Accounting for cloud cover and circannual variation puts the effect of lunar phase on deer-vehicle collisions into perspective

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Abstract Although several studies have focused on the influence of moonlight over deer-vehicle collisions, findings have been inconsistent. This may be due to neglecting the effects of cloud cover, a major impediment to moon illumination, and circannual variation in both deer and human activity.

We modeled how median cloud cover interacted with the illuminated fraction of the moon in affecting daily roe deer (*Capreolus capreolus*) roadkill in Slovenia (Central Europe). Data included nationwide roadkill (n = 49,259), collected between 2010 and 2019 on a mandatory basis by hunters as well-trained citizen scientists.

Roadkill peaked for medium-to-high cloud cover, while decreased at nights with low or extremely high cloudiness. This pattern was more pronounced at full moon nights. However, the effects of moon illumination and cloud cover had a lower predictive potential than circannual variation.

Our results suggest that moonlight could influence deer movements through compensatory foraging. However, at full moon nights collisions could then be modulated by weather conditions, affecting human movement and vehicle traffic, and likely also road crossing by roe deer.

Moon illumination may indeed affect wildlife-vehicle collisions and roadkill, but its effects should be quantified as a function of cloud cover. Because collisions with roe deer, the most common road-killed large mammals in Europe, peak at nights with full moon and casted skies, and at some precise periods of the year, interactive warning signs that detect ground illumination at these periods may improve drivers' awareness and increase their safety.

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Introduction

Understanding environmental and biological factors that affect wildlife roadkill is fundamental to predict their spatial and temporal occurrence, and thus mitigate their effects on human welfare [1][2] and wildlife populations [3][4]. Although many studies have focused on which landscape features are associated with collision hotspots or the circadian patterns of collisions, less attention has been paid to which environmental or seasonal factors drive their occurrence over time [5].

Among environmental factors associated to wildlife roadkill, moon illumination has received a certain attention, due to its widespread influence on ecological dynamics in terrestrial and aquatic ecosystems [6]. In terrestrial mammals, moon phase alters movement, primarily by acting on foraging and anti-predatory behavior [7]. For example, in cervids (deer species), probably the most studied mammals in road ecology [8] (see also Table S1), some species were found to increase their movements during full moons, although no universal consensus exists [9]. Thus, by affecting the movements of wild ungulates, full moon nights are thought to promote road crossings and collisions with vehicles. In addition, there is mounting evidence that full moon may also slightly increase accident risk by affecting drivers' behavior, through distraction [10][11] or an increase in perceptual errors [12][13].

However, findings from the few studies that have examined the effect of moon illumination on wildlife-vehicle collisions are quite contradictory (Table S2). While some indeed found an effect of moonlight on collision of deer with vehicles or trains, causing a peak at full moon nights [14][15][16][17][18], others found no effect at all [19][20] or showed that moonlight was associated to collisions only at certain times of the year [14][21]. Finally, studies that considered multiple species found significant species-specific differences in the effect of moonlight on roadkill [22].

This heterogeneity can be caused by several factors, including behavioral differences among deer species, or different traffic volumes and patterns. Moreover, while some studies relied on time-series analysis [18] or spatiotemporal modeling [22], others compared pooled data through null-hypothesis testing [14]. Another important but yet underestimated factor, that may have biased results from previous studies, is cloud cover. Although cloud cover generally increases the number of collisions due to precipitations, which make driving far more demanding than usual [23][24] and also affect traffic volume [23], clouds are also a major barrier to moonlight, reducing moon illuminance and irradiance up to 99.7% - 99.9% [25], and thus curtailing illumination on the ground. Illumination on the ground is the primary mechanism by which the moon affects ungulate nocturnal movement, as it enables the use of vision [26] and thus for effective spatial orientation and antipredatory vigilance [27], in turn enabling compensatory or cumulative foraging [28].

Thus, a failure to account for cloud cover may lead to false associations between the moon and wildlife-vehicle collisions: what makes terrestrial wildlife move at night is the available illumination on the ground, not the moon per se. Although this idea has already been considered in movement ecology [28][29], it has been ignored in road ecology, despite mentioned in some studies [14][16][20].

In this study, we provide the first quantification of the combined effect of moon phase and cloudiness on deer-vehicle collisions by combining: *i*) daily data on roadkill of European roe deer (*Capreolus capreolus*) as a reliable indicator of the number of collisions between this species and vehicles, collected across Slovenia in a ten-years period (2010–2019) through a robust and standardized protocol (for details, see Pokorny *et al*. [30]), *ii*) data on moon illumination, and *iii*) time series of remote sensing data on cloud cover.

