Dynamics of Roe Deer (*Capreolus capreolus*) Vehicle Collisions in Lithuania: Influence of the Time Factors

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Abstract**—**Animal vehicle collisions (AVCs) affect human safety, cause property damage and wildlife welfare. The number of AVCs are increasing and creating serious implications for the animal conservation and management. Roe deer (*Capreolus capreolus*) and other large ungulates (moose, wild boar, red deer) are the most frequently collided ungulate with vehicles in Europe. Therefore, we analyzed temporal patterns of roe deer vehicle collisions (RDVC) occurring in Lithuania. Using a comprehensive dataset, consisting of 15,891 data points, we examined the influence of different time units (i.e. time of the day, day of week, month, and season) on RDVC. We identified accident periods within the analyzed time units. Highest frequencies of RDVC occurred on Fridays. Highest frequencies of roe deer-vehicle accidents occurred in May, November and December. Regarding diurnal patterns, most of RDVC occur after sunset and before sunset (during dark hours). Since vehicle collisions with animals showed temporal variation, these should be taken into consideration in developing statistical models of spatial AVC patterns, and also in planning strategies to reduce accident risk.

Keywords**—**Animal vehicle collision, diurnal patterns, road safety, roe deer, statistical analysis.

I. Introduction

As the industrial revolution evolved, roads and traffic become recognized as major threats to wildlife and as a growing concern for road traffic safety. Understanding the effects of various elements in AVCs is essential for managing road safety and reducing accidents, which is why there are more roadkill-related publications appearing in journals of traffic, wildlife, and transportation safety [1].

In most parts of European countries AVCs have become the primary cause of direct ungulate mortality. That’s why AVCs have become one of research frontiers and hot topics. During the last decade, density and distribution of deer species have increased rapidly in United States as well as Europe. In parallel, there was a grow in road infrastructure, traffic speed and volume [2]. Cervids (*Cervidae*) are typically severely harmed by roadways as a result of car crashes [3].

Roe deer (*Capreolus capreolus*) is a smallest, but most common deer species, with being involved in the highest numbers of deer-vehicle accidents (DVAs) in Europe [4]-[6]. For instance, the majority of reported AVCs in Germany include roe deer, which are killed in crashes on a yearly basis to the tune of 200,000 [3]. Each year, these crashes hurt over 3,000 individuals and damaged property to the tune of 500 million euros [7]. Between 2001 and 2012 (a total of 12 years), Finland's roe deer kill rate peaked [8]. The majority of collisions (70.1%) that occur in the Dinaric region involve roe deer [9]. On a global scale, several million large mammal vehicle accidents are reported per year [2].

Although the majority of studies concentrated on temporal patterns (seasons, months), fine scaled temporal analyses of RDVC (e.g. time of day, day of week, month) are carried out less frequently because to the lack of high-quality accident data. [10]. However, the frequency of DVAs may be related to human involvement in traffic as measured by metrics like traffic volume, frequency, and density. Heavy traffic on or before workdays coincides with high deer activity at sunrise and sunset [11], which can inevitably lead to high numbers of RDVCs [10]. Given the economic aspects of deer mortality, road safety, and human and animal mortality, knowledge of spatiotemporal patterns and associated accident factors is essential for the most appropriately selected and focused prevention studies.

In this study, we analyzed temporal patterns of RDVC reported by Lithuanian police. A comprehensive data set of 15,891 data points made it possible to examine temporal patterns of DVAs on an unprecedented scale. We evaluate the number and frequency of accidents by season, month, day of the week, and time of day. The aim of this study was therefore to contribute to our understanding of these patterns. We assumed that the high frequency of RDVC is associated with:

I) roe deer rutting take time in late summer, lasting from the end of July until the beginning of August, as well as territorial roe deer behavior;
II) high traffic volume on weekdays;
III) roe deer collision activity peak around dusk and dawn (rush hours).

