	Age	Art	For	Het	FlS	FlSCl	df	logLik	BIC	Delta	Weight
Mod29	3.872	-0.439	-1.730	1.669	1.204			10	-12632.28	25357	0	0.882
Mod28	3.602		-1.707	1.670	1.195	0.103		10	-12635.02	25362	5.48	0.057
Mod21	3.774	-0.385	-1.722	1.671	1.203	0.051		11	-12631.85	25365	8.34	0.014
Mod8	3.864		-1.715	1.668	1.191		+	10	-12636.51	25365	8.47	0.013

Table 6. UDOI and VI indexes of sheep-LGDs movement range overlap.

Farm	Dog	VI	UDOI	VI	UDOI
		95%		50%	
A1	1	0.72	1.32	0.65	0.61
A1	2	0.83	1.77	0.77	0.85
A2	1	0.59	0.94	0.4	0.26
B1	1	0.47	0.98	0.24	0.16
B2	1	0.4	0.14	0.05	0.63
C	1	0.37	0.55	0.07	0.04
C	2	0.73	1.11	0.5	0.35
C	3	0.66	0.98	0.39	0.26
D	1	0.74	1.84	0.6	0.64
D	2	0.66	1.54	0.53	0.57
E1	1	0.85	1.42	0.74	0.73
E1	2	0.91	1.37	0.77	0.72
E2	1	0.7	1.59	0.57	0.56
E2	2	0.72	1.75	0.64	0.7
E3	1	0.8	1.81	0.77	0.85
E3	2	0.7	1.62	0.62	0.61
F	1	0.6	2.89	0.61	0.81
F	2	0.53	2.2	0.5	0.54
G	1	0.63	1	0.57	0.55
G	2	0.66	1.15	0.58	0.53
H	1	0.72	1.33	0.61	0.57
H	2	0.75	1.44	0.63	0.66
I	1	0.8	1.45	0.72	0.74
I	2	0.75	1.35	0.65	0.64
J	1	0.33	0.48	0.07	0.01
J	2	0.3	0.45	0.05	0
K	1	0.58	1.06	0.45	0.38
K	2	0.61	1.16	0.56	0.49
Mean		0.65	1.31	0.51	0.52
SD		0.16	0.56	0.22	0.25

Table 7. UDOI and VI indexes for the overlap of movement range between the LGDs of the same social group.

Farm	VI	UDOI	VI	UDOI
	95%		50%	
E1	0.91	1.48	0.85	0.89
E2	0.83	2.27	0.83	1.05
E3	0.73	1.69	0.66	0.71
F	0.73	3.38	0.76	0.96
G	0.73	1.51	0.7	0.8
H	0.81	1.68	0.76	0.77
I	0.89	1.67	0.83	0.9
J	0.73	3.35	0.74	1.06
K	0.79	2.21	0.8	0.92
Mean	0.79	2.14	0.77	0.90
SD	0.07	0.71	0.06	0.11

CHAPTER 4

HUSBANDRY CONDITIONS INFLUENCE THE EFFECTIVENESS OF USING LIVESTOCK GUARDING DOGS

Abstract

Like other preventive methods, the use of livestock guarding dogs does not prevent 100% of damages. Much depends on how the different protective measures are implemented and integrated with each other. Comparing 79 sheep farms with at least one adult guarding dog (> 1.5 years old), we highlighted the conditions that decrease the efficacy of these animals in reducing depredations. For each farm we measured: 1) the number of adult livestock guarding dogs; 2) the distance between the farmer's house and the night shelter; 3) night shelter permeability to predators; 4) flock size; 5) shepherd presence; 6) the number of depredation events over the last six months; 7) the depredation risk. We classified farms on whether or not they experienced depredation over the last six months, and compared the two groups using non-parametric tests and logistic regressions. Depredated and non-depredated farms differed only by the night shelter-farmer’s home distance value. The model averaging showed a significant positive correlation between damage occurrence and night shelter-farmer’s home distance length. Our results suggest that in environmental conditions that determine a similar depredation risk, human presence is the main feature that enhances the effectiveness of guarding dogs as a tool against canid attacks on flocks.

Key words: *livestock guarding dog, depredation, livestock management*

Introduction

The implementation of preventive measures is one of the challenges that sheep farmers need to address to protect their livestock against carnivore depredation. In fact, although wolves as other large carnivores prey on wild ungulate, they may kill domesticated breeds when are available, thus impacting on the livelihood of rural communities (Fritts et al. 2003, Polisar 2003). Several studies indicate that animal husbandry practices affect vulnerability to carnivores (Treves and Karanth 2003), but most of them did not clearly showed how (Barnes 2015). Furthermore, environmental conditions around the pastures are also involved in determining the probability of experiencing an attack (Bradley and Pletscher 2005, Zarco-Gonzáles et al. 2013, Abade et al. 2014).

Various methods to reduce depredations such as night penning, human presence and the use of livestock guarding dogs (LGDs), have been deployed (Shivik 2006). However all of them have their limits and will fail in some situations (Urbigkit and Urbigkit 2010), especially if misused. For this reason multiple preventive tools and husbandry techniques should be used in a context-dependent fashion, and integrated into a science based operation supported by livestock producers (Breck et al. 2012).

Improving livestock husbandry is essential to decrease predations (Gusset et al. 2009), but this requires changes in producer behavior, particularly where farming practices evolved in absence of predators (Treves and Karanth 2003), as happened in Grosseto province. Such changes, though, are often resisted for economic problems (Naughton-Treves 1997, Rust and Marker 2013).

Recently, the use of livestock guarding dogs has become increasingly popular in many parts of the world (Shivik, 2006, Gehring et al. 2010, Lescureux and Linnell 2014), though using LGDs to guard stock against predators has been used in Europe and Asia for millennia (Rigg 2001).

LGDs are a practical and effective tool for deterring predation under a variety of conditions, but are more likely to be successful in some situations as opposed to others (Green et al. 1984, Gehring et al. 2010, Barnes 2015). Indeed the effectiveness of using LGDs to reduce wolf depredation on sheep, depends of several factors such as landscape, and both the husbandry practices and the grazing management within which they are integrated (Green et al. 1984, Espuno et al. 2004, Barnes 2015). Moreover, in order for dogs to be useful they must show a great ability to guard the heard, which is generally measured through their attentiveness protectiveness and trustworthiness (Coppinger and Coppinger 1980). These qualities may be not enough if the conditions under which the dogs work are not suitable.

Thus, sometimes depredations still occur, and damages remain a chronic problem despite the presence of livestock guarding dogs (Mertens and Schneider 2005, Landry et al. 2014).

Using compensation records and analysis of farming practices we tried to understand in which livestock husbandry conditions LGDs can be used more effectively.

Methods

Study area

We sampled sheep farms within Grosseto province (4,504 km^2) located in the southern part of the Tuscany Region, Italy (Fig.1). The hilly landscape of the province is a mosaic of extensive cultivations, shrubs, fallows, pastures and woods dominated by holm oak (*Quercus ilex*), cork oak (*Quercus suber*), and beech (*Fagus sylvatica*) in mountainous areas (Selvi 2010). Populations of wild boar (*Sus scrofa*), roe deer (*Capreolus capreolus*), and fallow deer (*Dama dama*) are abundant and evenly distributed within the study area (AA.VV. 2012; Santilli and Varuzza 2013). Wolves (*Canis lupus*) and free ranging dogs (*Canis familiaris*) are the major threats to livestock productions, and occasionally foxes (*Vulpes vulpes*) predate on lambs.