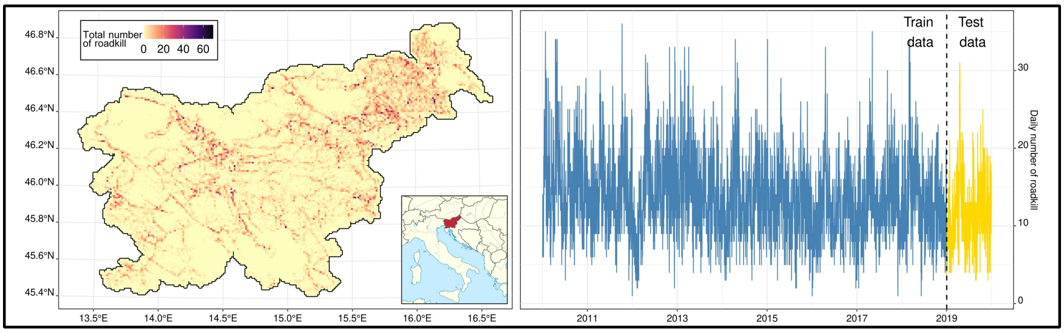

Figure 1: Map of the study area (on the left), depicting the total number of road-killed roe deer in Slovenia, between 2010 and 2020. Daily number of roadkill involving roe deer (on the right), between 2010 and 2019, highlighting train and test data used in the analyses.

Methods

Study area and data collection

The study area covered the entire land area of Slovenia, a central-European country spanning over 20,273 km^2, characterized by a complex assemblages of mammals, including high densities of large carnivores and ungulates [31][32][33]. There are no large urbanized areas in Slovenia, and environmental connectivity between undisturbed habitat patches makes wildlife prone to live alongside with humans and susceptible to collision with vehicles [30][34].

In our study, we considered collisions between vehicles and European roe deer, the most widespread deer species in Europe [35], and by far the most frequently involved in collisions with vehicles of all European ungulates [36]. Roe deer is common in anthropogenic areas, where it adapts its activity rhythms to cope with human disturbance [37], and it is most active at dawn and at dusk, when traffic volume is also high due to daily commuting movements. Therefore, roe deer is very often involved in collisions with vehicles [36][38][39]. In Slovenia alone, between 4,000 and 6,000 roe deer collide with vehicles each year [30][34].

Our data included all registered roadkill of roe deer in Slovenia (i.e., in all hunting grounds, managed by hunting clubs, Fig.1) between 2010 and 2019 (n = 49,259). Data from 2020 were not included because this year was characterized by a significant change in wildlife-vehicle collisions (including roe deer) in Slovenia, caused by COVID-19 lockdowns [30][40]. Data on roadkill were obtained from an on-line information system, developed in 2006 by the Hunters Association of Slovenia (HAS), with the aim of collecting and archiving data on wildlife mortality, including roadkill. A complete overview of the dataset and data collection protocol can be found in Pokorny *et al*. [30].

Statistical analyses

We predicted the number of daily collisions between vehicles and roe deer (based on registered roadkill data), according to a set of relevant covariates, by means of Generalized Additive Models. We adopted a Negative Binomial distribution of the response variable as this value approximated well the distribution of the roe deer roadkill (Fig. S1).

Relevant covariates were chosen, according to available evidence regarding the effect of moon illumination and cloud cover over the behavior of both deer and drivers. We did not include spatially-explicit covariates, such as artificial light at night [41][42] or rainfalls, as these can be quite hard to measure in a good spatiotemporal resolution.

Although some previous studies argued that roe deer activity decrease [43] or does not change with increasing moonlight [44], these studies did not quantify cloud cover, so we did not consider their findings.

Moon illumination was measured as the illuminated fraction of the moon, varying between 0 (dark nights) and 1 (nights with full moon). Values were extracted for Central European Timezone with R, through the package "suncalc" [45].

Cloud cover was measured through the MODIS Surface Reflectance products, obtained from Terra and Aqua satellites. Time series, with a spatial resolution of 1 km, were processed through the Google Earth Engine platform () exploiting the datasets: MODIS/061/MOD09GA and MODIS/061/MYD09GA. These data offer a daily estimate of the surface spectral reflectance as it would be measured at ground level in the absence of atmospheric scattering or absorption. Based on the "state_1km" band, we classified 1 km cells as covered by clouds (cloudy and mixed cloudy), or not (clear and not set, assumed clear). Values were then averaged between Terra and Aqua satellites, to merge morning (Terra) and afternoon (Aqua) MODIS data. Next, the proportion of covered cells was calculated for each day of the time series and for the entire study area (e.g. a value of 0.6 indicated that 60% of 1 km-wide cells were covered by clouds). As Slovenia covers a relatively small area, this approach was deemed to be suitable at the national scale to distinguish days on which weather conditions were generally bad from days with bright skies.

