Temporal Patterns of Ungulate Vehicle Collisions in the Thunder Bay Area

by

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ABSTRACT

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Keywords: human-wildlife conflict, moose, traffic, white-tailed deer, wildlife-vehicle collisions

Rising road densities, higher vehicle speed limits, and increased traffic volumes, combined with growth in the density of various deer species, have increased the risk of wildlife-vehicle collisions across the world. The result is a great deal of animal suffering, traffic safety problems and socio-economic costs. The objective of this investigation was to explore trends in vehicle collisions with moose and white-tailed deer in Thunder Bay and attempt to gain a better understanding of the temporal variation associated with collisions. Describing their temporal pattern allows for the development of measures to reduce wildlife-vehicle collisions. The monthly distribution of the 1,332 wild ungulate-related traffic accidents on regional highways in the Thunder Bay area occurring between January 2011 and December 2021 was not random; most occurred in May and June, coinciding with the breeding season when juveniles born the previous year are dispersing. The next most common months for accidents were October and November, coinciding with the rut. Averaged over the entire eleven years, daily peaks in accidents occurred more often during dawn and dusk hours, but the trend occurred only for two of eleven years, suggesting that peaks in deer and moose activity, which should correspond with these hours, are not consistently responsible for accident risk. Drivers can reduce collision risk and especially the risk of serious consequences by lowering their speed and by keeping alert for deer and moose.

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INTRODUCTION

Wildlife–vehicle collisions (WVCs) are a consequence of human population growth and urbanization. Although WVCs have occurred since the introduction of motorized vehicles, the WVC rate has increased geometrically with increasing traffic volumes and speeds (McDonald et al., 2019). Traffic infrastructure and traffic flows have rapidly developed in recent decades. This development brings benefits to society, but on the other hand has many negative impacts on the environment. The most significant impacts of road traffic are direct mortality of free-ranging animals due to vehicle collisions (Keken et al., 2016). Wildlife-related accidents are considered a serious problem globally since they threaten human safety and generate high economic losses due to damage to vehicles (Lagos et al., 2012). Roads are also a threat to wildlife since they can cause a high level of mortality on populations (Ferreras et al., 1992; Underhill & Angold, 1999). The rise of traffic volume and speeds, as well as the growth in the population size of ungulates, are the main factors associated with the increase of ungulate-related accidents (Lagos et al., 2012).

Many species of free-ranging animals are killed on roads. Out of the multitude of animal species killed in traffic, accidents with deer forming the Cervidae family are best documented because of high economic costs arising from crashes (e.g., vehicle damage, human and deer injury and mortality, loss of venison and trophy). Reducing these accidents is of vital interest for hunters, road safety agencies and insurance companies (Steiner et al., 2014). Deer are considered among the most problematic accident-prone ungulates on roads and cause the largest material losses due to their high densities, movement on road shoulders, and their large body size.

The temporal patterns in WVCs can be related to the behaviour of the drivers or to the behaviour of wildlife (Dussault et al. 2006). Usually, collisions increase with higher activity and vary seasonally with variation in movements by deer. Road crossings occur when ungulates are more active, i.e., during migration, rutting, hunting seasons and twilight hours (Neumann et al., 2012). To better understand, manage, and mitigate WVCs, a detailed knowledge of the temporal behavioral patterns of ungulates is essential. I examined time-dependent patterns of WVCs in Thunder Bay, the most populous municipality in Northwestern Ontario. Located on Lake Superior, the census metropolitan area of Thunder Bay had a population of 123,258 in 2021. The analysis included 1,332 WVC records from 2011 to 2021. I hypothesize that the WVCs in Thunder Bay will be higher when deer and moose are in the rut as this makes them more irritable and susceptible to collisions.

LITERATURE REVIEW

a) Factors exacerbating human conflict with wildlife

The exponential increase in human population has placed excessive pressure on wilderness areas around the world. Increasing population means more demand for infrastructure, more land for cultivation of food and extraction of resources, as well as space required for settlement. According to the planetary boundaries framework, we have entered the zone of uncertainty for land-use change, with serious implications for the earth's self-regulating processes (Steffen et al., 2015). Over the last 200 years, the rate of HWC has increased exorbitantly, with the competition for space and resources heavily reducing or annihilating certain species. The trends between the global human population and species extinction are positively correlated (Fig. 1). Extinction is a direct consequence of rapid population growth and excessive resource extraction to satisfy our needs (Scott, 2008).