[Fig.1]

Husbandry practices

Agriculture and farming play an important role in the local economy mainly related to dairy products and tourism. Sheep holdings are the primary type of farming. The most recent census reports 1,150 sheep farms with 200 sheep on average (BDN, national livestock database 2014). 95% of sheep and goat farms raise flocks outdoors or extensively on pastures surrounding the barn used for night penning (BDN, national livestock database). Each farm has on average 12 ha of pastures (ISTAT 2010) which are often subdivided in smaller plots bordered by fences about one meter high. This enclosure does not protect livestock from depredation because predators can cross it easily. Due to the heterogeneity of Grosseto landscape it is common that pastures are interspersed with wooded areas.

Livestock husbandry varies among farmers, partially because some of them turned to diversification producing milk, cereals, wine, olive oil, and work as agritourism. Diversification means that less time is available for taking care of the sheep (Garde 2015). Dividing the herd into three smaller groups is a general practice: ewe lambs are mostly stabled, yearlings and rams are left on pastures most of the day and ewes are stabled for longer time at dawn and dusk for milking. However the number of groups is highly variables in relation to seasons and farmer’s practice. The mean number of sheep groups in the surveyed farms was 2.7 (±1.3).

Because of the limited presence of predators in the study area until the last decades (Gazzola et al. 2006), the use of livestock guarding dogs and the preventive measures has began to spread only recently within the last few years, following the recovery of wolf population and the inspiring influence of wolf conservation and damage prevention projects operating in Grosseto province.

Data sampling

From March 2015 to August 2016 we randomly sampled 80 sheep farms with at least one working adult LGD (>1.5 years old, Espuno 2004) in good shape. Data from one farm were deemed confounding, thus were excluded from the analysis. Data were collected by a trained veterinarian who verified on site information related to the number of adult LGDs and their age, distance between farmer's home and night shelter, adequacy of night shelter, herd size, depredation events over the last six months, and presence of shepherd. All the variables were objectively quantified except for shepherd presence that was reported by the farmer as absent, present, or occasionally present. The number of dogs was double-checked on field and by consulting the Regional dog register. The distance between farmer's home and night shelter (pens, barns, or mix of both) was measured on GIS using aerial imageries, and was representative also of the distance between farmer's home and pastures. Night shelters were classified on whether they were predator-proof or not (i.e. whether or not the predator could get into the shelter). Pens were to be sturdy, chain-linked with a 10X10 cm mesh and at least 175 cm in height above the ground. The basal part of the fence had to be buried in the ground, while the upper part had to be bent over at 45° outwards. Barns were to be robust and completely closed. Shelter locks had to be at least 175 cm in height above the ground and fitted with a wooden or concrete sleeper. If one of these features was lacking or compromised, the shelter was considered not predator-proof. The veracity of the depredation event by canids was checked on the Health Authority database. To minimize the probability that the depredation event occurred in different husbandry conditions, we considered only the verified canid attacks on livestock until six months before the survey. In addition to these husbandry variables, we included the depredation risk for each farm. We quantified this variable using landscape features such as land use, watercourse, accessibility to livestock, and wild canid probability of occurrence following the procedure suggested by Zingaro and Boitani (in press, see Chapter 2).

Statistical procedure

To evaluate which variables limited the efficacy of the LGDs we conducted univariate tests. For continuous variables we used Wilcoxon rank sum test to compare farms with and without depredations. For categorical variables we used contingency tables and the χ^2 test. The level of significance was set at $p<0.05$.

To account for the cumulative effect of the variables on depredation occurrence we conducted a binomial regression analysis. As a first step we explored the data following Zuur et al. (2010) protocol, then several Generalized Linear Models (GLMs) were run. Interactions between LGDs and flock size, and between LGDs and number of sheep groups were considered in the models.

We used a natural average method to obtain the parameters estimates (Burnham and Anderson, 2002). First, we compared models with multiple combinations of covariates using Akaike Information Criterion corrected for small samples (AICc; Burnham and Anderson, 2002). AIC based-models are widely recommended in particular for categorical data analysis (Burnham and Anderson 1998). Then we selected the best models ($\Delta<2$) for model averaging (Burnham and Anderson 2002). The goodness of fit of the model averaging output was estimated using the Hosmer-Lemeshow test for the corresponding binomial GLM. God fit is reached if there is no significant difference between the model output and the observed data (i.e. p-value is above 0.05).

Statistical analyses were performed in R, version 3.2.0 (R Core Team, 2013) using the following packages: ggplot2 (Wickham 2009), MuMIn (Barton2014), ResourceSelection (Lele et al. 2016).

Results

36.3% (N=29) of the 79 sampled farms experienced depredations by canids over the last six months while 63.7% (N=50) did not (Tab. 1). Nearly half of the farms (48%, N=38) used LGDs as the only preventive tool against depredations. Among the farmers that implemented more than one preventive measure; 10% (N=8) used both the shepherd and the predator proof night shelter; 28% (N=22) built adequate barns and pens; and 18% (N=12) employed the shepherd.

[Tab.1]

With the exception of home-night shelter distance (W=455, p-value=0.005), depredated and not depredated farms showed similar husbandry features (Tab.2).

[Tab.2]

The binomial regression analysis resulted in four top models that included six variables: flock size/N LGDs ratio, adequacy of night shelter, presence of shepherd, home-shelter distance, flock size, number of LGDs (Tab 3). The GLM fitted with the variables with a higher averaged weight, had a good fit (χ^2=7.283, df=8, p-value=0.507) and included flock size/N LGDs ratio, adequacy of night shelter, presence of shepherd, and home-shelter distance.

[Tab.3]

According to the results, the proximity of the night shelter (and thus the pastures) to the farmer house was the only variable that significantly influenced the probability of depredation events by canids (p=0.022), when LGDs were implemented (Tab.4). Longer distances increased the probability of receiving an attack (Fig. 2).

[Tab.4]

[Fig.2]

Discussion

Results from this study showed that in environmental conditions that determine a similar depredation risk, human presence was the main feature that enhanced the effectiveness of guarding dogs as a tool against canid attacks on flocks.

Indeed, the proximity of night shelters and pastures to human dwellings allows farmers to supervise dogs and flocks for longer time. Poor surveillance of livestock is the most important factor associated with wolf depredation in many parts of the world (Fritts et al. 2003).

Pastures located far from residences might be most likely to experience depredation, although wolves often kill livestock near houses (Mech et al. 2000, Bradley and Pletscher 2005).

Human presence alone does not stop depredations if domestic animals are still available to wolves. For example in Poland, shepherds who use livestock guarding dogs on remote pastures lose annually much less sheep then farmers without dogs who keep the animals close to the farm buildings (Śmietana 2005). Wild predators in fact, can become habituated and learn their way to predate close to humans (Shivik 2006, Valeix et al. 2012). To reduce the probability of depredation, then, different preventive tools should be integrated (Boitani 2000; Espuno et al. 2004), used in a proper context, and modified periodically to avoid habituation by predators (Treves and Karanth 2003).

The main factor influencing how well LGDs work in Australia is the number of stock they are required to protect (van Bommel and Johnson 2012). Our analyses showed that neither the flock size nor the number of LGDs were significantly different between predated and non-predated farms, as also concluded by Rigg et al. (2011). The 79 farms we surveyed in this study had on average twice the sheep of the mean value in Grosseto province, suggesting that LGDs are implemented as preventive tool when farmers have larger stocks. The dog/sheep ratio was around 1:150 (SD=110) in the two groups of farms and was not related with the depredation occurrence as already reported in other works (Mertens and Schneider 2005, Dorresteijn et al. 2014).