To further regularize time series, we also included three more variables that can increase wildlife-vehicle collisions. The first one was the day of the year, as it captures the duration of the day and thus the importance of moonlight on animal movements (through multiple mechanisms [46][47][48]), the volume of vehicular traffic and its overlap with activity rhythms of deer [49]. The second one was the day of the week, as vehicular traffic is different between work-week days and the weekend, when the consumption of alcohol and drugs can also make driving more dangerous. We also included the year of each roadkill, to capture long-term population dynamics which could affect the risk of collisions through interannual changes in the abundance of roe deer. The day of the week was treated as ordered factors with zero-sum contrasts, where the value of each level was compared to the average value of roadkill. Continuous variables were centered and standardized.

Model selection adopted a stepwise approach. We started by fitting a null model and then added covariates, and interaction terms. The effect of moon illumination and cloud cover was modeled by considering thin-plate splines, tensor splines, and cyclic cubic splines. The effect of the day of the year, and in some cases its 3-way interaction with moon illumination and cloud cover, was modeled through a thin-plate spline, a tensor spline, a cyclic cubic spline, and a Gaussian process. A complete overview of these smoothers is provided in Wood [50]. Fitted models were then compared based on their Akaike's Information Criterion (AIC), their residual deviance and both the Root Mean Squared Error (RMSE) and the Mean Absolute Percentage Error (MAPE), when trained on test dataset containing daily roadkill in 2019. The MAPE expresses the mean absolute percentage errors of forecasts, expressed as the difference between observed and forecasted values of a time series. It is evaluated as a percent value, meaning that a value of e.g. 20% indicates that the average difference between predicted and observed values is 20% [51]. A complete overview of model fitting is available in Table 1 and in the reproducible software code (Supplementary Information). Statistical analyses were carried out in R [52], and a reproducible software code for R and Google Earth Engine, altogether with the reproducible dataset about road-killed roe deer, is available in the Supplementary Information.

Results

Model selection indicated relatively small differences among best candidate models. While model fitness improved when we accounted for the effects of each year, day of the week and interplay between moon illumination and cloud cover, most of the predictive accuracy came from accounting for circannual variation, by using the day of the year as a covariate (Table 1). Namely, the best candidate model, which had a MAPE of about 36% when tested on 2019 roadkill data, adopted a bivariate thin-plate spline for measuring the interplay between cloud cover and moon illumination, and an adaptive cyclic cubic spline for the effect of the day of the year. Interestingly, although the autocorrelation density function of model residuals highlighted temporal dependence between observations, this was not eliminated through first, second or third-order autoregressive correlation structures.

The number of road-killed roe deer increased with increasing values of the illuminated portion of the moon, and peaked at full-moon nights; there was also a non-linear relationship with cloud cover. Roadkill peaked for higher values of average cloud cover across the land area of Slovenia, while it decreased at low cloudiness or at nights with uniform cloudiness. The effect of cloud cover on roadkill had a clear interaction with moon illumination, being more pronounced at nights with high moon illumination than at nights without the moon. The lowest number of collisions was observed at nights with low moon illumination and very low or, on the contrary, high cloudiness through Slovenia (Fig. 2).

The day of the year had a much stronger marginal effect on collisions, in terms of magnitude, than moon illumination and cloud cover. Roadkill peaked at three distinct periods of the year. The first, and the most pronounced peak was in April/May, followed by a second one in September/October, while a third, lower peak was observed in July (Fig. 3).

Discussion and conclusions

Our results indicate that road ecology studies should take a holistic approach when evaluating the effects of environmental correlates on wildlife-vehicle collisions. This is especially true in complex and cross-related variables, such as moon illumination, whose effects depend on other factors, such as cloud cover. Consideration of cloud cover revealed an important, yet variable, effect of moon illumination on collisions between vehicles and roe deer: the highest roadkill occurs at nights with a full moon and with medium-to-high values of cloud cover, whereas the interaction between the moon and cloud cover is weaker at nights with dim moons.

