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Type

Short note

Keywords

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Abstract

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Explanation letter

Dear Editor in Chief,
We thank the subject Editor and the associate editor for this minor revision. We have made these two corrections to the text following their suggestions.
Yours sincerely,
Alessandro Forti (on behalf of all co-authors)

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Spatial avoidance between red deer and cattle in alpine pastures

Alessandro Forti[1, 2, *], Matteo Nava[3], Alessia Bortoloni[2], Valentina Sommei[2], Camilla Luzzago[2,4], Luca Pedrotti[1, 5], Luca Corlatti[1, 6]

[1] Stelvio National Park – Ersaf Lombardia, Via De Simoni 42, 23032 Bormio, SO, Italy

[2] Department of Veterinary Medicine, Università degli Studi di Milano, Via dell'Università 6, 26900 Lodi, Italy

[3] Department of Biosciences, University of Milan, 20133 Milano, Italy

[4] Coordinated Research Center "EpiSoMI", Università degli Studi di Milano, Milano, Italy

[5] Sustainable Development and Protected Area Service, Stelvio National Park Office, Autonomuos Province of Trento, Via Roma 65, 38124 Cogolo di Peio, TN, Italy

[6] University of Freiburg, Chair of Wildlife Ecology and Management, Tennenbacher Straße 4, 79106 Freiburg, Germany

***Corresponding author**: alessandro.forti90@gmail.com

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Abstract

The interaction between wild and domestic ungulates may have positive or negative effects. Cattle grazing, for example can preserve open space and improve forage quality but also decrease forage availability and favor disease transmission. Consequently, multiple patterns of space use can be expected between wild ungulates and livestock. Here, we investigate the spatial overlap between red deer (*Cervus elaphus*) and cattle in alpine summer pastures in the Stelvio National Park (central Italian Alps), using pellet groups counts estimated with distance sampling for red deer and bovine scats estimated with strip transects. After accounting for environmental covariates, our results showed that with increasing bovine scat density, red deer pellet group density decreased. These results suggest that red deer may avoid bovines, though other mechanisms (e.g., human presence) may concur to trigger spatial avoidance. Understanding the drivers of the interactions between wildlife and livestock in Italian Alps would help conservation measures by enhancing coexistence on pastures.

Keywords: avoidance, cattle, distance sampling, pastures, pellet group counting, red deer

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In the last decades, the distribution and densities of wild ungulates have increased steadily throughout Europe (Apollonio et al., 2010), with red deer (*Cervus elaphus*) being one of the most abundant species, especially in protected areas (Carpio et al., 2021). At the same time, open air livestock breeding increases the risk of contact between wildlife and livestock (Gortázar et al., 2007). The influence of domestic herbivores, particularly cattle (*Bos taurus*), on wild ungulates has been extensively studied, e.g., in North America (Loft et al., 1991; Wallace and Krausman, 1987), Africa (Hibert et al., 2010) and Europe (Martin et al., 2011; Gordon, 1988; Osborne, 1984).

Domestic ungulates can impact wild herbivore communities either positively or negatively (Schieltz and Rubenstein, 2016). Controlled cattle grazing, for example, may improve forage quality (Vavra and Sheehy, 1996): on the Isle of Rum (Scotland), winter grazing by cattle seemingly increased the amount of forage available to red deer in the following spring (Gordon, 1988). The shared use of resources, however, may cause spatial interference (Madhusudan, 2004), direct competition and favor the transmission of pathogens (Ferroglio et al., 2011; Martin et al., 2011). Nonetheless, information on the overlap in the use of Alpine pastures between wild and domestic ungulates is poor (Mattiello et al., 2002; Schieltz and Rubenstein, 2016).

In this study we investigate the effect of cattle on the abundance of red deer in Alpine pastures. Specifically, we aim to assess the spatial overlap between these two species on summer pastures.

We conducted our study in the central Italian Alps, in the Lombardy sector of the Stelvio National Park (SNP). In the SNP, local red deer density can seasonally reach values up to 27 ind./km^2 (Corlatti et al., 2016); hunting is not allowed and in our study area there is no stable presence of large carnivores. The study area consists of Alpine and subalpine meadows dominated by formations of Alpine sedge (*Carex curvula*), Haller's fescue (*Festuca halleri*), coloured fescue (*Festuca varia*), blue moor-grass (*Sesleria caerulea*), evergreen sedge *(Carex sempervirens*) and Nardus grassland, rarely mixed with bilberry (*Vaccinium myrtillus*), rhododendron (*Rhododendron*

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ferrugineum) or dwarf juniper (*Juniperus nana*). At lower elevations, pastures are surrounded by coniferous forests, mostly spruce (*Picea abies*).