Surprisingly we found that the presence of the shepherd wasn't related to the absence of depredation. This could indicate that LGDs can be successfully operated without human supervision. We cannot ignore, though, that the accuracy of the information on the shepherd presence at the time of the attack is questionable, since is particularly difficult to ascertain.

The adequacy of the night shelter in farms with LGDs did not affect loss occurrences. Our result was similar to the conclusions of Ogada et al. (2003) and Kolowski and Holekamp (2006) whom asserted that improved fencing is not necessarily an effective solution to livestock depredation. In our case, the reason could be that flocks were considerably more vulnerable when grazing on pastures because rarely guarded, rather than when they are penned during night time. Therefore, predations on domestic animals seemed to occur more frequently during daytime compared to the past (as described by Ciucci and Boitani 1998).

Although we couldn't prove it, we believe that often farms with at least one adult LGD still experienced depredations on pastures because flocks were not guarded by any dog during the attack. Our assumption relies on what was reported in other studies (Ciucci and Boitani 1998, Espuno et al. 2004, Sedefchev 2005, Dorresteijn et al. 2014), and on the husbandry practice widespread in Grosseto province, of dividing the heard into two or three groups where the presence of LGDs is not guaranteed. We recorded the number of sheep groups for each farm but we decided to not include this information in the analyses because it varies throughout the year and the data reported by the farmer could not coincide with the real situation at the time of the attack.

Even though human negligence plays an important role in influencing the attack rate (Graham 2005), we cannot exclude that depredations occurred because LGDs failed to protect the flock due to poor training, or because of the superiority of predators. However, these information are hard to obtain since require a long and ongoing monitoring which are not feasible to do on a large number of farms.

Except for night shelter-farmer's house distance, we found no differences between predated and non-predated farms with LGDs.

Nevertheless, it might be possible that our classification strategy failed to well define the two groups. Considering only the depredation events that occurred over the last six months to assess whether the use of LGDs was not effective might be misleading. Indeed, a small number of attacks could be considered ordinary and apt to be affected by random events (Mech et al. 2000). Other differences could have been arisen if we had considered the depredation frequency occurred in at least one year. However in Grosseto province farm conditions are improving rapidly thanks to the positive influence of conservation projects such as Life Medwolf (LIFE11NAT/IT/069) and the

Tuscany Region Wolf Conservation and Damage Prevention program, which raised farmers' awareness of the importance of a proper livestock management where wolf populations are recovering. These changes could have increased the difficulty to relate farm conditions to depredation events. Nevertheless our findings might be accounted in farms that suffer chronic losses despite the presence of LGDs to see whether attacks decrease.

As is typical in ecological studies, our results might have been confounded by a number of variables that we not considered and that can still affect results. For example we considered "adult" dogs to be those older than 1.5 years (Espuno 2004, Coppinger et al. 1983), though LGDs take up to two years to mature, and before maturity juvenile play behavior can still interfere with effective guarding (Lorenz and Coppinger 1986; Rigg 2001). For van Bommel and Johnson (2012) dogs were fully effective in the third year and later.

Moreover we did not account for the dogs' characteristics and attitude to protect livestock.

To determine the conditions that enhance the effectiveness of LGDs, we focused only on few variables that could have been verified by trained personnel on field. Several similar studies relied on questionnaires that are often biased by the lack of trust between producers and researchers (Breck et al. 2012), or because it is asked to farmers to report facts and circumstances that happened in the distant past. Moreover, what farmers perceive or remember often is not true. Although it was impossible to account for all the variability that influenced the effectiveness of the guarding dogs, we reported the framework in which sometimes dogs failed to protect livestock, suggesting which husbandry practices could be improved to minimize the losses when using LGDs.

As a general role to maximize the effectiveness of LGDs, we suggest to bunch livestock into a single cohesive herd that could be guarded by the dogs. High stocking density could also benefit the animals by reducing their individual need for vigilance (Laporte et al. 2010; Breck et al. 2012), resulting in a lesser stress for sheep. Barnes (2015) recommends keeping the herd in a limited portion of the landscape at any one time, and moving it across the landscape over time (rotational grazing) to benefit rangeland and livestock, while also minimizing conflicts with large carnivores. However this option is not always applicable in Grosseto province due to the small size of the pastures that most of the times are contiguous.

Another measure that could be taken to reduce depredations is to increase human presence by keeping the sheep groups without dogs where farmer's activities occur.

References

AA.VV. 2012. Piano faunistico venatorio 2012-2017. Relazione. Provincia di Grosseto.

Abade, L., Macdonald, D. W. and Dickman, A. J. (2014) 'Assessing the relative importance of landscape and husbandry factors in determining large carnivore depredation risk in Tanzania's

Ruaha landscape', Biological Conservation. Elsevier Ltd, 180, pp. 241–248. doi: 10.1016/j.biocon.2014.10.005.
Barnes, B. M. (2015) 'Livestock Management for Coexistence with Large Carnivores , Healthy Land and Productive Ranches'.
Barton K., (2014). 'MuMIn: Multi-model inference'. R package version 1.10.5. http://CRAN.R project.org/package=MuMIn
Boitani, L., (2000). 'Action plan for the conservation of wolves in Europe (Canis lupus)', (No. 18-113). Council of Europe.
Bradley, E. H. and Pletscher, D. H. (2005) 'Assessing factors related to wolf depredation of cattle in fenced pastures in Montana and Idaho', Wildlife Society Bulletin, 33(4), pp. 1256–1265. doi: 10.2193/0091-7648(2005)33[1256:afrtwd]2.0.co;2.
Breck, S., Howery, L., Johnson, D. and Associates, H. (2012) 'A Perspective on Livestock – Wolf Interactions on Western Rangelands'.
Burnham, K.P. and Anderson, D.R., (1998). 'Model Selection and Inference'. Springer New York.
Burnham, K. P., & Anderson, D. R. (2002). 'Information and likelihood theory: a basis for model selection and inference'. Model selection and multimodel inference: a practical information-theoretic approach, 49-97.
Ciucci, P., and Boitani, L. (1998). 'Wolf and dog depredation on livestock in central Italy'. Wildlife society bulletin, 504-514.
Coppinger, R. and Coppinger, L. (1980). 'Livestock Guarding Dogs. An Old-World Solution to an Age-Old Problem'. Country Journal, 7: 68-77.'
Coppinger, R., Lorenz, J., Glendinning, J., & Pinardi, P. (1983). 'Attentiveness of guarding dogs for reducing predation on domestic sheep'. Journal of Range Management, 275-279.
Dorresteijn, I., Hanspach, J., Kecskés, A., Latková, H., Mezey, Z., Sugár, S., von Wehrden, H. and Fischer, J. (2014) 'Human-carnivore coexistence in a traditional rural landscape', Landscape Ecology. doi: 10.1007/s10980-014-0048-5.
Espuno, Nathalie, Lequette, Benoit, Marie-Lazarine, Poulle, Migot, Pierre, Jean-Dominique and Lebreton (2004) 'Heterogeneous response to preventive sheep husbandry during wolf recolonization of the French Alps', Society Bulletin Winter, 32(4).
Fritts, S.H., Stephenson, R.O., Hayes, R.D., Boitani, L. (2003) 'Wolves and humans'. Pp 289-316. In: (Mech D. and Boitani eds.): Wolves: behavior, ecology and conservation. The University of Chicago Press.
Garde, L., (2015).'Sheep farming in France: facing the return of the wolf'. Carnivore Damage Prevention News, 11, pp.17-27.
Gazzola A., Viviani A. (a cura di). (2006). 'Indagine sulla presenza storica e attuale del lupo in Toscana'. Regione Toscana.
Gehring, T. M., Vercauteren, K. C., Landry, J.-M., Gehring, T. M. ; and Vercauteren, K. C. , (2010) 'Livestock Protection Dogs in the 21st Century: Is an Ancient Tool Relevant to Modern Conservation Challenges?', BioScience, 60(299). Available at: http://digitalcommons.unl.edu/icwdm_usdanwrc.
Graham, K., Beckerman, A. P. and Thirgood, S. (2005) 'Human – predator – prey conflicts : ecological correlates, prey losses and patterns of management', 122, pp. 159–171. doi: 10.1016/j.biocon.2004.06.006.
Green, J. S., Woodruff, R. A., & Harman, R. (1984). 'Livestock guarding dogs and predator control: A solution or just another tool?'. Rangelands Archives, 6(2), 73-76.