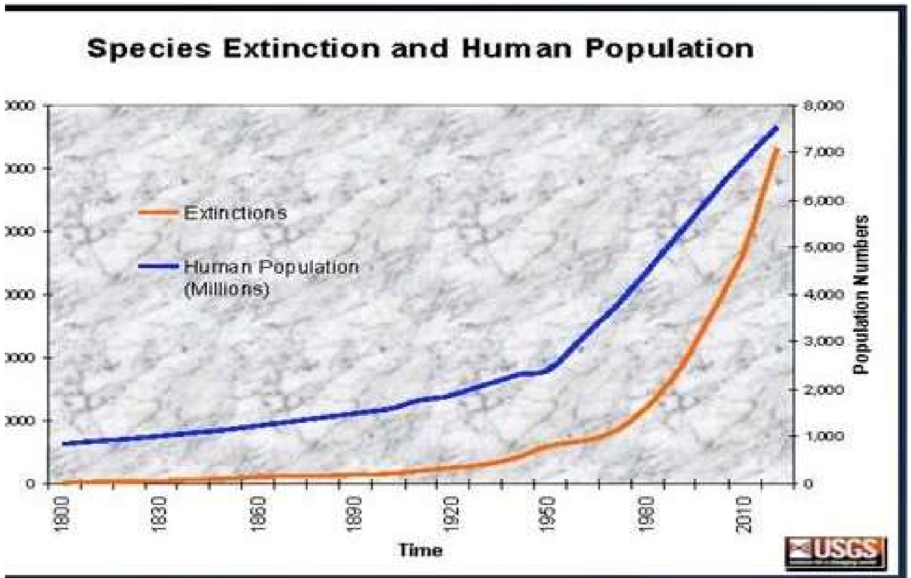

Figure 1. Relationship between size of the human population and rate of extinction of species from 1800-2010 (source, USGS).

b) Factors influencing the issue

Landscapes are characterised by continuous and dynamic change, which may be expressed by changes in landscape structural characteristics. The unstoppable force of human development has created an enormous problem in terms of human-wildlife conflicts. Since the beginning of motorization until today, roads and traffic have been recognized as a major threat to wildlife (Steiner et al., 2014). Among the most negative effects of traffic on wildlife are direct taking of land and transformation of natural biotopes, division of natural habitats, impediments to migration and mortality resulting from roadkill. Incessantly intensifying traffic infrastructure has a great impact on populations of free-ranging animals.

Roads and their associated vehicular traffic affect persistence of wildlife population in a multitude of ways, including habitat loss. Habitat loss can be direct, where habitat is removed to build roads or indirect, where habitat quality close to roads is reduced due to emissions from traffic (e.g., noise, light, pollutants). Reproduction is interrupted in areas of habitat destruction; further-more, reproductive rates are likely reduced, and mortality rates increased in lower quality habitat close to roads, leading to lowered chances of population persistence (Jaeger et al., 2005). Another factor is the increased traffic mortality due to collisions of individuals with vehicles on the road. If a significant proportion of a population is killed on roads, and this increased mortality is not compensated by higher birth rates, population persistence can be compromised (Bangs et al., 1989). In addition, traffic mortality contributes to population subdivision by reducing the flow of individuals between subpopulations separated by roads (Gerlach & Musolf, 2000). These increased risks subsequently reduce the cultural carrying capacity of the wildlife population (McDonald et al., 2019). Carrying capacity is defined as the maximum wild density of grown individuals attained by a species, and it tends to be uniform over a wide area, while the cultural carrying capacity is the social tolerance for a species (Dhondt, 1988).

Movement barriers contribute to population subdivision by reducing the flow of individuals between subpopulations separated by roads. Population subdivision occurs when populations become separated into smaller, isolated subpopulations. Both traffic mortality and resource inaccessibility contribute to population subdivision (Jaeger et al., 2005). Populations living in habitat surrounded by roads are less likely to receive immigrants from other habitats, and thus may suffer from lack of genetic input and inbreeding. An increase in genetic defects may lower the probability of population persistence. Moreover, small populations are known to be particularly vulnerable to stochasticity: the smaller a population, the greater its chance of going extinct due to a random demographic, genetic, or environmental event (Wissel & Stöcker, 1999).