This interaction is almost certainly based on several mechanisms, and may reveal a hierarchical dynamic between moon illumination and cloud cover. Roe deer probably move more at full moon nights because the ground is illuminated and there are more opportunities to forage safely, which in turn leads to more road crossings. However, cloud cover could also affect human activity, exerting a non-linear effect of this factor over collisions. At bright, low-clouds nights, roe deer might be less active along roads due to increased human presence (e.g. outdoors [53]) and sustained vehicular traffic [54][55]. Then, with medium-to-high cloud cover, human presence in the environment may be lower, i.e. low enough to increase deer movements across roads, but vehicular traffic can still be intermediate, thus maximizing the risk of collisions [22]. Under such conditions, poor visibility and rainfall can further impair the ability of drivers to detect and avoid crossing deer. Finally, under high levels of

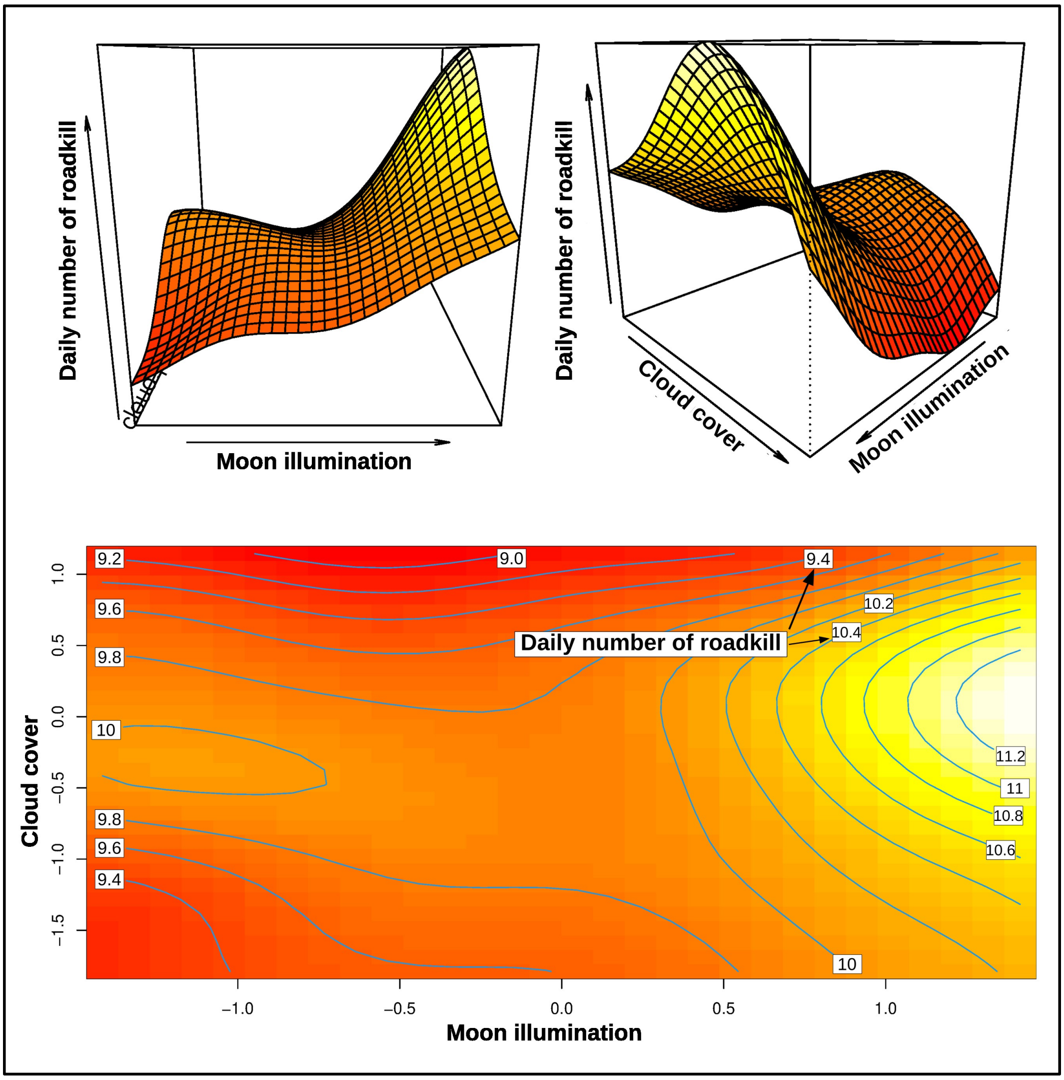

Figure 2: Surface plot (top left, top right) and mosaic plot (bottom) showing the interactive effect of moon illumination and cloud cover over the number of road-killed roe deer in Slovenia in the period 2010–2019.

cloud cover, weather conditions are likely to be characterized by rainfall, that reduce traffic volumes. This non-linear effect of cloud cover on collisions would not occur at dark nights, perhaps due to the lower movement of animals in response to lower illumination on the ground.

Interestingly, our best candidate model did not detect any change in the effects of moon illumination during the year. This finding is surprising, as the main effect of the full moon on the behavior of some wild ungulates is the increased opportunity to forage at night or during warm summer weather [28]. It is possible that circannual changes in human mobility, or in roe deer behavior other than foraging (e.g., breeding [56]; e.g., hunting disturbance [57]), are more important than movements associated with nighttime foraging in determining the risk of roe deer-vehicle collisions.