Gusset, M., Swarner, M.J., Mponwane, L., Keletile, K. and McNutt, J.W., (2009). 'Human–wildlife conflict in northern Botswana: livestock predation by endangered African wild dog Lycaon pictus and other carnivores'. Oryx, 43(01), pp.67-72.

Kolowski, J. M. and Holekamp, K. E. (2006) 'Spatial, temporal, and physical characteristics of livestock depredations by large carnivores along a Kenyan reserve border', Biological Conservation, 128(4), pp. 529–541. doi: 10.1016/j.biocon.2005.10.021.

Landry J.-M., Millischer G., Borelli J.-L., Lyon G. (2014) 'The CanOvis Project : Studying internal and external factors that may influence livestock guarding dogs' efficiency against wolf predation', Carnivore Damage Prevention News 10 : 21-30.

Laporte, I., Muhly, T. B., Pitt, J. A., Alexander, M. and Musiani, M. (2010) 'Effects of Wolves on Elk and Cattle Behaviors : Implications for Livestock Production and Wolf Conservation', 5(8). doi: 10.1371/journal.pone.0011954.

Lele, S. R., Keim, J.L., Solymos, P., (2016).' ResourceSelection: Resource Selection (Probability) Functions for Use-Availability Data'. R package ver. 0.2-6. https://CRAN.R project.org/package=ResourceSelection

Lescureux, N. and Linnell, J. D. C. (2014) 'Warring brothers: The complex interactions between wolves (Canis lupus) and dogs (Canis familiaris) in a conservation context', Biological Conservation. doi: 10.1016/j.biocon.2014.01.032.

Lorenz, J. R., and Coppinger, L. (1986). 'Raising and Training a Livestock guarding Dog'. (Oregon State University: Corvallis, OR.).

Mech, L.D., Harper, E.K., Meier, T.J. and Paul, W.J., (2000). 'Assessing factors that may predispose Minnesota farms to wolf depredations on cattle'. Wildlife Society Bulletin, pp.623-629.

Mertens, A. and Schneider, H., (2005). 'What is wrong with Romanian livestock guarding dogs? A discussion'. Carnivore Damage Prevention News, 9, pp.9-14.

Naughton-Treves, L., (1997). 'Farming the forest edge: vulnerable places and people around Kibale National Park, Uganda'. Geographical Review, 87(1), pp.27-46.

Ogada, M. O., Woodroffe, R., Oguge, N. O. and Frank, L. G. (2003) 'Limiting Depredation by African Carnivores : the Role of Livestock Husbandry', 17(6), pp. 1521–1530.

Polisar, J., Maxit, I., Scognamillo, D., Farrell, L., Sunquist, M.E. and Eisenberg, J.F., (2003). 'Jaguars, pumas, their prey base, and cattle ranching: ecological interpretations of a management problem'. Biological conservation, 109(2), pp.297-310.

Rigg, R. (2001) 'Livestock guarding dogs: their current use worldwide'. Available at: http://www.canids.org/occasionalpaper/livestock_guarding_dogs.htm.

Rigg, R., Find'o, S., Wechselberger, M., Gorman, M. L., Sillero-Zubiri, C. and Macdonald, D. W. (2011) 'Mitigating carnivore–livestock conflict in Europe: lessons from Slovakia', Oryx, 45(2), pp. 272–280. doi: 10.1017/S0030605310000074.

Rust, N. A. and Marker, L. L. (2013) 'Cost of carnivore coexistence on communal and resettled land in Namibia', 41(1), pp. 45–53. doi: 10.1017/S0376892913000180.

Santilli, F. and Varuzza, P. (2013) 'Factors affecting wild boar (Sus scrofa) abundance in southern Tuscany', Hystrix, 24(2), pp. 169–173. doi: 10.4404/hystrix-24.2-4776.

Sedefchev, S. (2005). 'The Karakachan Dog – Continuation of an Old Bulgarian Tradition'. Carnivore Damage Prevention News, 9, pp.14-19.

Selvi, F. (2010) 'A critical checklist of the vascular flora of Tuscan Maremma (Grosseto province, Italy)', Flora Mediterranea, 20, pp. 47–139.

Shivik, J. a. (2006) 'Tools for the Edge: What's New for Conserving Carnivores', BioScience, 56(3), p. 253. doi: 10.1641/0006-3568(2006)056[0253:TFTEWN]2.0.CO;2.
Śmietana, W. (2005) 'Use of Tatra Mountains Shepherd Dog in the Bieszczady Mountains and the Bieszczady Foothills, Poland', Carnivore Damage Prevention News, 8(January), pp. 10–14. Available at: http://www.kora.ch/en/proj/cdpnews/cdpnews008.htm.
Treves, A. and Karanth, K. U. (2003) 'Human-Carnivore Conflict and Perspectives on Carnivore Management Worldwide\rConflicto entre Humanos y Carnívoros y Perspectivas de la Gestión Mundial de Carnívoros', Conservation Biology, 17(6), pp. 1491–1499. doi: 10.1111/j.1523-1739.2003.00059.x.
Urbigkit, C., and Urbigkit, J. (2010). 'A review: the use of livestock protection dogs in association with large carnivores in the Rocky Mountains'. Sheep & Goat Research Journal, 25(8).
Valeix, M., Hemson, G., Loveridge, A. J., Mills, G. and Macdonald, D. W. (2012) 'Behavioural adjustments of a large carnivore to access secondary prey in a human-dominated landscape', Journal of Applied Ecology, 49(1), pp. 73–81. doi: 10.1111/j.1365-2664.2011.02099.x.
Van Bommel, L., & Johnson, C. N. (2012). 'Good dog! Using livestock guardian dogs to protect livestock from predators in Australia's extensive grazing systems'. Wildlife Research, 39(3), 220-229.
Wickham. H, (2009). 'ggplot2: Elegant Graphics for Data Analysis'. Springer-Verlag New York.
Zarco-González, M. M., Monroy-Vilchis, O., & Alaníz, J. (2013). 'Spatial model of livestock predation by jaguar and puma in Mexico: Conservation planning'. Biological Conservation, 159, 80-87.
Zuur, A. F., Ieno, E. N. and Elphick, C. S. (2010) 'A protocol for data exploration to avoid common statistical problems', Methods in Ecology and Evolution, 1(1), pp. 3–14. doi: 10.1111/j.2041-210X.2009.00001.x.

Table 1. Summary table of the research farms.