If animals can detect vehicles and recognize them as a hazard, intense traffic should lead to fewer road crossings, but at the same time more vehicles will exponentially increase the chances of animals being hit while crossing the road (Killeen et al., 2014). In areas where highways act as barriers to movement, increasing traffic volume decreases the probability of highway crossings. However, decreasing traffic alone will not prevent vehicle collisions and other mitigation measures must be evaluated (Gagnon et al., 2007). Deer are better detected when there are no reflective highway signs and the car's high-beam lights are on (Jensen, 2014). Motorists were able to detect deer equally whether they were moving or stationary; the same study discovered that deer vehicle collisions occur more often in urban areas, where the vegetation along the road was dense and diverse, and along roads with narrow-width rights-of-way.

c) Temporal aspect of accidents

As a result, mainly of human activities, there has been a shift in free-ranging ungulate activity. The temporal patterns in WVCs can be split into annual, seasonal, weekly, and diurnal patterns. Temporal trends in number WVC match animal behavior and biology, with WVCs occurring mainly during breeding and dispersal periods at a seasonal scale, and to daily foraging and resting requirements of animals (Morelle et al., 2013). Most studies analyzing temporal variation have focused on single temporal aspects, and multivariate analyses comparing several drivers are few (Steiner et al., 2014), thus leaving the relative contribution of different sources of temporal variation in WVCs unknown.

For instance, most ungulate-vehicle collisions occur at dawn and dusk, but this pattern can be driven by both elevated animal activity during that part of the day and by reduced road visibility (Haikonen & Summala, 2001; Dussault et al., 2006; Neumann et al., 2012; Ignatavičius et al., 2020; Kučas & Balčiauskas, 2020). Similarly, highest collision frequency occurs in spring and autumn, which could be explained by twilight hours overlapping daily traffic peaks in these seasons, as well as by increased animal mobility related to seasonal migrations, rutting, parturition, or dispersal (Putman et al., 2011; Steiner et al., 2014; Karjalainen et al., 2017). Regionally, even within the same species, peaks in WVCs occur in different months, largely associated with latitudinal differences in seasonal light conditions (Haikonen & Summala, 2001; Danks & Porter, 2010; Neumann et al., 2012).

The number of WVCs can also be shaped by several additional factors. These include temporal variation in daily traffic volume, weather conditions (e.g., temperature, presence/absence of rain, snow, or fog), and moon phases, which all could affect both road visibility and animal activity (Lavsund & Sandegren, 1991; Rolandsen et al., 2011; Hothorn et al., 2015; Laliberté & St-Laurent, 2020). However, complex analyses linking various direct and indirect factors of observed temporal patterns in WVCs are scarce (but see Danks & Porter, 2010; Neumann et al., 2012; Hothorn et al., 2015), and knowledge on mechanisms in collision risk over time for different species and regions is limited.

The number of WVCs is highest during the hours of dusk and dawn, periods when many species of deer, as well as many other animals, are at their peak of activity. At a fine temporal scale, it has been shown that collisions with deer were most frequent at dawn and dusk, (e.g., white-tailed deer, *Odocoileus virginianus*; Allen & McCullough, 1976, Haikonen & Summala, 2001). On a seasonal basis, moose, *Alces alces*, and white-tailed deer accidents are frequent in May and June (Nugent et al., 1997), but typically moose accidents are most common during winter or during the rut (October through November and early December in some cases). Some studies report peaks in accident numbers in autumn (e.g., for white-tailed deer, Allen & McCullough, 1976), while others report peaks in number of car-deer collisions both during spring and autumn (for white-tailed deer, Hubbard et al., 2000). Evidence suggests that the long-term trend is closely related to harvest size and traffic volume (for white-tailed deer, McCaffery, 1973), but, generally, much less attention has been paid to determining the causes of annual variation in number of car-killed deer. It has been recommended that future research efforts on WVCs should more closely examine deer behaviours.