Integrating data on animal movements, vehicular traffic and outdoor activities would be essential to test these mechanisms we mentioned. However, even without this information, our results already provide two concrete advice for future research on wildlife-vehicle collisions.

First, rather than attempting to assess an "average" effect of moon illumination (e.g., Steiner *et al.*, [18]), future studies should focus on estimating its interaction with other environmental variables, such as cloud cover. So far, this interplay has been largely ignored in road ecology, but it would make findings from different studies truly comparable. Nowadays, open datasets allow to retrieve daily-level information on moon and atmospheric conditions effortlessly; indeed, there is no longer a need to use moon quarters, and it is possible to rather work on more refined, and comparable, temporal scales. We also believe that the results of previous studies should be replicated, i.e. by considering cloud cover.

The second point is to avoid using simple univariate comparisons to test for the effect of moon illumination over collisions (e.g., chi-square testing [14]). Our results suggest that other time-varying factors, such as the day of the year, have a much larger effect on roe deer-vehicle collisions, and should be accounted for through appropriate time-series analysis. Focusing on the magnitude of the effect of each covariate (see Cumming [58]) would also allow the effect of moon illumination itself to be considered with caution. Although model selection, in our case, did not provide evidence in favor of an interplay between moon and the day of the year, model residuals still had strong temporal autocorrelation. This may suggest that relevant time-varying covariates are likely still missing and they could affect the estimated effect of moon illumination itself, once included in a statistical model.

These efforts would not be in vain: disentangling the interplay between moon illumination and weather conditions, and their "weight" in determining wildlife-vehicle collisions, in the form of a highly predictive algorithm, could also be important in avoiding the risk of collisions. For example, interactive road signals could be programmed to detect risky situations, i.e. by measuring illumination on the ground and traffic intensity with sensors, and to activate warning signs that address drivers on specific temporal scales, and therefore increasing their attention towards wildlife road crossing [59].

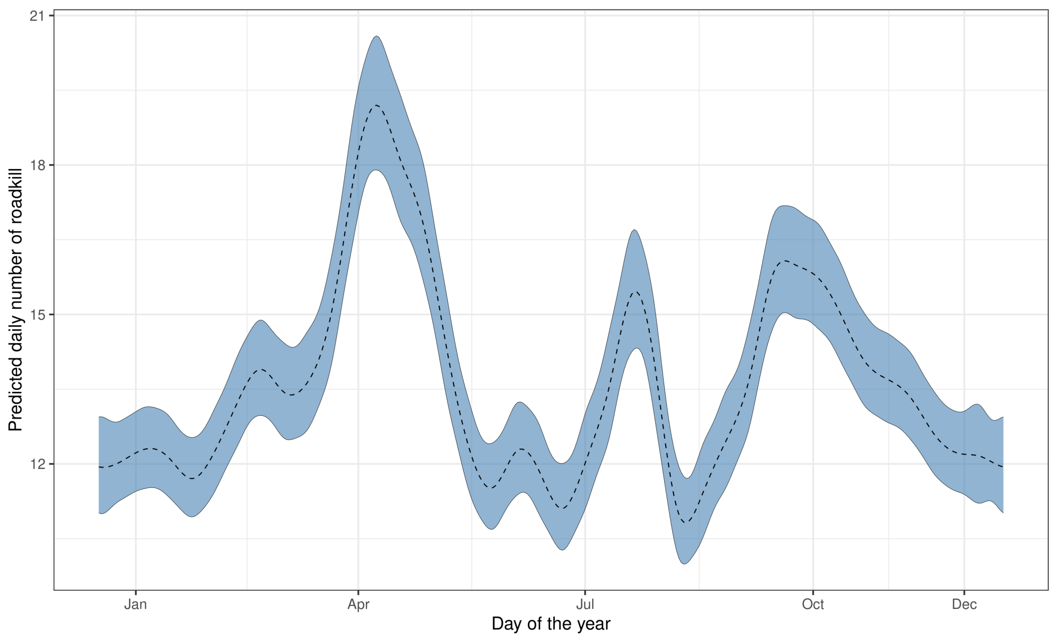

Figure 3: Marginal effect plot, representing changes in the volume of road-killed roe deer in Slovenia (period 2010–2019), according to the day of the year.