To investigate the occurrence of spatial avoidance between red deer and cattle, we collected data on both species in 21 pasture areas (min. 2.5 ha, max. 5 ha), distributed between 1870 m a.s.l. and 2489 m a.s.l.. The boundaries of the sampling sites were defined based on the area used by cattle; where cows were absent, we chose grasslands whose extent was similar to the average size of the areas where cows were present, to avoid inconsistencies. To estimate deer pellet group (PG) density, we used a distance sampling approach (Buckland et al., 2001). First, we followed a systematic design where, in each of the 21 areas, 30 parallel transects of 50 m were identified and superimposed onto the survey region with the software *Distance* 7.3 (Thomas et al., 2010), using random starting points to avoid subjective deployment of transects. As the slope may affect PG detectability, we chose to orient all line transects perpendicularly to the maximum slope. Transects were considered as sampling units for encounter rate variance estimation with respect to the distribution of the red deer PGs within the sampling area. Distance sampling was performed in two occasions, in June and September 2020. In the absence of information about PG decay rate, density values of different occasions were averaged to obtain deer PG density over the cattle grazing period; potential issues of varying decay rate across areas (as a function of area-specific features) are accounted for in subsequent regression analysis. PGs were searched by eye and their perpendicular distance from the transect was measured with a graduated rod divided into bins of 20 cm. A 5 m truncation distance was set a priori to avoid misidentification of PGs; the minimum distance between adjacent transects was 10m, thereby ensuring avoidance of contagion among transects when counting PGs. The *ds* function in the R *distance* package (Miller et al., 2019) was used to estimate the abundance and density of the observed red deer PGs. Specifically, we used a Multiple Covariate Distance Samping (MCDS) approach (Marques et al. 2007) where the 21 areas were fitted as an individual covariate. We modeled detection by fitting three key functions (half-normal, uniform and hazard-rate) with adjustment terms (cosine, simple polynomial and Hermite

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polynomial) (Buckland et al., 2001). Model selection was based on the Akaike Information Criterion (AIC, Burnham and Anderson, 2002). Cattle occurred in 12 of the 21 areas. To estimate bovine scat density in these areas, in August 2020 we walked 4 strip transects (McClintock and Thomas, 2020) of 100 x 4 m, and the number of cow scats was used to obtain bovine scat density over the entire pasture. Therefore, our data returned deer PG and bovine scat density per hectare, which were used as proxies of animal density. We acknowledge that cattle could affect red deer PG detection probability, for example by trampling; since we deem unlikely that PGs could be destroyed entirely, we tried to minimize this issue by considering a PG when this had a number of individual pellets as low as 6, produced in the same defecation event (i.e., of similar size, texture and color, *cf*. Mayle et al. 1999).

To investigate the relationship between red deer PG density and bovine scat density, a generalized regression model (GLM) was used, where red deer PG density was set as a response variable and bovine scat density as the explanatory variable. A negative binomial conditional distribution was assumed for the response variable. To account for potential confounding effects on deer abundance (and area-specific PG decay rates), we also included in the predictor the additive effects of area-specific ecological covariates: Normalised Difference Vegetation Index (NDVI, a proxy for vegetation quality, averaging values from beginning of June to mid-September, downloaded from Copernicus Open Access Hub), aspect, elevation, slope, and an index of pasture “attractiveness” for red deer. Intuitively, variations in grassland coverage around the sampling sites may impact the density and distribution of deer (e.g., a pasture surrounded by forest is expected to be very attractive if it is the only one available in the surroundings). This latter variable was estimated as the ratio between grassland surface in the sampling area and grassland surface in three buffer zones around the pasture: 750 ha, 1600 ha and 2500 ha. Grassland coverage was assessed using Copernicus Land Monitoring Service (2018). We fitted 3 global GLMs (one for each buffer) with all potential explanatory variables as additive terms, and inspected them for multicollinearity through the variance inflation factor (VIF). These models were compared based on their AIC value

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with the *model.sel* function (*MuMIn* R package Bartoń, 2020); once the optimal buffer size was found, the final model was selected with a stepwise selection procedure using the *stepAIC* function in the *MASS* package (Venables and Ripley, 2002). The goodness of the final model was assessed by inspecting simulated quantile residuals against the predicted values with the package *DHARMa* (Hartig, 2020). Marginal effects were visualized with the package *visreg* (Breheny and Burchett, 2017). All analyses were performed with R (R Core Team, 2020) in RStudio (R Studio Team, 2020).