MATERIALS AND METHODS

Study area

Thunder Bay is a remote midsized city located on the shores of Lake Superior in northern Ontario, Canada. It is a small urban island in a vast and sparsely populated landscape (Fig. 2). The city is situated along the west coast of Lake Superior, the largest freshwater lake in the world, and between the Great Lakes-St. Lawrence and the boreal forest regions. The northern climate around the city is characterized by long and harsh winters with very low temperatures and significant snowfall. Its population of approximately 108,000 (48.3 people per square kilometre) has been in decline over the past decade due to an aging population and out-migration of youth and young adults. Historically, Thunder Bay's transportation system and culture has been automobile centric.

With an average of 2094 traffic fatalities per year (2013–2019), road traffic in Canada is considered relatively safe. This corresponds to 5.7 accident fatalities per 100,000 inhabitants per year. By comparison, this same figure is 12.3 in the USA and 17.0 worldwide.

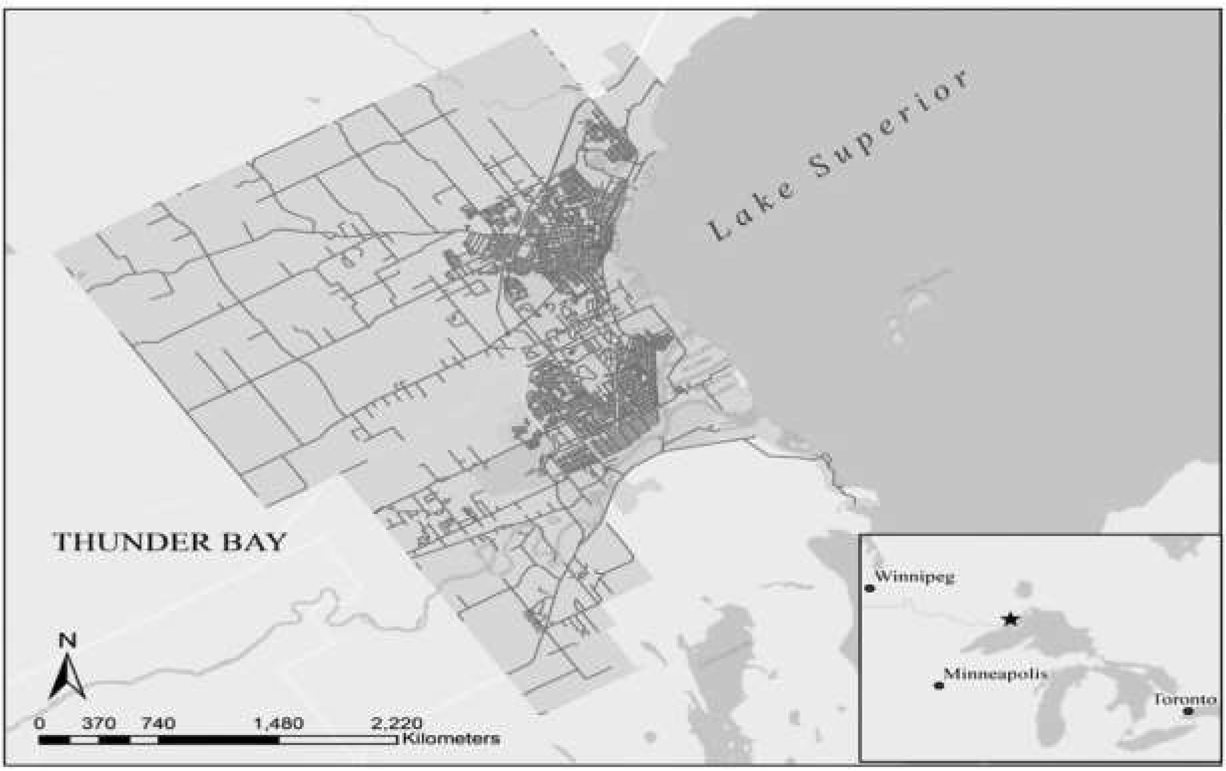

Figure 2. Map of the Thunder Bay area.

