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Research Article

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.

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

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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 4504 km^2. With only 5 residents per square kilometer, Grosseto is among the Italian provinces with the smallest population densities. Apart from Mt. Amiata (1738 m asl) and the mountainous group of Colline Metallifere (1060 m asl) in the northern part, the Province is hilly country. 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 1150 sheep farms (please see Supplemental Figure S2) with 194422 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

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

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.

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 10000, 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 (15000), the burn-in (10000), 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.

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

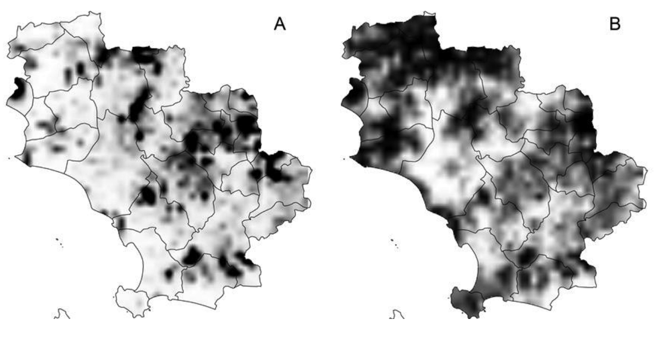

Figure 1 – Distribution of wild canid probability of occurrence Maxent model using (A) and BPOD model (B). Darker areas show were wolves are more likely to occur.

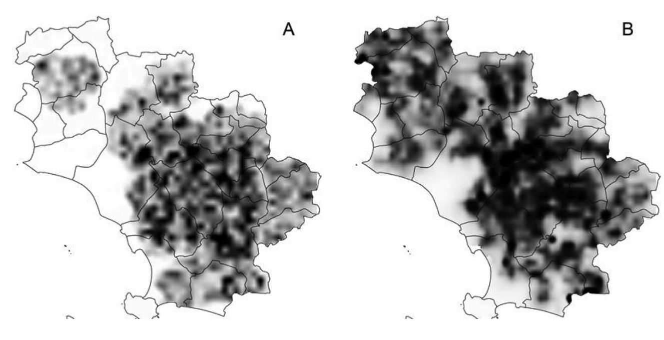

Figure 2 – Maxent model (A) and BPOD model (B) of depredation event probability. Areas with higher probability of depredation are darker.

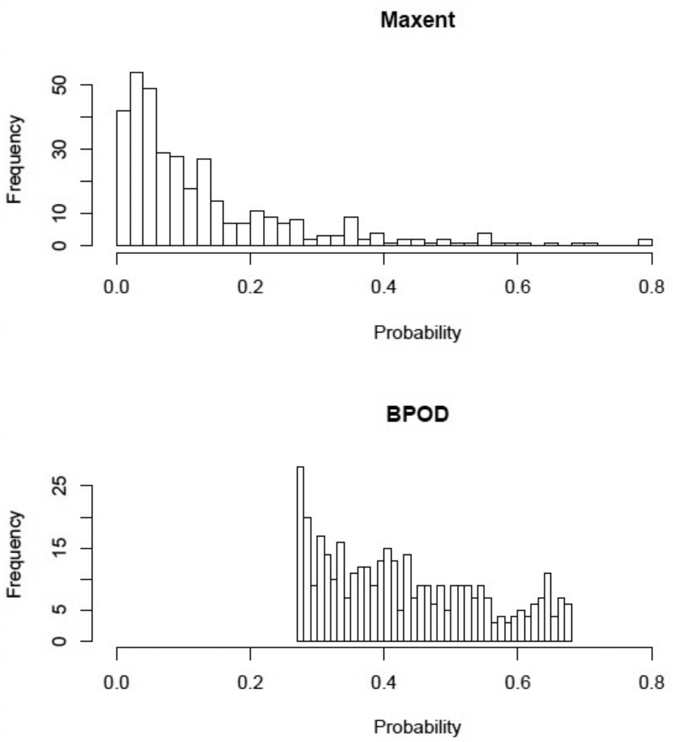

Figure 3 – Distribution of probability of wild canid occurrence in cells with sheep density and probability of livestock depredation events above the threshold.

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.

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.

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 S3 for the risk map estimated using Maxent).

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 (1150) fall within higher risk area, suggesting that depredation is facilitated by environmental conditions, rather than by the availability of domestic prey alone.

Discussion

According to our results, wild canids are widely distributed in the Grosseto province. Compared to brown bears and lynx, wolves and wolf-dog

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

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 and 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

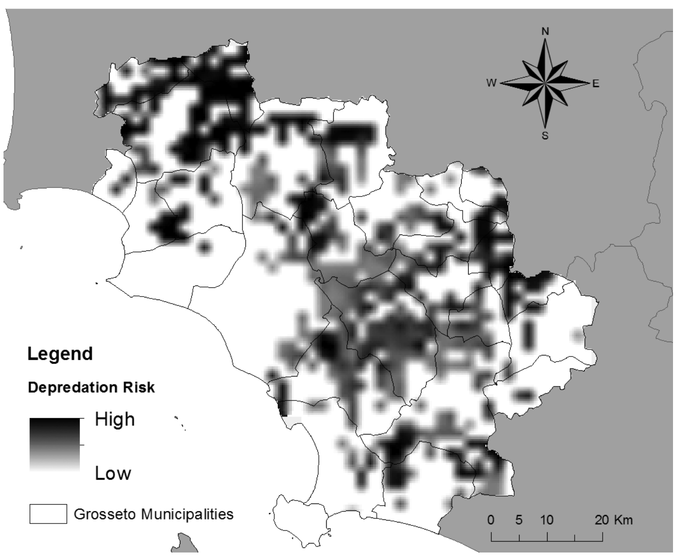

Figure 4 – Predictive map of livestock depredation risk by wild canids in the Grosseto province. Darker color indicates the areas with higher depredation risk.

and Pletscher, 2005). Nevertheless, livestock accessibility, in line with Ciucci and Boitani (1998)'s 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-González 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-González et al., 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-González 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 et 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., 2013). 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 et 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.

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Supplemental information

Additional Supplemental Information may be found in the online version of this article:

Table S1 Result of ENFA analysis.

Figure S2 Distribution of sheep farms, waterways and forests within the study area.

Figure S3 Predictive map of livestock depredation risk by wild canids in the Grosseto province using Maxent.