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TEMPORAL PATTERNS OF ROE DEER (*CAPREOLUS CAPREOLUS*) TRAFFIC ACCIDENTS IN LITHUANIA: EFFECTS OF DAYTIME, SEASON AND LUNAR PHASE

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Abstract. In many countries road safety and animal protection pose a serious problem due to wildlife-related accidents. Profound information of temporal and spatial patterns of deer-vehicle accidents is necessary for safe mitigation efforts and further accident analysis. We described the temporal patterns of roe deer (*Capreolus capreolus*) vehicle collisions from 2014 till 2021 in Lithuania. Using a comprehensive dataset, consisting of 19.707 data points, we examined the influence of different time units (i.e. day of year, day of week, month) and moon illumination percentage. Therefore, we identified roe deer peak accident periods within the time units. Highest frequencies of collisions occurred in May, November and December. Between days of the week collisions increased on Friday with a secondary peak on Saturday. Relationships between roe deer vehicle collisions (RDVc) and lunar phases were analyzed, providing evidence for high frequencies of RDVc during full moon illumination. We believe that RDVc are dependent both on human activity in traffic and wildlife activity. Overall our results highlight, that RDVc disturbance among time is nonrandom. Methods to effective reduce deer-vehicle accidents should be adapted to species-specific temporal periods or place and concentrated to short-term mitigation measures (e.g. speed limits, wildlife warning signs, traffic controls).

Keywords: Wildlife–vehicle collisions (WVCs), temporal fluctuations, behavior, temporal deer activity.

Introduction

Globally roads are the most common and prevalent human-made structure. By providing access to resources, markets and jobs, they are important for socioeconomic development. It is projected that by 2050, 25 million km of new paved roads will be developed worldwide (Alamgir et al., 2017). Nevertheless, road structures affect environment both directly and indirectly. Indirectly effect can be understood changes in ecosystem services, such as ecosystems degradation (i.e., the variation of ecosystem induced by air and water pollution, unnatural light) and the fragmentation (i.e., more isolated and smaller ecosystem patches) as well as deforestation. Directly roads function as barriers to wildlife movement. Not only sensitive species (as reptiles, birds, amphibians) but ungulates too, although this category do not usually cause concern for species extinction. However, one of the most important direct roads impacts on wildlife is animal vehicle collisions (AVCs). AVC are a large and steadily increasing safety concern among drivers, roads managements, wildlife conservationist and insurance company's. According to a new study of Europe roads, each year about 194 million birds and 29 million mammals may be killed via AVCs (Grilo et al., 2020). Approximately 500 000 collisions with animals occur each year in Europe causing over one billion Euro in material damage (Freitas et al., 2015). In Sweden, ungulate vehicle collisions per year accounted for over 60% of all reported road accidents with cost approximately 100 million Euro damage. Similarly, in the United States, around 1 to 2.1 million deer-vehicle accidents occur per year, count of $8.4 to $10 billion in economic losses also around 359,000 people injuries, and 200–440 human deaths (Canal et al., 2018; Cunningham et al., 2022).

Most common species involved in AVCs consider to be roe deer (*Capreolus capreolus*). Alone roe deer accounted for the largest part of all AVCs in Europe (Freitas et al., 2015; Seiler, 2004; Sáenz-de-Santa-María & Tellería, 2015; De Vries, 2015). Studies focused on temporal patterns found that RDVC are associated with a bimodal activity rhythm. In this study we analyzed temporal patterns of roe deer vehicle collisions reported by police authorities in the Lithuania. Dataset, consisting of 19,707 data points, allowed investigating temporal patterns of roe deer-vehicle accidents. According to time (month, day of the week, time of the day) and lunar illumination.

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1. Materials and methods

1.1. Study area

Our study area covers the entire territory of Lithuania (Figure 1), it represents a total area of 65,286 square kilometers. Relief is characterized as a plain. Landscape of Lithuania contain of anthropogenic features as well as natural features: meadows, forests, marshes and variety of different water bodies. Due to political economic and social development Lithuanian landscape have experienced dynamic changes. At the 2022, the resident population of Lithuania comparing to 2021 population declined by 1.31% (Official Statistical Portal, 2022). Regardless of resident population fluctuation, number of vehicles in Lithuania has been increase 3.24%. According to their social and economic significance, roads in Lithuania are divided into: national (4926 km), main (1750 km) and regional roads (14 574 km) (Ministry of Transport and Communications, 2021). At the beginning of 2021 together roads form a 21,2349 km network (Lithuania Road Administration, 2023a). In the period 2012–2021, the annual average daily traffic (AADT) increased from 7518 to 9492 vehicles a day on main roads, from 4193 to 2330 vehicles a day on national roads, and from 357 to 438 vehicles a day on regional roads (Lithuania Road Administrator, 2023b).