Ungulate-vehicle collision data

I worked with collision reports collected by the Ontario Ministry of Transportation (MTO) from 2011 until 2021. The accident-related information in the MTO database includes highway number, year, month, time of day, hour, impact location, light visibility (dark, dusk, daylight, artificial dark, artificial dusk, artificial daylight), day of week, vehicle travel direction, road surface conditions, and coordinates of the accident location. All the data was collected by the first responders and collated into a database by the MTO.

Data analysis

The WVCs reported within the area from 2011 to 2021 were separated by month, day of week, and hour of the day in which they occurred. Chi-square tests of independence were used to determine whether the WVCs occurred more frequently during certain months and days of the week, following McCance et al. (2015). Further, the hours of the day were separated into those that fell within an hour of sunrise, within an hour of sunset, and in the remaining 20 hours of the day, based on the sunrise and sunset times for Thunder Bay obtained from the National Aeronautics and Space Administration (NASA) website. A Chi-square test of independence was used to assess for each year of data whether a significantly higher number of WVCs occurred during the four-hour sunrise and sunset periods. Because twelve tests were done on eleven years plus the total across all years, Bonferroni's adjustment to $\alpha = 0.05$ required a comparison of expected versus observed number of accidents to meet $p < 0.004$.

RESULTS

Averaged over all eleven years of records, there were more accidents in the sunrise and sunset hours; however, these daily peaks reflect just two years within the time series (Table 1). The monthly occurrence of accidents was not uniformly distributed ($\chi^2 = 57.9$, $p < 0.001$). The two months with much higher accident occurrences were November and June (Fig. 3). The calving season (April to June) was when 24% of the accidents occurred, and during the rut (October and November), 31% of the accidents occurred.

Overall, the highest incidence of collisions occurs between 7:00–8:00 a.m. and 6:00–11:00 p.m., a strong bimodal pattern (Fig. 4). The early morning and late evening hours constitute 14% and 39% of collisions, respectively, while the period between 9:00 a.m. and

Table 1. Time of day when wildlife-vehicle collisions were experienced in the Thunder Bay area. Sunrise and sunset are defined by the periods one hour before and one hour after.

Year	Number of collisions			Chi-square	*P*-value
	Total	Sunrise or sunset	Other hours		
2011	123	31	92	6.4	0.01
2012	169	45	124	12.1	0.001
2013	148	27	121	0.3	0.61
2014	124	20	104	0.03	0.87
2015	138	22	116	0.05	0.82
2016	121	27	94	2.8	0.10
2017	119	37	82	17.8	<0.001
2018	109	21	88	0.5	0.47
2019	100	14	86	0.5	0.47
2020	98	25	73	5.5	0.02
2021	83	20	63	3.3	0.07
Total	1332	289	1043	24.3	<0.001