Over a total of 630 transects, 9,064 red deer PGs were detected for an overall effort of 61,890 m (some transects partially overlapped, and to avoid double PG counting, they were truncated <50 m). As expected, the number of detected PGs decreased monotonously with distance. Detection on the trackline was certain, and the detection function had a broad shoulder, suggesting that pooling robustness holds (Buckland et al., 2004), i.e. we assume data can be pooled over the many variables that could affect deer PG detection probability. The selection of distance sampling models showed that a MCDS model with hazard-rate key function and a simple polynomial adjustment and area as a covariate was the best fit for both rounds of distance sampling. Since the number of levels in the covariate (i.e., n = 21) was greater than the number of bins, no Goodness-of-Fit test was available for the selected models. Inspection of the detection function, however, suggests no major issues of misfit (Fig. 1). The site-specific red deer PG density estimate had a mean value (±SD) of 391 PGs/ha (±459) for the first sampling occasion, and 294 PGs/ha (±392) for the second sampling occasion. The CV were, respectively, 24% (±22) and 26% (±19). Red deer PG density estimates within the 21 areas were thus highly variable, ranging between 0 and 1688 PGs / ha. In the 12 areas with bovines we estimated a mean of 608.4 scats / ha (±764), between 342 and 2500 scats / ha.

The global GLM with 750 ha buffer was the most supported model (AICc = 292) compared to 1600 ha (AICc = 297) and 2500 ha (AICc = 303). VIF values were all < 3 (Zuur et al., 2010). Table 1 shows the results of the final model selected to investigate the potential spatial effects of cattle on

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red deer, which included pasture attractiveness, northness and bovine scat density. As pasture attractiveness increased, the estimated density of red deer PGs also increased. The areas with northern exposure had a higher number of red deer PGs than those facing southwards. Notably, with increasing density of bovine faeces, red deer PG density decreased (Fig. 2).

Distance sampling applied to PG counts is often used to study abundance of wild ungulates (Marques et al., 2001), including red deer (Torres et al., 2015), possibly because pellet groups favors the fulfilment of methodological assumptions (cf. Buckland et al., 2015). Red deer PG density increased with high pasture attractiveness. Intuitively, when the availability of grasslands is limited in the surroundings, more deer are likely to feed in the same areas used by bovines. Furthermore, the increasing density of red deer PGs in north-facing slopes is consistent with the thermoregulatory behaviour of the species in this time of the year (Arnold, 2020) as well as with the presence of higher forage quality in the northern than in the southern exposures (Del Toro et al., 2016). Most importantly, our data also suggest that as bovine scat density increases, the density of red deer PG decreases. As long as we assume these proxies to be linearly related to animal density, this pattern would suggest spatial avoidance by red deer when cattle is present. This result would be particularly interesting, as previous studies in similar areas did not report negative effects of cattle on red deer, except for the percentage of time spent alert (Mattiello et al., 2002). However, other studies have reported that wild ungulates may avoid areas grazed by cattle: for example, Bowyer et al. (1984) found lower southern mule deer (*Odocoileus hemionus fuliginatus*) density and fewer PGs on the areas grazed by cattle. Also, the endemic Italian roe deer (*Capreolus capreolus italicus*) seems to avoid the areas most frequented by cattle (Gaudiano et al., 2021).

The effects of cattle presence on the use of pastures by red deer may have several important consequences. For example, cattle might reduce forage availability for wild ungulates (Austin et al., 1983; Skovlin et al., 1983). There is also a risk of transmission of pathogens between wildlife and livestock (Ferroglio et al., 2011; Gortázar et al., 2007). One of the most important is *Mycobacterium*

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avium subsp. paratuberculosis (MAP), the etiological agent of paratuberculosis, a chronic infection of the intestinal tract of cattle and other domestic and wild ruminants (Fecteau, 2018), which is present in the red deer population of SNP (Galiero et al., 2018). According to Van Campen et al. (2010), a potential risk factor for the transmission of MAP is the sharing of pastures, also indirect, between red deer and cattle. Pastures with high bovine scat density could therefore explain red deer spatial avoidance as a possible mechanism to minimise the risk of infection, as observed in chamois (*Rupicapra rupicapra)* (Fankhauser et al., 2008). Ecological and epidemiological factors may thus concur to explain the potential spatial avoidance of cattle by red deer.