Models without an autoregressive structure			
Covariates	**AIC**	**Deviance**	**MAPE**
~1	20029.15	3345.47	53.37
~day of the week	19914.41	3337.84	52.60
~day of the week + year	19820.97	3338.49	43.70
~day of the week + year ^{2}	19814.83	3336.95	47.26
~day of the week + year ^{3}	19813.78	3335.74	52.03
~day of the week + year + tp (illuminated fraction of the moon)	19780.40	3335.49	43.26
~day of the week + year + tp (illuminated fraction of the moon) + tp(cloud cover)	19728.96	3329.98	43.09
~day of the week + year + te (illuminated fraction of the moon)	19780.24	3335.59	43.27
~day of the week + year + te (illuminated fraction of the moon) + te(cloud cover)	19729.58	3330.94	43.05
~day of the week + year + cc(illuminated fraction of the moon)	19799.64	3334.66	43.37
~day of the week + year + cc(illuminated fraction of the moon) + cc(cloud cover)	19754.34	3330.26	43.25
~day of the week + year + tp(illuminated fraction of the moon, cloud cover)	19728.76	3323.66	43.07
~day of the week + year + te(illuminated fraction of the moon, cloud cover)	19728.24	3325.66	43.04
~day of the week + year + ti(illuminated fraction of the moon, cloud cover)	19727.18	3327.40	43.02
~day of the week + year + tp(illuminated fraction of the moon, cloud cover) + tp(day of the year)	19285.46	3329.91	37.26
~day of the week + year + tp(illuminated fraction of the moon, cloud cover) + gp(day of the year)	19283.99	3329.98	37.26
~day of the week + year + tp(illuminated fraction of the moon, cloud cover) + cc(day of the year)	19276.11	3331.52	37.40
~day of the week + year + tp(illuminated fraction of the moon, cloud cover) + te(day of the year)	19503.95	3319.63	39.00
~day of the week + year + tp(illuminated fraction of the moon, cloud cover) + ad(day of the year)	19181.78	3315.75	36.55
~day of the week + year + tp(illuminated fraction of the moon, cloud cover) + ad.cp(day of the year)	19194.09	3318.71	36.95
~day of the week + year + tp(illuminated fraction of the moon, cloud cover) + ad.cc(day of the year) (best candidate model)	19193.32	3314.85	36.92
~day of the week + year + tp(illuminated fraction of the moon, cloud cover, day of the year)	19489.13	3269.42	39.67
~day of the week + year + te(illuminated fraction of the moon, cloud cover, day of the year)	19504.90	3296.54	39.30
~day of the week + year + tp(illuminated fraction of the moon, cloud cover) + ad.cp(day of the year)	19373.80	3285.33	38.03
Models with an autoregressive structure			
~day of the week + year + tp(illuminated fraction of the moon, cloud cover) + tp (day of the year) + AR1	-	-	37.29
~day of the week + year + tp(illuminated fraction of the moon, cloud cover) + tp (day of the year) + AR2	-	-	37.27
~day of the week + year + tp(illuminated fraction of the moon, cloud cover) + tp (day of the year) + AR3	-	-	37.24

Table 1 Comparison of selected models, through the Akaike's Information Criterion (AIC), model deviance and the Mean Average Percentage Error (MAPE, calculated on 2019 data). For each model, the formula mimics that of the "mgcv" package (Wood, 2022): "tp" = thin-plate splines, "te" = full tensor product smooth, "cc" = cyclic cubic splines, "ti" = tensor product interaction, "gp" = Gaussian process, "ad" = adaptive thin-plate spline, "ad.cc" = adaptive cyclic cubic spline, "ad.cp" = adaptive p-spline. "AR1", "AR2" and "AR3" indicate a first, second, and third-order temporal correlation between residuals. Models with an autoregressive structure of residuals were fitted through penalized quasi-likelihood and thus only the MAPE was calculated. For further guidance about splines, see Wood (2017).

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Dataset and reproducible software code

The dataset, altogether with the reproducible software code are available on the Open Science Framework repository, at the following link: https://osf.io/zwm4n/