II. Materials and Methods

A. Study Area

Lithuania is a Central European country located in the middle of Europe on the eastern coast of the Baltic Sea. It lies in the Eastern European plains with its characteristic lowlands and hills. Lithuania has an area of 65,300 square kilometers. The geographic coordinates of Lithuania extend between latitudes 56°27'N (extreme north) and 53°54'N (extreme south), and longitudes 20°56'E (extreme west) and 26°51'E (extreme east) [12]. Alisov's climate classification divides Lithuania into

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subregions of temperate and mixed and deciduous forests in the Atlantic and continental Europe [13]. The average annual temperature in Lithuania is 7.4 °C. July is the hottest month in Lithuania. January is the coldest month. At the end of the 20th century, the number of extremely hot days with maximum temperatures exceeding 30 °C increased. On the other hand, the number of frosty days when the daily minimum temperature falls below -20 °C has decreased significantly. Normal climate precipitation from 1991 to 2020 is 695 mm. [14]. After the analysis of the landscape of Lithuania, it was established that in 2020 the anthropogenic landscape includes: built-up areas, roads and damaged land occupied the largest part of the country's landscape (55.79%), the smallest part of the landscape was occupied by anthropogenized landscape (5.65%): agricultural land (arable land, orchards as well as meadows and natural pastures), tree and shrub plantations, unused land. The natural landscape (forests, water bodies and wetlands are components that make up the natural landscape) in Lithuania occupied a 38.56% of the country's territory [15].

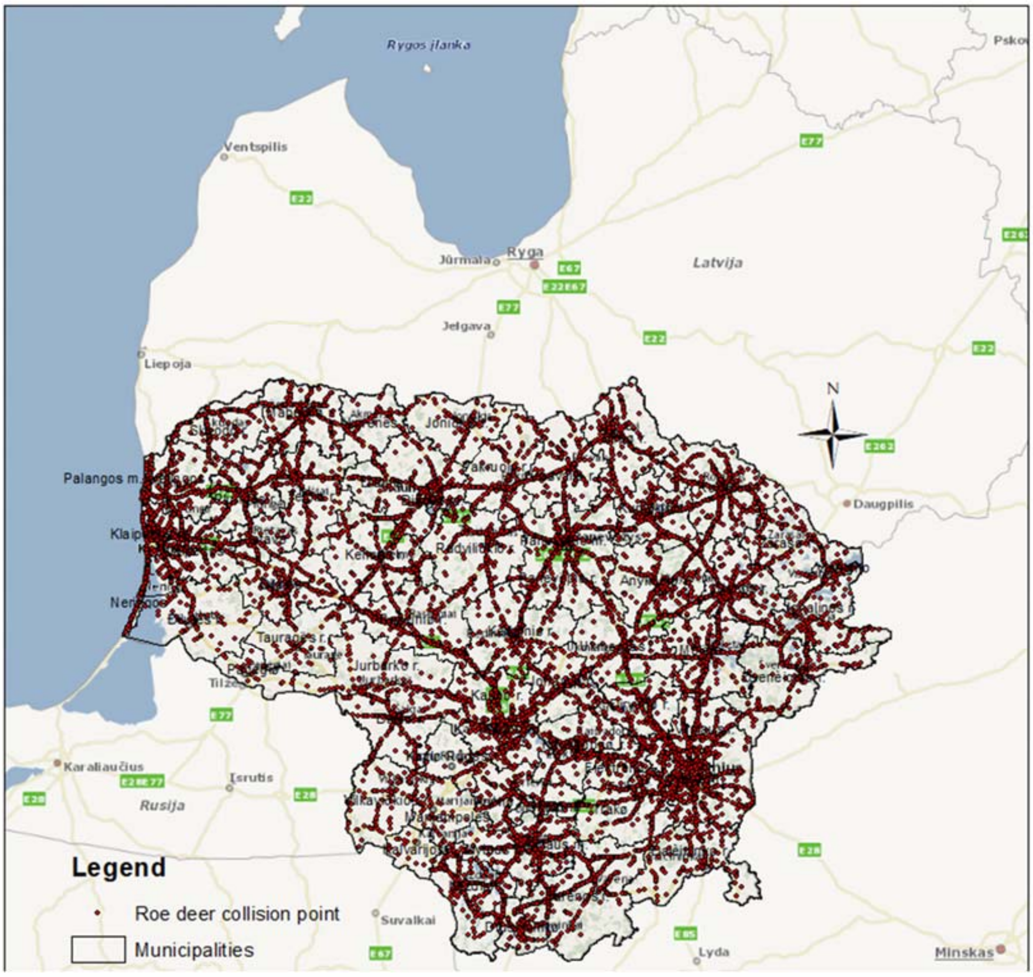

Fig. 1 Map of RDVC locations (red points) between 2014 and 2020 in Lithuania

Data based on projections of the latest United Nations show that current population of Lithuania decreased and in current time (2022) is 2,671,266. The average human density is 43 inhabitants/km². According to 2020-year data 71.3% of the population lives in urban area [16].