Our results, however, must be treated with some caution. It remains unclear, for example, if avoidance may be due to the actual presence of bovines or to other factors associated with cattle presence, such as human disturbance and dog sheparding. Tourists may also affect deer daily activity patterns (Oberosler et al., 2017), and displace red deer from open terrain (Lovari et al. 2007). Human avoidance may be particulary evident in areas where deer are hunted. While in the SNP hunting is not allowed, some issue of poaching have been reported (Corlatti et al., 2019), therefore we cannot exclude that avoidance of areas with human presence may owe to a "landscape of fear" (Brown et al., 1999; Laundré et al., 2001) caused by this illegal activity. Furthermore, several factors could also affect defecation rates within a species in different habitats, including forage intake, sex and age (Lunt and Mhlanga, 2011). This, in turn may make the interpretation of the observed pattern problematic, especially when comparing grazed and ungrazed pastures. Diet quality, however, appears to be of limited significance in affecting defecation rate (Lunt and Mhlanga, 2011), and the habitat-type was fairly homogenous across our sampling sites. Although, in principle, we cannot exclude that our results could, to some extent, be affected by differences among animals or their activity level or behavior on the different pastures, defecation rates are less variable than other parameters used in density estimation, thereby supporting the use of PGs as a proxy of deer density.

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Red deer spatial avoidance may ultimately result from a combination of human presence and cattle abundance in alpine pastures. Given the small sample size used is this study, we encourage to conduct further research on red deer-cattle interaction in summer pastures, to improve our understanding of the potential interactions between wildlife and livestock.

Acknowledgement: We thank Eric Rexstad (University of St Andrews) for useful advices on distance sampling analysis. We also thank Alessandro Bianchi, Anna Chiara Garbarino and Alessandro Gugiatti for their support in conceiving the sampling design. We thank two anonymous reviewers and the Associate Editor for insightful comments to earlier drafts of the manuscript. This work was partially funded by Italian Ministry of Health (Ricerca Corrente IZSLER10/19RC) and Alessandro Forti was supported by University of Milan. There are no potential conflicts of interest for any of the authors.

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Table 1. Estimates of the final model fitted to investigate the effects of cattle presence on red deer, within the Stelvio National Park in 2020. The table reports estimates, standard errors (SE), 95% lower and upper confidence levels (95% CI), z-value (z) and p-value (p) for each parameter.

Parameter	Estimate	SE	95% CI	z	p
(Intercept)	5.37	0.17	5.06, 5.72	31.91	<0.001
Bovine scat density (ha)	-0.71	0.18	-1.13, -0.24	-3.91	<0.001
Northness	0.38	0.17	0.07, 0.69	2.17	0.03
Attractiveness	0.82	0.17	0.51, 1.21	4.74	<0.001

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Figure 1. Probability density from Hazard-rate detection function with simple polynomial adjustments returned by the best fitting model for the distances collected with MCDS for first (a) and second (b) distance sampling occasion to estimate red deer PG density on summer pastures of the Stelvio National Park during June-September 2020.

Figure 2. Marginal effect of bovine scat density (Bovine scats / ha) on the expected deer scat density (Red deer PGs / ha) on summer pastures of the Stelvio National Park in 2020. The grey shaded area indicates 95% confidence interval.

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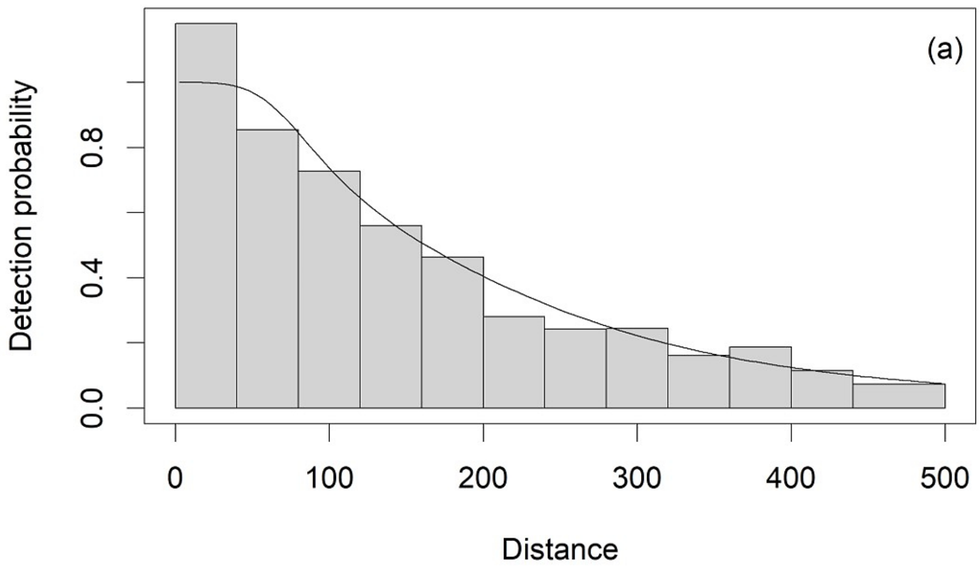