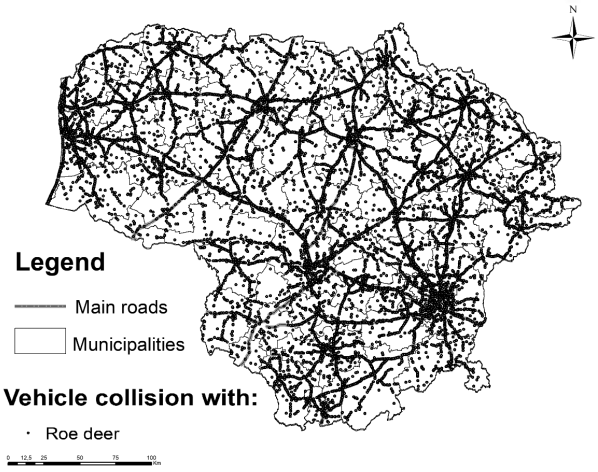

Figure 1. Study area and the locations of the RDVC in period of 2014–2021 (n = 19707)

Our data shows that most common species involved in AVCs in Lithuanian roads are roe deer (*Capreolus capreolus*) (69.25% of all AVCs). In the last decade ungulates population growth has been exponential, number of roe deer in Lithuania being estimated as 172,599 individuals in 2022. Lunar disc illumination % were obtained from official NASA page: Scientific Visualization Studio (2022). Since, each collision has an accurate time, the percentage of moon illumination for that hour was applied to each fixed collision.

Data of animal-vehicle collisions (AVCs) provided by Lithuanian Police Traffic Supervision Service. A total of 28,455 AVCs were recorded over the period of 2014–2021 in Lithuania. For the further analysis we considered reports of 19,707 roe deer (*Capreolus capreolus*). Each year RDVC accounts for about 24 633 collisions.

2. Results

2.1. Temporal analysis of roe deer- vehicle collisions

Roe deer vehicle collisions analysis showed strong hourly pattern. It is clear that incidents with this species are distributed nonrandom. Significantly more occurrences took place in morning hours 07.00 (9.23%). Evening collisions reach peak in 22.00 (10.16%). Frequency of RDVC from 9.00 to 15.00 were not noticeable. Distribution of roe deer vehicle collisions in time is presented in Figure 2.

There were no significant differences in frequency of RDVC between days of the week. However, frequency of RDVC peaked on Friday (15.73%), but decreased again on Saturday (14.56%), before it reached the lowest value on Sunday (13. 82%). Coefficient of determination $R^2 < 0.0921$.