Predation	N farms	N LGDs		N heards		N sheep		Sheep/LGD		Predator proof night shelter	N farms with sheperd	Distance home-night shelter		Predation risk	
		mean	SD	mean	SD	mean	SD	mean	SD			mean	SD	mean	SD
NO	50	3.1	2.2	2.69	1.54	394.5	303.8	154.6	115.1	18	7	447.3	1098.4	0.122	0.10
YES	29	3.2	1.8	2.60	0.86	413.9	317.5	143.5	101.4	12	5	1223.8	1667.3	0.106	0.09
Total	79	3.1	2.1	2.66	1.32	401.6	307.0	150.5	109.7	30	12	732.3	1377.6	0.116	0.09

Table 2. Results of univariate analysis of the characteristics of farm with and without depredations.

Variable	W	p-value	Variable	χ^2	p-value	df
N LGD	655	0.467	**Shelter adequacy**	0.055	0.815	1
Distance	455	0.005				
N sheep	705	0.839				
Flock/LGD	741	0.875				
Shepherd	838	0.126				
Predation risk	797	0.453				

Table 3. Top models with a Δ AICc <5 used for model averaging

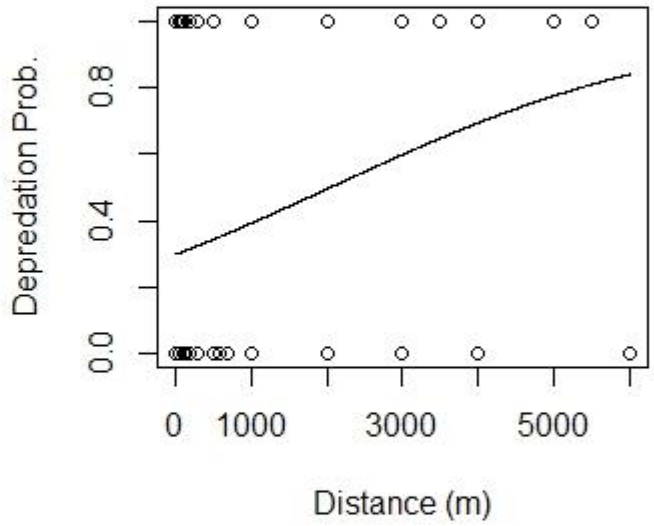
Model	K	logLik	AICc	delta	weight
Gre_Ca + Perm + Past + Dist	5	-47.332	105.5	0	0.176
Cani + Perm + Past + Dist	5	-47.378	105.6	0.09	0.169
Gre_Ca + Perm + Dist	4	-48.551	105.6	0.16	0.163
Gre + Perm + Past + Dist	5	-47.518	105.9	0.37	0.147

Table.4. Coefficient and p values obtained by averaging the top binomial regression models (Δ AICc <2) for the farm features related to a higher vulnerability to predator attacks.

Variable	Averaged coefficient	p value	Weight
Gre_Ca	-0.0010	0.643	0.52
PermF	0.3378	0.517	1
Past	-0.8492	0.304	0.75
Dist	0.0005	0.022	1
Cani	0.0196	0.786	0.26
Gre	0.0001	0.891	0.22

Figure1. Distribution of monitored farms within Grosseto province.

Figure 2. Positive correlation between nigh shelter-farmer house distance and depredation probability.



CHAPTER 5

DISCUSSION

This research showed how the ecological context could be used at different scales of analysis to limit wolf depredations on livestock.

On a broader scale, the environmental variables were used to detect higher depredation risk zones where the implementation of protective measures should be seriously considered. Whereas on a finer-scale, environmental variables were analyzed along with husbandry practices, in order to understand how farm's local conditions could affect the use of one of the most valued protective tool against wolf depredation: the livestock guarding dog (LGD).

The topics were analyzed taking into account the critical issues that characterized some of the previous studies on the same subject. Specifically have been identified as necessary (Ciucci et al. 2005):

1. developing predictive models for the identification of potential conflict areas and conditions that increase the depredation risk in order to promptly prevent the attacks.
2. refining and implementing more objective sampling methods that can provide higher resolution data. Most of the studies on depredation, in fact, were largely descriptive and based on indirect data;
3. refining survey and analytical protocols.

The first objective of this research was, then, producing a wild canid depredation risk map proposing a new three-step method and an alternative approach to model only-presence data.

Using that map it was possible to infer that depredations are more likely to occur in areas with landscape features, such as the smaller watercourses network and the forests, which allow wild canids to reach pastures with minimum effort. The ultimate significance of depredation risk models was recently questioned as they are based on landscape attributes associated only to livestock kill data (Miller 2015). Instead, the environmental features describing locations where attacks were unsuccessful or where attacks did not occur are not considered. Therefore it was argued (Hebblewhite et al. 2005) that spatial risk models quantify the realized predation risk (where direct mortality occurs) rather than the overall fundamental predation risk (where mortality and indirect non-consumptive effects may occur). Recognizing this distinction could be notable to better understand the extent of the non-consumptive effects of predators on livestock stress (Miller 2015). Livestock producers, indeed, are often concerned about the consequences of the risk effects of predators in general on livestock, such as increased stress and reduced foraging time which results in less weight gain and milk production or more difficulties in rebreeding and producing offspring (Howery and DeLiberto 2004, Muhly et al. 2009).

Nevertheless considering scale of analysis used in my study, distinguish from fundamental and realized predation risk was not possible since pastures, where livestock were confined, were smaller than map's resolution.

At farm level, management choices that increase livestock accessibility seem to predispose farms to depredation more than environmental variables do (Ciucci and Boitani 1998, Bradley and Pletscher 2005, Musiani et al. 2005, Gazzola et al. 2008, Iliopoulos 2009, Linnell et al. 2012, Barnes et al. 2015).

Usually farmers protect their livestock using shepherds, dogs and electric or traditional fences (Mertens et al. 2005, Iliopoulos et al. 2009). In addition they can adopt some practices as clumping livestock into fenced pastures, penning the animals during nighttime, synchronizing calving/lambing (Breck 2012, Barns 2015).

However the great variability of situations in which depredations occur precludes the possibility that a single method or husbandry practice can be the most effective to solve the problem. Rather, different approaches should be integrated depending on the context and needs of the individual farmer (Ciucci and Boitani 2005).

Despite other preventive tools are also widely used, I focused only on LGDs because they have been used and fine-tuned for at least 6000 years (Rigg 2001), are widespread and highly adaptable to different contexts and types of livestock management (Rigg et al. 2011, van Bommel and Johnoson 2012, Lescureux and Linnell 2014). Moreover their use is expected to increase in the coming years as wolf, bear and lynx populations are recovering (Chapron et al. 2014). Several carnivore conservation programs in fact, are proposing LGDs as a preventive tool where their traditional use was lost due to the prolonged absence of large carnivores. However promoting the use of LGD should be done accounting for the changes occurred over the last centuries in the ecology of the environments and the social, cultural and economic systems surrounding pastoralism (Linnell and Lescureux 2015). Moreover, the environmental impacts that an increasing number of these free ranging dogs can potentially cause should also be considered (Vanak and Gompper 2009). In fact it is known that dogs, when not properly managed, can kill wildlife and livestock, can hybridize with wild canids and may act as reservoir for diseases (Kopaliani et al. 2014, Lescureux and Linnell 2014, Wierzbowska et al. 2016). From this perspective improving our knowledge on how the LGDs work in the current agro-pastoral context is of paramount importance in order to suggest how to maximize the effectiveness of these dogs and minimize the likelihood of further contributing to the well-known problems associated with free ranging dogs.