Supplementary Information

Exploration of daily roadkill data

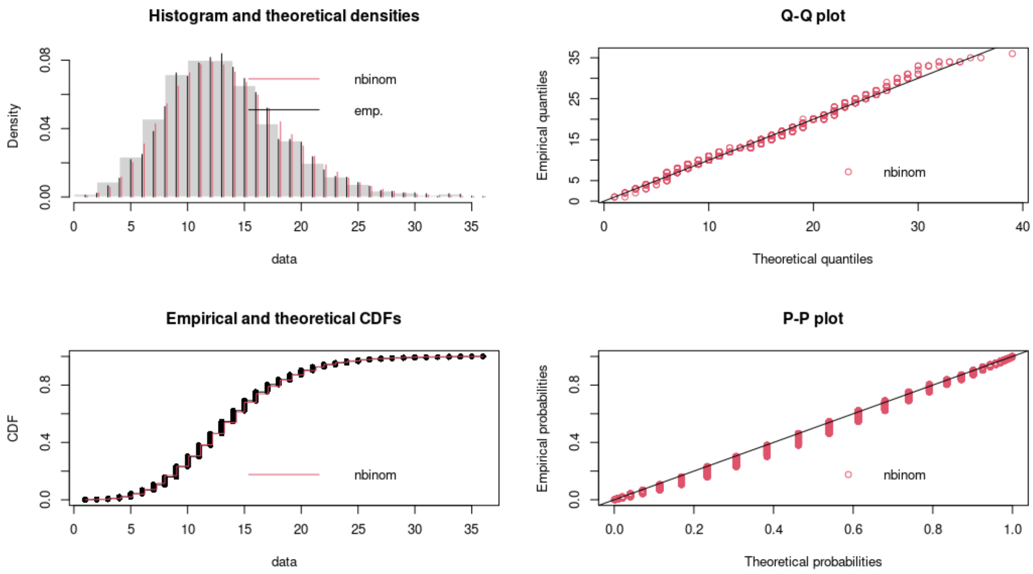

Figure S1: Fitness of the daily number of road-killed roe deer in the dataset, with respect to a Negative Binomial distribution. Only 9 days out of 3,660 had no reported roadkill.

Authors	doi	Species	Findings	Moon	Clouds
Beier and McCullogh (1990)	https://www.jstor.org/stable/3830629	White-tailed deer	• Neither moon presence, moon visibility, nor moon phase appeared to influence habitat use by deer in any season. • Neither activity nor habitat use of deer were markedly influenced by moonlight. A statistically significant decrease in deer activity in spring as moonlight increased was small and perhaps not biologically important. Furthermore, it was not supported by the results for other sea-sons.	Mix	Yes
Brown *et al*. (2011)	https://brynathyn.edu/_media/documents/Brown-Deer-Moonlight.pdf	White-tailed deer	• Deer appear to prefer fields when the moon is above the horizon, and forested habitat when the moon is below the horizon. The preference for open fields during moonlight periods may be determined by predator avoidance behavior in deer. • Findings suggest that deer did not alter their daytime habitat use in response to presence or absence of the moon. This study suggests that it is the luminosity of the moon that affects deer movement and habitat preference.	Timing of sunrise and sunset	No
Jasińska *et al*. (2020)	https://doi.org/10.3390/IECF2020-07913	Roe deer	• Roe deer was more active during dark nights than bright nights. • Therefore, authors hypothesized that roe deer will be more active during darker nights. Indeed, activity in moon phases showed that roe deer was active more often in first quarter, waxing crescent, and new moons, when the level of illumination reflected by the moon is the lowest.	8 levels	No

Table S1 Review of the previous studies on the effect of moon over deer movements (It continues on the next page).

Authors	doi	Species	Findings	Moon	Clouds
Kjaer *et al.* (2008)	https://doi.org/10.2193/2007-489	White-tailed deer	• Contact rates were elevated during full moon compared to other lunar periods. • Elevated contact rates during full moon could reflect increased nocturnal activity, but the observed lunar effect was generally slight.	Quarters	No
Ladine et al. (2020)	https://doi.org/10.1656/058.019.0211	White-tailed deer	• Lowest activity occurred on nights when illuminance was the lowest (e.g., new moon with overcast skies) and highest activity on nights when illuminance was the greatest. • Study indicates white-tailed deer are more active during full moons with low cloud cover, perhaps because foraging under such conditions makes predators easier to see.	Quarters	Yes
Mori *et al.* (2021)	https://doi.org/10.1007/s11756-021-00790-1	Siberian roe deer	• Siberian roe deer showed a bimodal temporal behavior, with activity peaks at dawn and at early night, irrespective from moon phases. • Nocturnal activity of mostly diurnal species peaks in brightest nights as their visual acuity is fundamental for orientation. • Results showed that, despite the local presence of several large carnivores, the activity rhythms of Siberian roe deer were independent from moon phases.	Quarters	No
Muller *et al.* (2014)	https://doi.org/10.1002/wsb.446	White-tailed deer	• There was no effect of moon phase for all records combined. • More deer-vehicle collisions occurred with the full moon during gestation and with the last quarter moon during fawning. • Moon phase (full moon) only affected the number of male deer-vehicle collisions during gestation and the deer-vehicle collisions occurred primarily in the younger age classes.	Quarters	No

Table S1 Review of the previous studies on the effect of moon over deer movements (it continues on the next page).