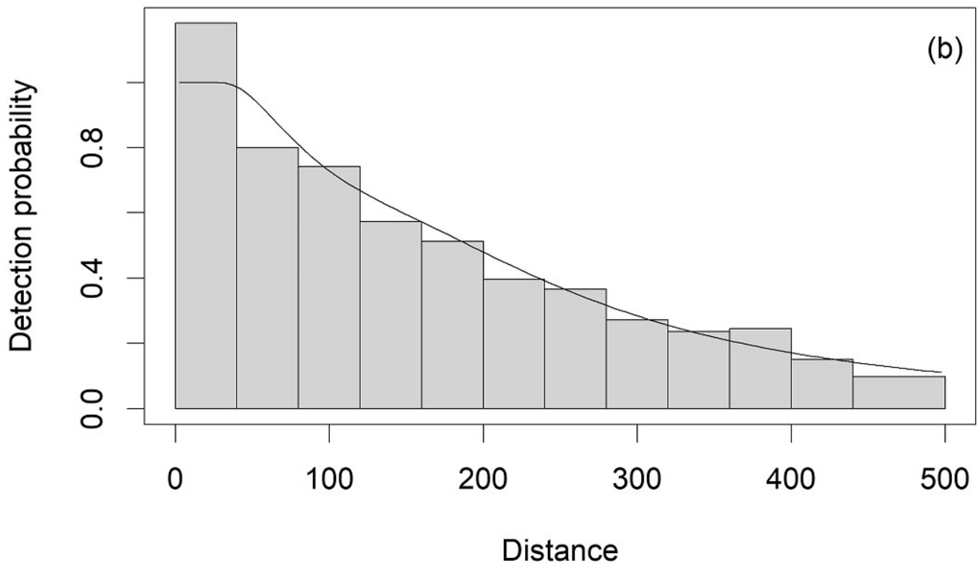

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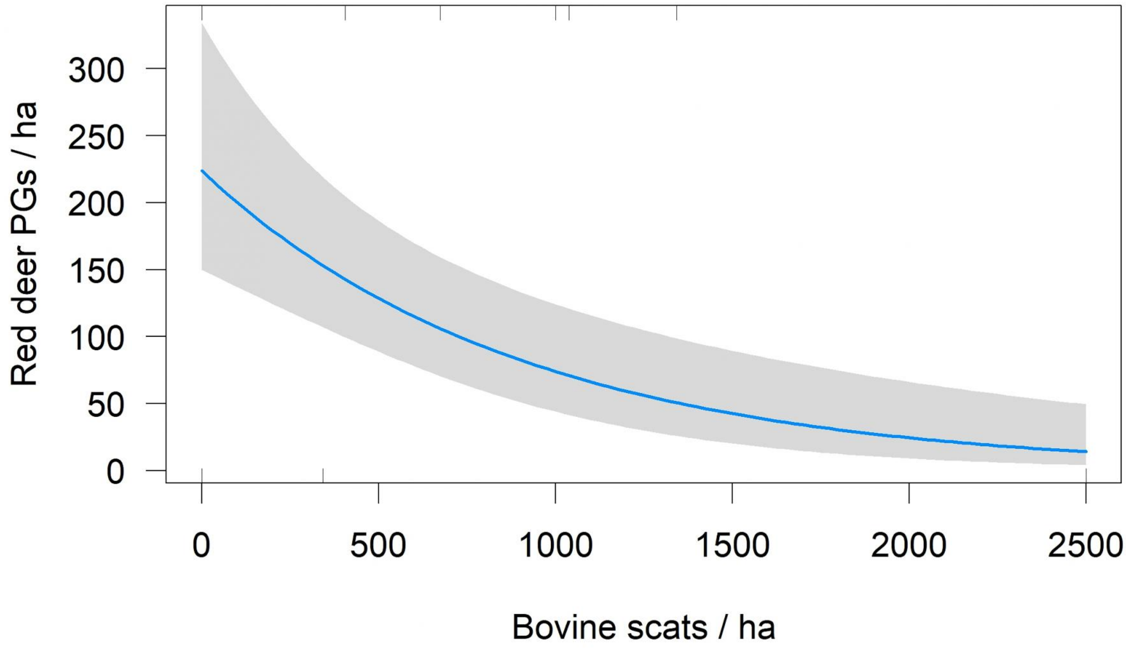

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