Livestock guarding dogs can deter predators to approach livestock even though, like the other preventive measures, they are not unfailing. As I pointed out in the second and third sections of this research, husbandry practices and environmental features can impact on the effectiveness of guarding dogs. In order to protect livestock, dogs should stay close to them. Analyzing GPS data of LGDs and sheep emerged that LGDs spent the majority of their time close to livestock and the dog-sheep distance was mostly influenced by environmental variables and the age of the dog. However to be effective, dogs should be used in an appropriate farming context. Therefore I highlighted some conditions that could decrease the efficacy of LGDs in reducing depredations. These were poor human presence, and the practice of dividing the heard in sub-units, some of which were left without dogs.

Depredations are inherently multivariate events, thus studying their occurrence means accounting for a considerable number of variables (Bradley and Pletscher 2005). The effect of husbandry, ecological and environmental factors and their interactions make it overly complex controlling the study context (Ciucci and Boitani 2005).

To develop the depredation risk map only wild canid and depredation occurrences that were verified on field by trained personnel were retained. Specific protocols set up for collecting these data were followed. In order to model these only-presence data, a new approach called Bayesian for Presence-Only Data (BPOD) was successfully used to overcome some of the limitation of Maximum Entropy (Maxent). One of the disadvantages of Maxent, which was also observed in this work, is that the prediction area is generally smaller contrasted to the results from other algorithms (Zarco-González et al. 2013). This tendency may have serious consequences in risk maps as lead to underestimate the potential risk area.

Another problematic approach in depredation studies is the extensive use of questionnaires as they provide subjective, and sometimes misleading, information (Graham et al. 2005). In this study farmer interviews were not considered a good approach to record the conditions of sheep farms with livestock guarding dogs. In fact although the effectiveness of preventive methods hinges on livestock management and ecological contexts (Shivik 2004), it is how these measures are implemented (whether or not correctly) that makes all the difference. For instance, declaring to having predator-proof fences doesn’t necessarily means that livestock is safe within them. There might be cases where the fence is not complete or is damaged and allows predators to get in. Alternatively farmers may consider as predator-proof fences that really are not. On these occasions the presence of predator-proof fence will be wrongly related to predation occurrence. Including only visual checked data was then preferred to keep from adding further error sources, albeit some potential useful information went lost.

Nowadays collecting more objective data is possible thanks to the development of new technologies. For example GPS collars enabled researchers to investigate how LGDs actually behave (e,g. van Bommel 2014). Studies on LGDs were mostly oriented at evaluating their effectiveness through satisfaction questionnaires (Marker et al. 2005), censuses of livestock losses (Andelt 1992) and focal animal sampling (Coppinger et al. 1983, Ribeiro and Petrucci-Fonseca 2005, Tedesco and Ciucci 2005). Although traditional approaches offer valuable information, they pose limits to investigate other interesting aspects of LGDs. Focal sampling for instance, is labor intensive, can affect subject behavior, and usually does not offer 24-h monitoring over an extended period (Gipson et al. 2012). In this research such limits have been overcome using GPS collars to collect accurate locations also during nighttime without interfering with subject behavior. A large amount of spatial data allowed assessing the spatial bonding between sheep and LGDs using two new metrics: the real distance between sheep and dog, and the overlap of their movement range. Moreover it was possible to relate some environmental features to the dog tendency to bond with the flock, a poorly addressed but meaningful aspect in damage prevention. In fact dog-sheep bonding affects the most relevant functional mechanisms for the effectiveness of the guarding dog (Tedesco and Ciucci 2005) as it is simply by its presence that an LGD can deter a predator from attack livestock (Coppinger et al. 1988).

As ecological interactions between species are complex, my conclusions are not free of confounding factors.

Factors related to wolf ecology were only partially accounted, as were limited at the environmental features associated with the wolf probability of occurrence. However several other aspects of wolf ecology such as: the individual wolf's attitude to prey on domestic animals, the phase of predator's life cycle and biology, the distribution of dens and rendezvous sites, packs size and number, could influence the depredation rate (Ciucci and Boitani 2005, Marucco and McIntire 2010, Behdarvand et al. 2014). Unfortunately most of the time, these information are difficult to gather since require a great effort in terms of time, logistics and expenditure. Consequently proxies and generalization such as predictive models of wolf presence are often used instead.

The timing of depredations is another important variable that was not considered. It has been demonstrated that wolves attack livestock more frequent in some periods of the years, namely in summer and early autumn (Ciucci and Boitani 1998, Musiani et al. 2005, Gazzola et al. 2008, Iliopoulos et al. 2009, Li et al. 2013). The recurrence of depredation events ground partially in wolf biology since the peaks of depredation coincided with the period when wolf pup require large food intake. On the other hand, from May to September livestock are left grazing free range significantly longer and are thus more vulnerable to predation.

Therefore, of the whole set of variables and their interactions that could drive depredations to happen, I've considered just a few of them, giving some examples on how the ecological variables can be used to prevent damages.
However bringing back the negative impact of predators on livestock activities to sustainable levels through damage prevention only affect the surface of the problem.
Although wolf damage has been widely cited as a reason for conflict, subsequent management policies and programs aimed at reducing such damage has not resulted in long-term conflict resolution (Naughton-Treves et al. 2003; Young et al. 2015). Indeed, just because a particular technical solution may be effective at reducing impacts does not mean that conflicts between conservation and livelihood objectives are addressed (Redpath et al. 2015). If the physical threat to and economic value of the livestock were the only concerns, affected livestock producer's problems would be sufficiently addressed by compensating losses, educating livestock owners in preventive measures, and providing technical support to implement such measures (Bangs et al. 2005, Breck 2004, Musiani and Paquet 2004, Madden and McQuinn 2014). Unfortunately, in many cases technical assistance and compensation have remained ineffective (Naughton-Treves et al. 2003).
This is not surprisingly considering that although the random wolf effect adds another source of risk to livestock production (that is an inherently risky business), actually the output price variability is the most significant driver of risk (Steele et al. 2013). Secondly it is well recognized that half of the challenge of addressing the conflict depends on the social, political, economic, cultural contexts of human populations, and legal complexities (Madden 2004, Young et al. 2015).
Deep-rooted social conflict is one of the most powerful factors that undermine tolerance toward predators (Naughton-Treves et al. 2003, Madden and McQuinn 2014), making hard any dialogue among stakeholders which do not see recognized their respective needs as important. It is not rare that these needs have nothing to do with wildlife but rather are linked to the livelihood of rural areas and people's wealth (Madden 2004).
In other cases farmers or hunters may experience wildlife protection laws as an infringement upon their sense of autonomy (Simon 2013).
Therefore coexistence should be bottom up, practical, science-based, and collaborative, rather than top down and regulatory (Barnes 2015). In this regard, Conflict Transformation approach (CT) could be a promising tool to mitigate human wildlife conflict as represent the capacity to envision and the willingness to respond to conflict positively, as a natural phenomenon that creates potential for constructive growth (Lederach 2003 cited in Madden and McQuinn 2014).
Human perception is another key factor that should not be undervalued since perception, not fact, often determines people's tolerance in conflict resolution (Dickman, 2010), and affects their behavioral intention (Young et al. 2015).

A greater effort is needed to effectively communicate to the general public the scientific knowledge about wildlife, and its real impact on human activities. A first step could be reconsidering the terministic screen formed by the phrase "human–wildlife conflict" as it may label nature as threatening, leading to misunderstanding and ultimately a negative consequences for nature (Peterson et al. 2010, Redpath et al. 2015). Researchers proposed instead human–wildlife coexistence (Peterson et al. 2010).
Therefore, although technical approaches aimed to reduce damages are an important part of the solution, encouraging dialogue between the interest groups to understand mutual goals, exploring the evidence and negotiate ways forward, it is equally important (Redpath et al. 2013, 2015).