Due to their capacity, social and economic significance, all the roads in Lithuania are divided into: national, regional and main. Main roads consist of 1,751.293 km, National roads 4,927.712 km, regional roads 14,558.613 km. The total length of the road network is equal to 21,237.617 km [17]. From 2016 till 2020 the number of vehicles in Lithuania increased by 339055 vehicles [18].

Depending on road type, the annual average daily traffic (AADT) on most of the Lithuania roads has also grown. For example, from 2014 till 2019 AADT on the main roads (road number A1) increased from 16 873 in 2014, to 21 653 in 2019. On other national road types (road number 122) it increased from 2724 in 2014, to 2984 in 2019) [17].

B. Study Data Collection

AVCs data were provided by Lithuanian Road Police Service. Total of 23,918 AVCs were recorded over the period of 2014–20120 in Lithuania. However, in the recorded data, the cases in which location information was incorrectly described, were excluded from the temporal analysis (531 records). Out of all the AVCs we selected, 15,891 collision reports involved roe deer. Approximately, 2270 collisions with roe deer were recorded each year for the period of analyses. Alone in Lithuania roe deer accounted for about 66,8% of all AVCs. While compering other ungulates like moose (*Alces alces*), 6,25% wild boar (*Sus scrofa*) record consisted of 3,83%, red deer (*Cervus elaphus*) 1,71% AVC's, alone roe deer is responsible for about 66,8% of all AVCs in Lithuania.

Accidents with animals that are registered in Lithuania have information on date, time (Eastern European EEST time zone UTC+02:00 and UTC+03:00 during the period of daylight saving) and location (indicating the geographic coordinates) of the event (Fig. 1), as well as the species involved (when possible).

C. Statistical Data Analysis

In the temporal study, a total of 15,891 RDVC were divided by month to analyze the monthly patterns, by hour and by the time of the week. Seasons were also defined by the four categories: spring (March–May), summer (June–August), autumn (September–November), and winter (December–February). Statistical operations were carried out using Microsoft Excel package. ArcMap 10.6.1 was used to create a fishnet for combining time of the day and month when a collision with roe deer was registered.

III. Results

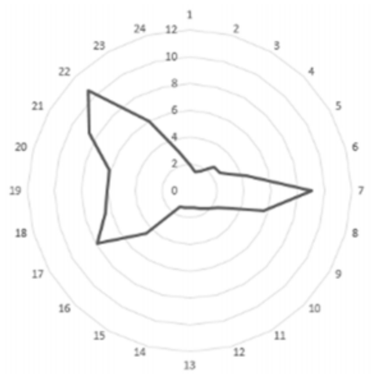

Fig. 2 (a) Hourly variation of RDVC (%)

Fig. 2 (b) Weekly variation of RDVC (%)

Temporal patterns of all RDVC were non-randomly distributed. There were three peaks during the day. Strong first peak at 7:00 h, second peak were registered at 17:00 h, last major peak at 22:00 h (Fig. 2 (a)). Throughout the week, slightly more RDVC took place on Friday (Fig. 2 (b)).

May (14.78%) and November (11.23%) had highest percentage of roe deer vehicle collisions, Fig. 3. During the seven-year period, September was the month with lowest collision rate (5.25%).

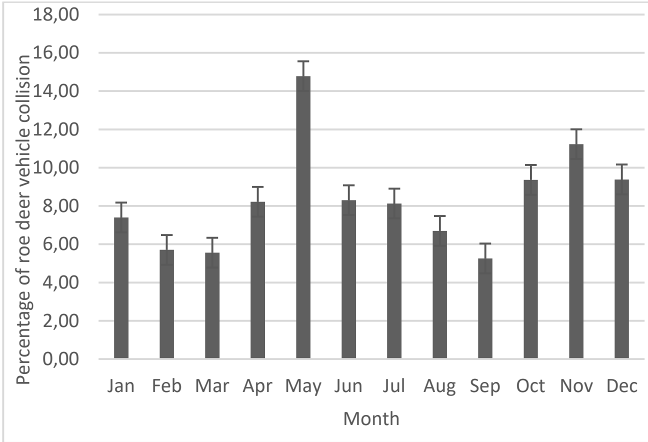

Fig. 3 Monthly pattern of RDVC 2014-2020 (%)