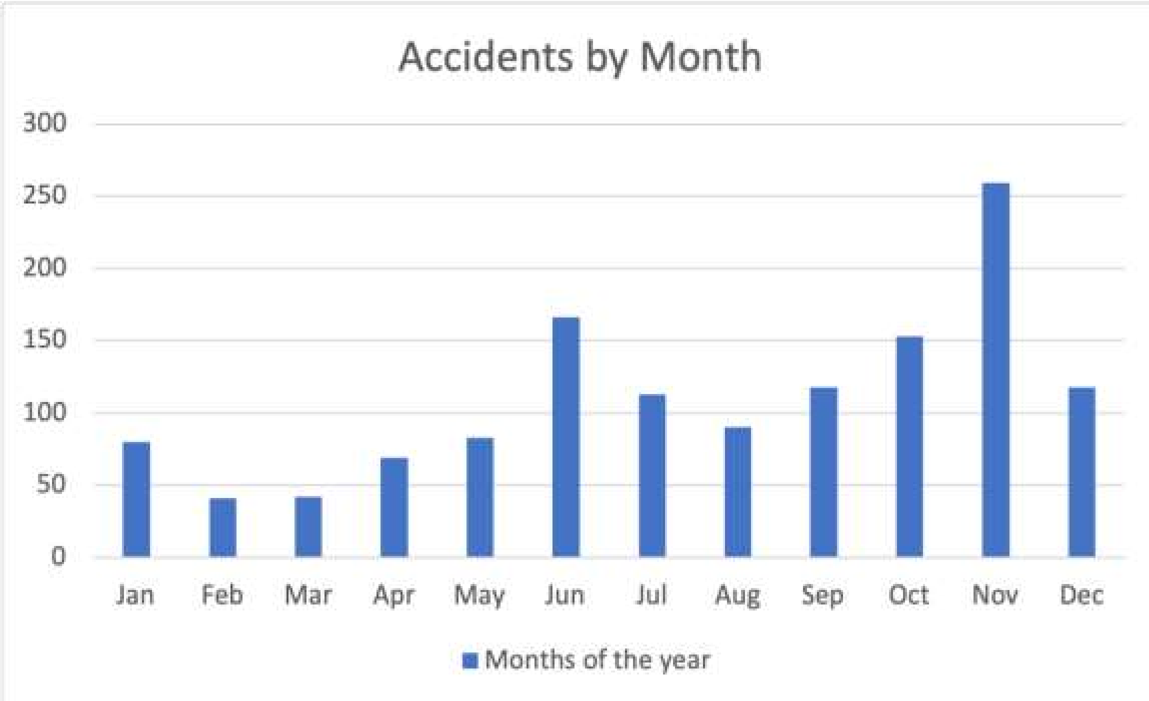

Figure 3. Wildlife-vehicle collisions in the Thunder Bay area, pooled across 2011-2021, by month.

5:00 p.m. has less risk for collision with ungulates. There were slightly more accidents on Thursday (15.1%) and Friday (15.3%), while Sunday (13.3%), Monday (13.7%) and Tuesday (13.9%) had the fewest number of accidents (Fig 5).

DISCUSSION

Averaged over the entire eleven years, daily peaks in accidents occurred more often during dawn and dusk hours, but annually only for two of eleven years, suggesting that peaks in deer and moose peak activity, which should correspond with these hours, is not consistently responsible for accident risk. Apart from variations in traffic volume, several factors may influence the monthly pattern of WVCs, the changing length of the day over the year and the

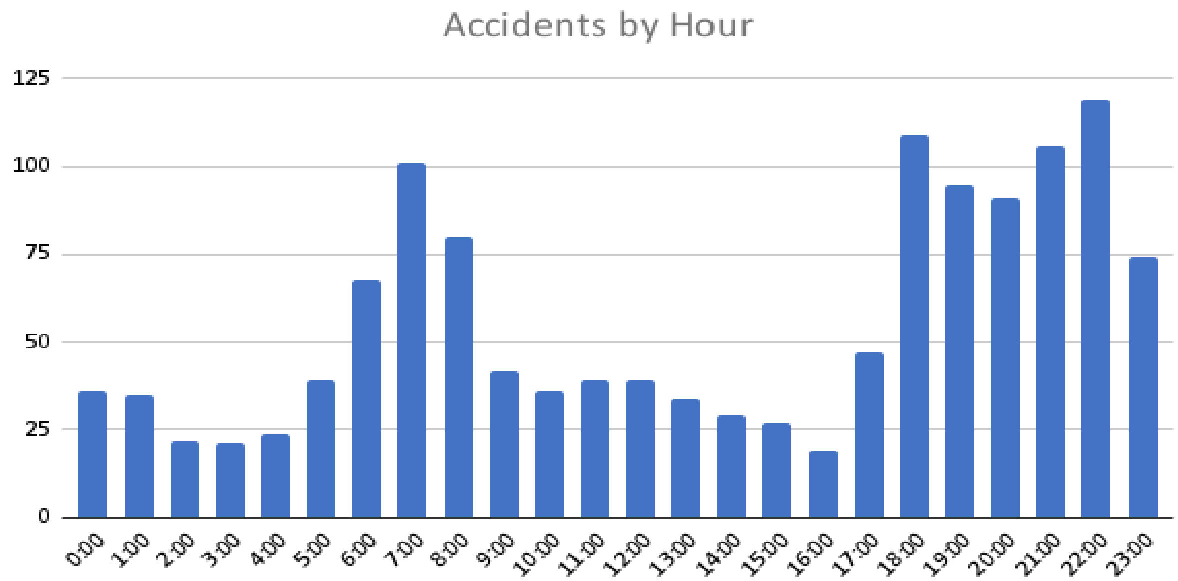

Figure 4. Wildlife-vehicle collisions in the Thunder Bay area, 2011-2021, by hour.