Management implication

Investigating the role of some of the variables involved in depredation events helps to ensure that the wolf-livestock interactions occur in a sustainable manner.
The identification of environmental conditions associated with livestock predations could be used to generate predictive spatial models and identify high-risk areas, allowing the implementation of preventive measures where they are primarily needed (Zarco-González et al. 2012). Both farmers and carnivores will benefit from the timely application of prevention techniques that reduce depredation (Musiani et al. 2005, Rainhardt et al. 2012, Rust and Marker 2013). Predation risk models and maps point the way to more selective interventions at various scales (Kaartinen et al. 2009, Zarco-González et al. 2012, Miller et al. 2015). Using depredation risk map like the one proposed in this work, private citizens may be able to select routes for grazing, modify activities, animal husbandry, or habitats to reduce livestock vulnerability with a diverse array of antipredator deterrents (Treves et al. 2009). Managers can focus prevention efforts and mitigation measures in high risk areas working proactively with residents on cost-effective preventions. Policymakers may use risk maps to allocate financial resources for livestock insurance or compensation schemes (Laporte et al. 2010). Finally future conservation projects may benefit from these maps to select areas of intervention.
A better knowledge of the characteristics of preventive tools in relation to the context in which they are implemented could increase their effectiveness in reducing wolf damages (Breck et al. 2012, Barnes 2015). Results from this work provide some hints for farmers and conservationists to improve the use of LGDs for an effective livestock protection: some of the recommendations affect the dog management, while other the livestock husbandry practices.
During the early stages of the dog's work, particular attention should be given to those dogs that follow the sheep in pastures interspersed by forests. Young dogs that work close to wooded areas in fact are more likely to move away from the flock. If not promptly correct, wrong behavior can lead

to dogs that are not interest in livestock protection and thus may start to wander or to return to the barn or the farmer's home. In this regard GPS pet collars could provide a very useful tool for a proper management of LGDs. On the other hand, the use of these devices to collect data could allow the direct involvement of the farmers with whom sharing different expertise.

The effectiveness of guarding dogs as a prevention tool is not only affected by the environmental features or by LGD's characteristics and training. In fact, to be effective, livestock guarding dogs should work in conditions that allow them to protect the entire livestock. Therefore, in situations where the herd is often divided into several groups in which the presence of the dog is not guaranteed, as in Grosseto province, the use of guarding dogs will be more effective when combined with increased human presence. The best strategy would be then to gather the sheep into one group or otherwise when it is not possible, to graze the sheep groups without dogs close to the center of farmer's activity.

Generalizing, collaboration, innovation, and integrated actions, are the key components to effectively prevent depredation and mitigate wolf-livestock conflict (Madden 2004).

References

Andelt, W. F. 1992. Effectiveness of livestock guarding dogs for reducing predation on domestic sheep. Wildlife Society Bulletin, 20(1), pp. 55–62.

Bangs, E.E., Fontaine, J.A., Jimenez, M.D., Meier, T.J., Bradley, E.H., Niemeyer, C.C., Smith, D.W., Mack, C.M., Asher, V. and Oakleaf, J.K., 2005. Managing wolf-human conflict in the northwestern United States. CONSERVATION BIOLOGY SERIES-CAMBRIDGE-, 9, p.340.

Barnes, B. M. 2015. Livestock Management for Coexistence with Large Carnivores , Healthy Land and Productive Ranches. Keystone Conservation Bozeman, Montana, USA.

Behdarvand, N., Kaboli, M., Ahmadi, M., Nourani, E., Mahini, A.S. and Aghbolaghi, M.A., 2014. Spatial risk model and mitigation implications for wolf–human conflict in a highly modified agroecosystem in western Iran. Biological Conservation, 177, pp.156-164.

Bradley E. H., Pletscher D. H. 2005. Assessing factors related to wolf depredation of cattle in fenced pastures in Montana and Idaho. Wildlife Society Bulletin, 33(4), 1256-1265.

Breck, S.W., 2004. Minimizing carnivore-livestock conflict: The importance and process of research in the search for coexistence. People and predators: from conflict to coexistence, pp.13-17.

Breck, S., Clark, P., Howery, L., Johnson, D., Kluever, B., Smallidge, S. and Cibils, A., 2012. A perspective on livestock–wolf interactions on western rangelands. Rangelands, 34(5), pp.6-11.

Chapron G., Kaczensky P., Linnell J. D., Von Arx M., Huber D., Andrén H., ... & Nowak S. 2014 Recovery of large carnivores in Europe's modern human-dominated landscapes, Science, 346(6216), 1517-1519.

Ciucci P., Boitani L. 1998. Wolf and dog depredation on livestock in central Italy. Wildl. Soc. Bull. 26, 504–514.

Ciucci, P. and Boitani, L.2005. Conflitto tra lupo e zootecnia in Italia: stato delle conoscenze, ricerca e conservazione. Grandi Carnivori e Zootecnia tra conflitto e coesistenza. Biol. Cons. Fauna 115: 26-52

Ciucci P., Teofili C., Boitani L. (a cura di), 2005 - Grandi Carnivori e Zootecnia tra conflitto e coesistenza.Biol. Cons. Fauna 115: 1-192

Coppinger, R., Lorenz, J., Glendinning, J., & Pinardi, P. 1983. Attentiveness of guarding dogs for reducing predation on domestic sheep. Journal of Range Management, 275-279.

Coppinger, R., Coppinger, L., Langeloh, G., Gettler, L. and Lorenz, J., 1988. A decade of use of livestock guarding dogs.

Dickman, A.J., 2010. Complexities of conflict: the importance of considering social factors for effectively resolving human–wildlife conflict. Animal conservation, 13(5), pp.458-466.

Gazzola, A., Capitani, C., Mattioli, L. and Apollonio, M., 2008. Livestock damage and wolf presence. Journal of Zoology, 274(3), pp.261-269.

Gipson, T. a., Sahlu, T., Villaquiran, M., Hart, S. P., Joseph, J., Merkel, R. C. and Goetsch, a. L. 2012. Use of global positioning system collars to monitor spatial-temporal movements of co-grazing goats and sheep and their common guardian dog. Journal of Applied Animal Research, 40(4), pp. 354–369. doi: 10.1080/09712119.2012.692475.

Graham, K., Beckerman, A.P. and Thirgood, S., 2005. Human–predator–prey conflicts: ecological correlates, prey losses and patterns of management. Biological Conservation, 122(2), pp.159-171.

Hebblewhite, M., Merrill, E.H. and McDonald, T.L., 2005. Spatial decomposition of predation risk using resource selection functions: an example in a wolf–elk predator–prey system. Oikos, 111(1), pp.101-111.

Howery, L.D. and DeLiberto, T.J., 2004. Indirect effects of carnivores on livestock foraging behavior and production.

Iliopoulos, Y., Sgardelis, S., Koutis, V. and Savaris, D., 2009. Wolf depredation on livestock in central Greece. Acta theriologica, 54(1), pp.11-22.

Kaartinen, S., Luoto, M. and Kojola, I., 2009. Carnivore-livestock conflicts: determinants of wolf (Canis lupus) depredation on sheep farms in Finland. Biodiversity and Conservation, 18(13), pp.3503-3517.

Kopaliani, N., Shakarashvili, M., Gurielidze, Z., Qurkhuli, T. and Tarkhnishvili, D., 2014. Gene flow between wolf and shepherd dog populations in Georgia (Caucasus). Journal of Heredity, 105(3), pp.345-353.