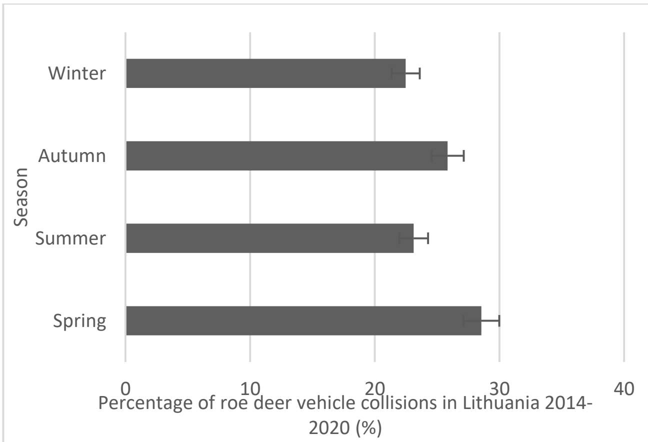

Fig. 4 Seasonal pattern of RDVC (2014-2020, %)

The fewest road-kills were seen in summer (Fig. 4). Longer day length reduces the number of AVCs, because the largely nocturnal habits of roe deer lead to most road-kills occurring during the dusk-to-dawn period, when most of wild animals have commenced foraging.

Hourly distribution of RDVCs varied seasonally (Fig. 5). During May-July the morning peak of RDVCs occurred earlier in the day 4-5 am. Nevertheless, in the autumn-winter (October-December) the morning peak of RDVCs occurred between 6 and 8 am. The evening peak showed opposite tendency. In May-July it occurred between 9 and 10 pm. In October-December the evening peak was earlier from 4 to 6 pm.

IV. Discussion

This study confirmed temporal patterns of RDVC frequencies throughout the different time units in Lithuania. Analyses were performed based on data collected within seven years. The temporal distribution of RDVC expressed non-random patterns. Our results were similar to early findings on a distinct temporal collision pattern for roe deer as well as other ungulates like moose (*Alces alces*), red deer (*Cervus elaphus*), white-tailed deer (*Odocoileus virginianus*), wild boar (*Sus scrofa*) [1], [10], [19], [20]. Following our expectations, the time periods of increased RDVC risk were linked to specie specific roe deer behavior. Beneath, we discuss potential mechanisms behind the observed temporal patterns of RDVC.

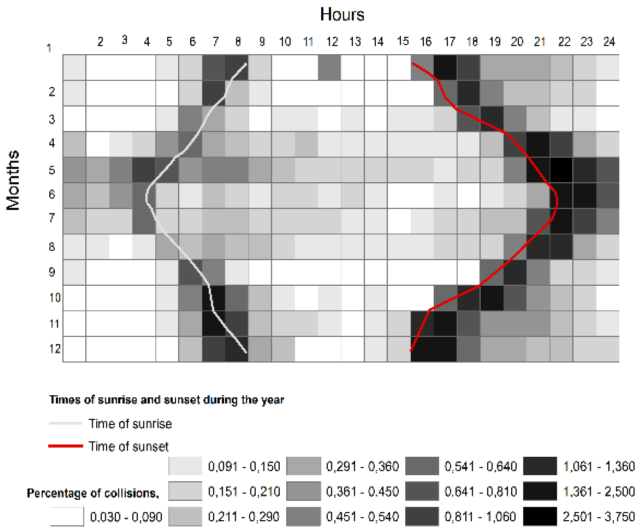

Fig. 5 Cumulative daily and seasonal variability of RDVC during 2014–2020 in Lithuania; Square represents percentage of collisions; The white line indicates sunrise and the red line indicates sunset

Depending on the season, habitat use, and level of disturbance (heavy machinery in the arable land, human disturbance), predators (wolves, lynx, fox), roe deer exhibit a variety of diurnal activity-bouts. Several studies have described bimodal crepuscular twilight DVA patterns with peaks around dusk and dawn [10], [21]. Results of our study show a main prolonged peak around dusk (after sunset), a smaller peak around sunrise. Similar results were found in Spain [1], Germany [22], Bosnia and Herzegovina [9]. It is apparent that collisions are related to sunrise and dusk (light), as shown in our study.

RDVC difference may be explained by the seasonal variation in animal behavior associated with weather conditions, habitat changes, human disturbance and predators [2]. The probability for collisions to occur at dust and down hours, which coincides with the period of maximum animal activity, was the most common daily pattern observed in roe deer and other cervids [2]. Due to relatively lower visibility at night hours, driver reaction to animal presence on the road is likely to decrease [23].