Authors	doi	Species	Findings	Moon	Clouds
Pagon *et al.* (2012)	https://doi.org/10.3109/07420528.2013.765887	Roe deer	• The prediction that roe deer would show lower activity levels during full moon nights, when the predation risk was assumed to be higher, was not confirmed. • The best model selected did not show any evidence that the moon influenced the variation in nocturnal roe deer activity. • No difference in nocturnal activity was recorded between nights with a new and a full moon. • Authors did not find any evidence for the prediction that roe deer would modify their activity levels in relation to the different moon phases as an indication of wolf-related predation risk perception, whereas they confirmed the prediction that they would reduce their activity levels in connection to open stalking season.	Dichotomous	No
Reimoser (2014)	http://www.reimoser.info/download/2014_Reimoser_Influence%20of%20anthropogenic%20disturbances.pdf	Roe deer	• For roe deer, no significant differences between activity at full moon and new moon could be found in this study. • Red deer showed significant increase of activity at night during full moon and highly significant increase of activity in the morning during new moon phases.	Dichotomous	No
Webb *et al.* (2010)	https://doi.org/10.1155/2010/459610	White-tailed deer	• Moon phase had no effect on daily, nocturnal, and diurnal deer movements and fine-scale temporal weather conditions had an inconsistent influence on deer movement patterns within season.	Percentage	Yes

Table S1 Review of the previous studies on the effect of moon over deer movements.

Authors	doi	Species	Findings	Moon
Colino-Rabanal *et al.* (2018)	https://doi.org/10.1007/s10531-017-1458-x	• Wild boar • Red deer • Roe deer • White-tailed deer	• For the three species that had a lunar phase effect on wildlife-vehicle collision rates, the strength of the lunar effect varied by month. • For roe deer, wildlife-vehicle collisions were higher during the full moon in every month, and were significantly higher during January, March, May, and July to November; the lunar effect was strongest in September. • Authors concluded that wildlife-vehicle collisions at night occur most frequently during the full moon for three of the four ungulate species included in the study: wild boar, roe deer, and white-tailed deer.	Lunar phase (quarters)
Gundersen and Andreassen (1998)	https://doi.org/10.2981/wlb.1998.007	• Moose	• The probability of moose-train collisions was higher during nights of full moons than during nights of half or no moons.	Factor with 3 levels
Ignatavičius *et al.* (2021)	https://doi.org/10.3390/ani11030908	• Roe deer • Moose • Red deer • Fallow deer • Wild boar	• Note: findings are based on multiple species, pooled together. • WVCs are more apt to occur during periods of higher illumination such as near the full moon phase • Discrepancy (between Lithuania and Spain) in the quantitative response of wildlife-vehicle collisions vs moon light could be explained by differences in cloud cover (number of days, percentage, etc.).	Percentage disk method
Kawata (2011)	http://tru.uni-sz.bg/bjvm/BJVM%20March%202011%20p.01-10.pdf	• Sika deer	• The number of accidents tended to increase during the first quarter moon, full moon, and the third quarter moon, and to decrease in periods in between.	Lunar phase (daily)

Table S2 Review of the previous studies on the effect of moon over deer-vehicle collisions.

Authors	doi	Species	Findings	Moon
Kreling *et al.* (2019)	https://doi.org/10.1002/jwmg.21692	• Black-tailed deer	• Authors did not observe a relationship between moonlight and overall roadkill. • They found no relationship between moon phase and roadkill patterns, in accordance with some other studies.	3 moon phases
Muller *et al.* (2014)	https://doi.org/10.1002/wsb.446	• White-tailed deer	• There was no effect of moon phase for all records combined.	Quarters
Steiner *et al.* (2014)	https://doi.org/10.1016/j.aap.2014.01.020	• Several deer species (review)	• Gundersen and Andreassen (1998) found a higher probability of moose–train accidents during nights with full moon than during nights with half or no moon. • Only one reference addresses the influence of lunar phases on white-tailed deer accidents: Pierce (2010) found highest numbers of deer-vehicle accidents during the full moon in the gestation and fawning season. • Regarding lunar patterns of deer-vehicle accidents, information in the reviewed studies is scarce but where lunar information was analyzed, results indicate that there are indeed effects of moon phases and there is a need for further research. • There was no information in reviewed roe deer literature about deer-vehicle accidents pattern regarding weekdays or lunar phases.	-
Steiner *et al.* (2021)	https://doi.org/10.1371/journal.pone.0249082	• Roe deer	• Frequency of deer-vehicle accidents was highest during full moon phase (moon day 15), and lowest during new moon periods.	Different days of the moon cycle
Vrkljan *et al.* (2020)	https://hrcak.srce.hr/file/348793	• Roe deer • Wild boar	• For roe deer, collisions had no association with lunar phase. • For wild boar, collisions during twilight (dawn or dusk) were more common during twilight periods on days with less moonlight.	8 moon phases

Table S2 Review of the previous studies on the effect of moon over deer-vehicle collisions.