Lescureux, N. and Linnell, J. D. C. 2014. Warring brothers: The complex interactions between wolves (Canis lupus) and dogs (Canis familiaris) in a conservation context. Biological Conservation. doi: 10.1016/j.biocon.2014.01.032.

Li, X., Buzzard, P., Chen, Y. and Jiang, X., 2013. Patterns of livestock predation by carnivores: human–wildlife conflict in Northwest Yunnan, China. Environmental management, 52(6), pp.1334-1340.

Linnell, J.D., Odden, J. and Mertens, A., 2012. Mitigation methods for conflicts associated with carnivore depredation on livestock. Carnivore ecology and conservation: a handbook of techniques, pp.314-332.

Linnell, J.D.C. and Lescureux, N. 2015. Livestock guarding dogs-cultural heritage icons with a new relevance for mitigating conservation conflicts. Norwegian Institute for Nature Research, Trondheim.76pp

Madden, F., 2004. Creating coexistence between humans and wildlife: global perspectives on local efforts to address human–wildlife conflict. Human Dimensions of Wildlife, 9(4), pp.247-257.

Madden, F. and McQuinn, B., 2014. Conservation's blind spot: the case for conflict transformation in wildlife conservation. Biological Conservation, 178, pp.97-106.

Marker, L.L., Dickman, A.J. and Macdonald, D.W., 2005. Survivorship and causes of mortality for livestock-guarding dogs on Namibian rangeland. Rangeland ecology & management, 58(4), pp.337-343.

Marucco F., McIntire E. J. B. 2010. Predicting spatio-temporal recolonization of large carnivore populations and livestock depredation risk: wolves in the Italian Alps. Journal of Applied Ecology, 47(4), 789-798.

Mertens, A. and Promberger, C., 2001. Economic aspects of large carnivore-livestock conflicts in Romania. Ursus, pp.173-180.

Miller, J.R., 2015. Mapping attack hotspots to mitigate human–carnivore conflict: approaches and applications of spatial predation risk modeling. Biodiversity and Conservation, 24(12), pp.2887-2911.

Muhly, T.B. and Musiani, M., 2009. Livestock depredation by wolves and the ranching economy in the Northwestern US. Ecological Economics, 68(8), pp.2439-2450.

Musiani, M., Mamo, C., Boitani, L., Callaghan, C., Gates, C.C., Mattei, L., Visalberghi, E., Breck, S. and Volpi, G., 2003. Wolf depredation trends and the use of fladry barriers to protect livestock in western North America. Conservation Biology, 17(6), pp.1538-1547.

Musiani, M. and Paquet, P.C., 2004. The practices of wolf persecution, protection, and restoration in Canada and the United States. BioScience, 54(1), pp.50-60.

Musiani, M., Muhly, T., Gates, C.C., Callaghan, C., Smith, M.E. and Tosoni, E., 2005. Seasonality and reoccurrence of depredation and wolf control in western North America. Wildlife Society Bulletin, 33(3), pp.876-887.

Naughton-Treves, L., Grossberg, R. and Treves, A., 2003. Paying for tolerance: rural citizens' attitudes toward wolf depredation and compensation. Conservation biology, 17(6), pp.1500-1511.

Peterson, M.N., Birckhead, J.L., Leong, K., Peterson, M.J. and Peterson, T.R., 2010. Rearticulating the myth of human–wildlife conflict. Conservation Letters, 3(2), pp.74-82.

Redpath, S.M., Young, J., Evely, A., Adams, W.M., Sutherland, W.J., Whitehouse, A., Amar, A., Lambert, R.A., Linnell, J.D., Watt, A. and Gutiérrez, R.J., 2013. Understanding and managing conservation conflicts. Trends in Ecology & Evolution, 28(2), pp.100-109.

Redpath, S.M., Bhatia, S. and Young, J., 2015. Tilting at wildlife: reconsidering human–wildlife conflict. Oryx, 49(02), pp.222-225.

Reinhardt, I., Rauer, G., Kluth, G., Kaczensky, P., Knauer, F. and Wotschikowsky, U., 2012. Livestock protection methods applicable for Germany–a Country newly recolonized by wolves. Hystrix, the Italian Journal of Mammalogy, 23(1), pp.62-72.

Ribeiro, S. and Petrucci-Fonseca, F. 2005. The Use of Livestock Guarding Dogs in Portugal Carnivore Damage Prevention News, 9, pp.27-34.

Rigg, R. 2001. Livestock guarding dogs: their current use worldwide', The Canid Specialist Group, (1), p. 133.

Rigg, R., Find'o, S., Wechselberger, M., Gorman, M.L., Sillero-Zubiri, C. and Macdonald, D.W., 2011. Mitigating carnivore–livestock conflict in Europe: lessons from Slovakia. Oryx, 45(02), pp.272-280.

Rust, N.A. and Marker, L.L., 2013. Attitudes toward predators and conservancies among Namibian farmers. Human Dimensions of Wildlife, 18(6), pp.463-468.

Shivik, J. A. 2004. Non-lethal alternatives for predation management. Sheep and Goat Research Journal 19:64–71.

Simon, A., 2013. A historical and case study analysis of the reasons why many trophy hunters are hostile toward wolves and wolf advocates. Capitalism Nature Socialism 24 (1), 104–120.

Tedesco, E. and Ciucci, P. 2005. Monitoraggio dell'efficienza dei cani da guardiania: applicazione preliminare sui cani dati in affidamento nell'arco alpino. Grandi Carnivori e Zootecnia tra conflitto e coesistenza. Biol. Cons. Fauna 115: 181-190

Steele J. R., Rashford B. S., Foulke T. K., Tanaka J. A., Taylor D. T. 2013. Wolf (Canis lupus) predation impacts on livestock production: direct effects, indirect effects, and implications for compensation ratios. Rangeland Ecology and Management, 66(5), 539-544.

Treves, A., Wallace, R.B. and White, S., 2009. Participatory planning of interventions to mitigate human–wildlife conflicts. Conservation Biology, 23(6), pp.1577-1587.

van Bommel, L., and Johnson, C. N. 2012. Good dog! Using livestock guardian dogs to protect livestock from predators in Australia's extensive grazing systems. Wildlife Research, 39(3), 220-229.

van Bommel, L. and Johnson, C. N. 2014. Where do livestock guardian dogs go? Movement patterns of free-ranging Maremma sheepdogs. PLoS ONE, 9(10), pp. 1–12. doi: 10.1371/journal.pone.0111444.

Vanak, A.T. and Gompper, M.E., 2009. Dogs Canis familiaris as carnivores: their role and function in intraguild competition. Mammal Review, 39(4), pp.265-283.

Wierzbowska, I.A., Hędrzak, M., Popczyk, B., Okarma, H. and Crooks, K.R., 2016. Predation of wildlife by free-ranging domestic dogs in Polish hunting grounds and potential competition with the grey wolf. Biological Conservation, 201, pp.1-9.

Young, J.K., Ma, Z., Laudati, A. and Berger, J., 2015. Human–Carnivore Interactions: Lessons Learned from Communities in the American West. Human Dimensions of Wildlife, 20(4), pp.349-366.

Zarco-González M. M., Monroy-Vilchis O., Rodríguez-Soto C., Urios V. 2012. Spatial factors and management associated with livestock predations by Puma concolor in Central Mexico. Human ecology, 40(4), 631-638.

Zarco-González M. M., Monroy-Vilchis O., Alaníz J. 2013. Spatial model of livestock predation by jaguar and puma in Mexico: Conservation planning. Biological Conservation, 159, 80-87.