activity pattern of the species involved in the accidents being the main ones (Joyce & Mahoney, 2001; Madsen et al., 2002; Dussault et al., 2006). Several factors directly and indirectly related to sunset affect both the quantity and quality of the encounters between deer and motor vehicles. In a study focused on the general timing of traffic accidents, Åkerstedt et al. (2001) reported that late afternoon and nighttime accidents have a more pronounced peak than early morning accidents due to a variety of factors including road visibility, intoxication, impatience that leads to speeding, and drowsiness (McDonald et al., 2019). Increasing darkness affects the driver's ability to detect a deer, thereby affecting the proportion of unsuccessful animal road crossings (Lagos et al., 2012). At the same time, the circadian rhythms in deer are synchronized to sunset and sunrise; indeed, light is the primary external cue regulating the diurnal circadian functions even in humans (Duffy et al., 1999). Thus, the effects of the endogenous circadian rhythm and light on the behavior of both deer and

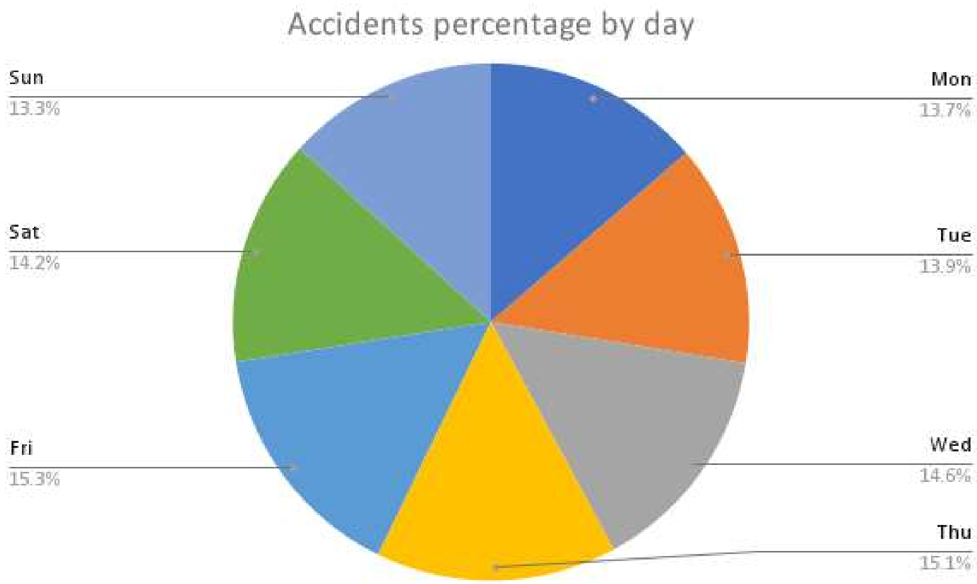

Figure 5. Percent by weekday of wildlife-vehicle collisions in the Thunder Bay area, 2011-2021.

humans must be considered as potential explanations for sunrise and sunset crash peaks (Aschoff, 1966). The feeding rhythm of deer consists of altering periods of activity and passivity, lying down to ruminate (Cederlund, 1989). In addition, deer and many other animals have two diurnal peaks of high activity closely related to dusk and dawn. For white-tailed deer, dusk is a period of high activity and may be a stimulus to cross a road. White-tailed deer usually avoid entering an open space in the daylight compared to nighttime, and it seems likely that the highway environment (including the noise) further accentuates cautious behaviour during daytime hours (Kammermeyer, 1977). In sum, hourly distributions of vehicle collisions with white-tailed deer in southern Michigan (Allen, 1976) and with moose in Maine (Farrell et al., 1996) are similar to those I document in the Thunder Bay area. For the Thunder Bay data, the morning peak in WVCs was lower than the peak at dusk.