Monthly analyses showed that RDVC occurred most frequently on May. This late spring month with the highest frequency of RDVC is the period when roe deer fawns are born and begin to move around with their mothers. It has been documented that lactating female travels longer distances than a non-lactating female to improve the nutrition of their milk [20]. In line with our expectations, RDVC risk was positively associated with roe deer activity peaks – they were highest in the growing season (May-November). Periods of elevating roe deer activity due to seasonal migration movements considered to be late spring and autumn, meanwhile the autumnal RDVC peak (November-December) corresponds to increased roe deer activity during the second rut.

Reference [24] results concur with our results. They found critical peaks with roe deer in spring (April–May) and autumn (September–November). The spring peak is associated with increased post-winter foraging, dispersal to new areas (yearlings and especially males), and territorial behavior of the species, while the autumn peak is associated with more favorable winter relevant to habitat exploration. The mating season is a time of high ungulate activity and movement [25], and a time when vehicle collisions with wild animals are frequent. In addition to roe and red deer, which show strong rutting peaks in the annual distribution of collisions [21], other North American *Odocoileus* stags have also recorded collision peaks associated with mating activity [26], most of the collisions occur in November [9].

Since no deer-specific biological, ecological, or behavioral factors are known for the distribution of roe deer accidents per weekday, we, like other authors, assumed that traffic is the main element. According to State Enterprise Lithuanian Road Administration traffic intensity on working days reach a peak in Friday (1%). Traffic intensity respectively decrees on Saturdays (0.63%) and Sundays (0.61%) [27]. Therefore, we had assumed that highest frequencies of roe deer collisions are occurring during workdays. In our investigation, however, practically uniform low RDVC values were reported for the first four days of the week. A peak in DVA occurred on Friday (15.85%) with a secondary peak on Saturday (14.61%, Fig. 2 (b)) which is in line with what has been discovered in the literature [28]-[30]. Tuesday had the lowest RDVC values in our study (13.5%). However, the higher frequency of collisions on Friday afternoon and Saturday could be due to higher average driving speeds and increased human disturbance (hunting, tourism, agriculture and recreation) in roe deer habitat.

V. Conclusions

Although the temporal RDVC pattern determined in our study is in partial agreement with other findings from Europe, it also indicates peak accident times that cannot be explained by deer activity rhythms alone. It must be caused by other factors like human disturbance, hunting or traffic intensity. It is unclear what factors influence RDVC, and how these factors combine. However, there is strong evidence that most of the relevant factors are steadily deteriorating and that their impact is increasing [10].

As mentioned earlier, from a scientific point of view, knowledge of detailed temporal traffic accident patterns is important for extracting and assessing the causes of traffic accidents, but it is best practiced by stakeholders and practitioners. It is also important so that appropriate mitigation methods can be applied to reduce the number of RDVCs.

Actions by hunters, farmers and road authorities to improve habitats such as: maintenance of land cover and post-harvest food supplies are important measures to address suspected strong agricultural impacts on RDVC patterns. These actions may help avoid or mitigate negative animal-vehicle conflict. However, the location of such coverage areas can dictate their effectiveness, as they are often located adjacent to transportation infrastructure, exacerbating the underlying problem. Signage of potentially affected roadside hunting and harvesting activities certainly helps in better identification.

The dangers of road traffic due to increased animal activity are regularly published by the Austrian Road Safety Association and Automobile Clubs and should be strengthened in the most dangerous months to further raise awareness among motorists. Permanent signs by road authorities, warnings about possible animal crossing, are often used frequently for legal reasons and, as a result, are mostly ignored by motorists. Enhanced awareness campaigns, permanent or digital signage and navigation device warnings are only activated in the event of a major incident. In the future, further developments in the automotive industry could also help identify crossing animals earlier and avoid collisions. Therefore, further studies analyzing temporal patterns of roe deer mortality using high-resolution temporal data are highly recommended. This allows us to extract detailed driving factors for roadkill in addition to species-specific phenology. Further studies are needed to address the apparent increase in deer nighttime activity during the full moon and the associated DVA. Precise knowledge of spatial and temporal patterns is required to enhance road safety for both humans and animals. This allows researchers, hunters, and road managers to take appropriate mitigation measures in space and time to get the best results in reducing DVA.

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