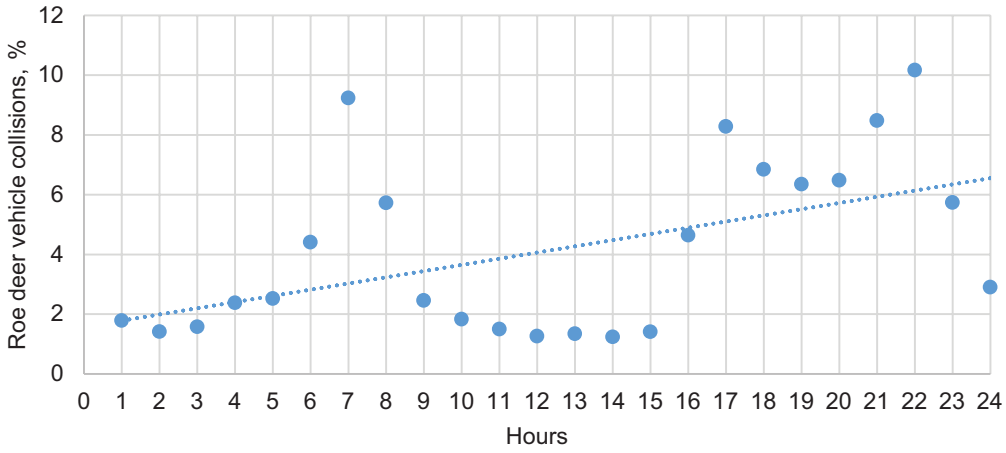

Figure 2. Roe deer vehicle collisions distribution in by hour, %

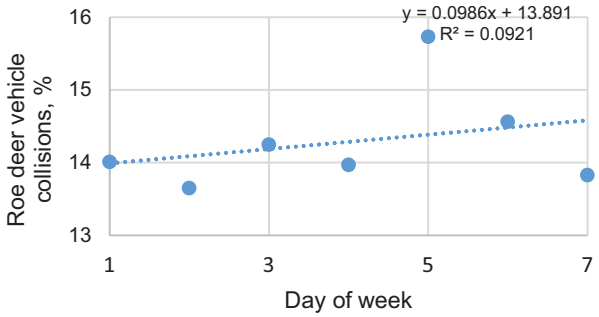

Figure 3. Roe deer vehicle collision distribution in week days, %

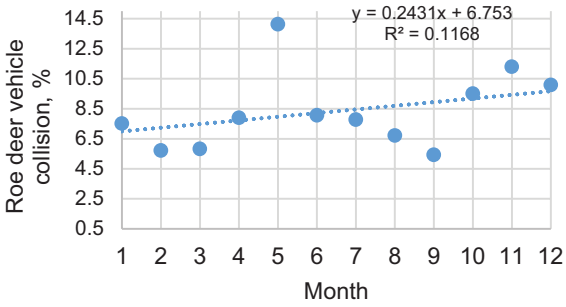

Figure 4. Roe deer vehicle collisions distribution by months, %

RDVC analysis showed strong monthly pattern. Significantly more occurrences took place in the middle of year, in May (14.13%) with a higher risk of accidents at the end of the year, during November (11.3%). Distribution of RDVC for different months is presented in Figure 4. The lowest frequencies of RDVC were recorded in February (5.7%) and September (5.4%). $R^2 < 0.1168$.

The results of time analyses are presented in the follow graphs. Figure 5 shows calendar heat map of R. To show the general numbers of collisions in Lithuania, by year, month, and day of the week in one figure.

The relationships between lunar illumination and roe deer-vehicle accidents were analyzed and presented in the follow graph (Figure 6). We found that more collisions with roe deer were registered when lunar illumination percentage was 99.8%. This provides evidence for high frequencies of RDVC during full moon phases. Second high collisions rate was found when lunar illumination was between 0–10% (19.77% of RDVc). And then decreased rapidly, 11–20% of illumination (8.55% of RDVc). The lowest frequencies of RDVc were recorded when lunar disc illuminations were between 41–50% (6.26% of RDVc).

3. Discussion

Animal vehicle collisions are global safety, economical and conservation concern worldwide (Bissonette et al., 2008; Kušta et al., 2014; Pagany, 2020; Krukowicz et al., 2022). Analysis of RDVC in Lithuania provides interesting and novel information on different time units and moon illumination. Studies shown that there are multivariate factor influencing AVC (as traffic intensity (Steiner et al., 2021), road structure (Sugiarto, 2022), use of land (Torres et al., 2023), or specie-specific behavior (Steiner et al., 2021; Morales et al., 2013). Nevertheless, we believe that time fluctuations (basis of seasonal, daily, monthly, hourly) should not be ignored. Vehicles accidents with roe deer do not occur randomly over time (Morales et al., 2013; Seiler & Helldin, 2006). Our study showed that highest collision peaks are recorded at morning (dawn) and evening (dusk) hours. Our findings are in line with the results described in the past study (Pagon et al., 2013; Vrkljan et al., 2020; Zanni et al., 2021; Gaudiano et al., 2021; Pokorny, 2006). A nadir activity for roe deer was found to be from 9 am till 15 pm (±7h). So activity during the day is low (this trend was found in our study as well). In the dusk, and during afternoon activity peaked again. It is clear that collisions could be associated with quantity of light (dawn and dusk).