There is no strong weekly pattern in the ungulate collisions in the Thunder Bay area, even though traffic increases with urban and suburban traveling habits. For example, in Quebec, collisions with moose might be 42% more frequent on Fridays when road traffic levels were highest (Dussault et al., 2006). On the other hand, the first calendar-year peak in ungulate collisions in June in the Thunder Bay area matches the result of other studies, which conclude that the higher risk of collision during spring months coincides with the period of dispersal of young males (Nardo et al., 2001; Pokorny, 2006; Lagos et al., 2012). The dispersion of yearlings from natal ranges to new ranges leads to an increased probability of crossing main roads, resulting in a greater vulnerability to collision (Langbein & Putman 2006; Langbein 2007). Moreover, in this period, large wintering groups collapse (Vincent et al., 1995), established males initiate a territorial behavior (Wahlström 2013), and many females start important migratory movements (Ramanzin et al., 2007).

The second calendar-year peak in ungulate collisions in the Thunder Bay area, ending in November, is more consistent with the conclusions made for studies in moose over white-tailed deer. For example, Neimi et al. (2016) found that moose-vehicle collisions peak in autumn and winter. Neumann et al. (2012), in a study of moose road-crossing activity and vehicle accidents in northern Sweden, concludes that the autumn and winter peaks are more likely due to poorer light and road conditions than an increase in moose movements on the road area. Limited visibility due to darkness is known to influence a driver's ability to detect ungulates crossing roads (Mastro et al., 2010), and the dark-time detection distance of moose could average as little as 100 m (Rodgers & Robins, 2006). On the other hand, increased moose movements during the rutting season are also suggested to contribute as a collision peak in the fall (Lavsund & Sandegren, 1991). Thus, as for the pattern in the 24-hour clock, the pattern over the 12-month calendar leaves ambiguity in an answer to the question of whether moose and white-tailed deer activity or driver behaviour more influences vehicle collisions.

Efforts to identify and plan mitigation measures require identification of animal species involved in vehicle collisions, and the absence of identification is a drawback of the Ontario reporting system. Accurate identification (e.g., sex, age, and size of the animal) can supply important behavioral information of animals (Rodríguez-Morales et al., 2013). Despite these drawbacks, the information provided by this study provides a credible picture of the seasonal, monthly, weekly, and daily variation in ungulate collisions in rural and suburban Thunder Bay areas.

Efforts to reduce wildlife collisions are easier focused on driver attitudes and road conditions than on animal behaviour (Putzu et al., 2014). Variation in the intensity of movement activity on a daily and seasonal scale can be the main predictors of ungulate road-crossing behaviour used in planning of mitigation measures (Kammerle et al., 2017). Mitigation of collision risk usually focuses on identifying species-specific spatiotemporal patterns in ungulate-vehicle collisions and adjusting animal warning systems for the drivers (Ament et al., 2008; Garriga et al., 2017; Lin et al., 2019; Ascensao et al., 2019). Other studies propose to integrate spatiotemporally flexible warning mechanisms into mapping or navigation systems that are already widely used, e.g., as a plug-in application for google maps or built-in navigation system in the vehicle itself (Mayer et al., 2021). Electronic animal warning signs placed in the vicinity of the roads can be remotely updated with temporal collision pattern data that help drivers to react depending on the driver's actual place and time. Such mitigation measures could be activated and work in more sensitive modes during peaks (e.g., twilight hours) in risk (Garriga et al., 2017). Such applications could give a visual or acoustic warning signal at high-risk times and in high-risk areas.

CONCLUSIONS

Knowing the patterns of ungulate-related accidents according to month, day of the week, and time of the day can help to reduce the rate of collisions with vehicles. Having precise knowledge of the temporal pattern of wild ungulate-related accidents may help authorities to improve measures to mitigate these kinds of accidents. Since wild ungulates' behaviour can hardly be modified, the mitigation should be centred on drivers. In Thunder Bay, a large proportion of WVCs occur just after sunset. Such high concentration of crashes—a "black spot"—makes countermeasures focused on reducing the peak more cost effective and thus more practical both for society and for individual road users. At the very least, drivers can reduce crash risk and especially the risk of serious consequences by lowering their speed and keeping alert for deer during the relatively short period of the peaks in the twilight hours, in June and in September through November. Knowledge of the high-risk periods should inform actions to reduce WVCs, such as implementing variable speed limits and informing drivers of the high-risk period by incorporating this information to deer-crossing signs.

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