Variation throughout the week in collision with roe deer is most likely is a response to traffic factors. There is no evidence of specie-specific interaction between behavioral, biological or ecological factors that could increase deer activity per day of the week. We found a peak of RDVC on Friday (15.73%) with a secondary peak on Saturday (14.56%, Figure 3). Similar results were obtained from previous studies (Steiner et al., 2021; Morales et al.,

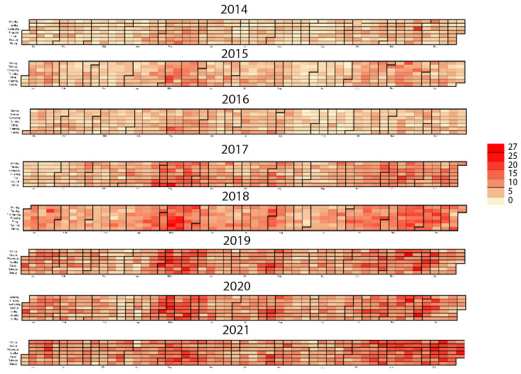

Figure 5. Heat map of roe deer vehicle collision in Lithuania between 2014 and 2021 in units

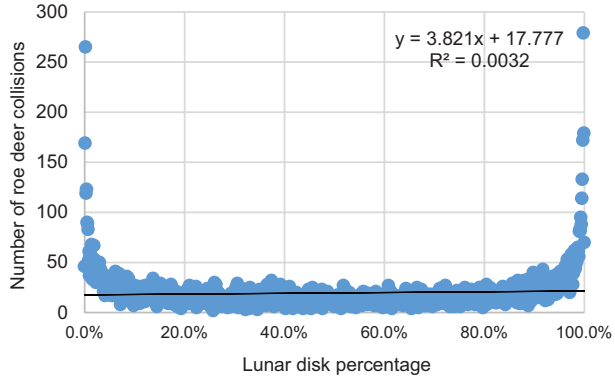

Figure 6. Roe deer vehicle collisions accodring to lunar disk ilumiation %

2013). Weekly accidents with roe deer shows difficulties of finding variables to explain increase of collisions, and we agree that further multivariate analysis is needed to determinate the statistically significant factors.

Understanding seasonality is crucial to comprehending RDVC. In analyzing deer collisions in Lithuania we found strong monthly pattern. Our findings are in line with the results described in the past study (Morelle et al., 2013; Steiner et al., 2021; De Vries, 2015; Gomes et al., 2021; Baek & Lee, 2021). Collisions according to month can be separated into two seasons. Spring season (April-May) and autumn season (September–November) (Figure 4). In Lithuania seasonal fluctuation of RDVC are mostly associated to specie-specific behavior (food search, winter herd falling apart, strong territorial and aggressive behavior). The percentages of collisions slightly decrease during rut period (Figure 4). During autumn and winter second more precise RDVC peak are found. When temperatures start decries, harsh wind and snow depths increase, one again deer change their behavior and winter herds are formed back. In winter roe deer as well as other ungulates spend more time searching for high quality food or shelter (Parker et al., 2009; Weiskopf et al., 2019). Unfortunately, these circumstances increase collisions with vehicles.

Studies revealed that lunar illumination affects animals in many different ways. For example, it is found that phase of moon can affect activity and behavior of animals (Colino-Rabanal et al., 2018; Kawata, 2011). Nevertheless, surprisingly little is known about correlation between animal vehicle collisions and illumination of lunar. Contrary to our results researchers suggest that there is no statistical significant effects or association with lunar phases on collisions with roe deer (Vrkljan et al., 2020; Reimoser, 2014; Pagon et al., 2013). We discovered that when the lunar illumination percentage was 99.8%, there were more collisions with roe deer that at any other moon illumination percentage. We agree that this factor had a limitation. For instance, we did not consider the characteristics of cloud cover. During the night it is not easy to observe cloud cover. Although, cover of clouds could have a fundamental impact (barrier) on the observation moon illumination in the night (Krieg, 2021). Nevertheless, we, as well as Steiner et al. (2014, 2021); believe that great increase in animal vehicle collisions may cause by higher activity of roe deer during full moon. Our findings suggest that RDVC was most closely associated with the high percentage of lunar illumination, indeed further research is needed.

Conclusions

The number of animal-vehicle collisions is increasing worldwide. Therefore, comprehensive knowledge of temporal collision patterns and influencing factors should be analyzed to reduce risk of AVCs by applying optimal mitigation methods in space and time. In addition, the number of studies that analyses time factors are limited. The important conclusions from our study can be summarized as follows: (1) Roe deer are the most common species involved in AVC in Lithuania; (2) Vehicles accidents involving roe deer are not random in time; (3) Factors affecting the collision rate are species specific (strong rut activity, mating activity, territorial behavior); (4) Illumination of moon can cause changes in animal behavior, for roe deer increasing illumination of the moon showed a tendency of increased collisions rate. Therefore, we believe that further research is needed to address the species specific phenology in analyzing AVCs.

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Conflicts of interest

The authors declare no conflict of interest.

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