DRIVER- AND LANDSCAPE-RELATED FACTORS ASSOCIATED WITH REPORTED WILDLIFE-VEHICLE COLLISIONS IN THUNDER BAY, ONTARIO.

By

Nicole Carson
1100564

Faculty of Natural Resources Management
Lakehead University
Thunder Bay, Ontario

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Nicole Carson
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DR. BRIAN MCLAREN
MAJOR ADVISOR

MR. DAN BRAZEAU
SECOND READER

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ABSTRACT

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Keywords: land cover class, Thunder Bay, *Odocoileus virginianus*, posted speed limit, white-tailed deer, wildlife-vehicle collision

The ever-expanding road network in Ontario has created serious implications for wildlife and their movement within the province. This has led to the discovery of many factors that have the potential to increase the risk of wildlife-vehicle collisions related to both deer and driver behaviours. White tailed-deer are the most abundant ungulate species in Ontario, leading them to be involved in a large portion of wildlife-vehicle collisions. Deer-vehicle collisions (DVCs) have been a cause of concern for decades due to human and deer injury or death and cost of vehicle damage. In this study, Ministry of Transportation Ontario (MTO) data for wildlife-vehicle collisions around Thunder Bay, Ontario from 2011-2021 was spatially analyzed using Quantum Geographic Information System (QGIS). The spatial relationships between DVCs and Ontario land cover class (LCC), nearby streams, and posted speed limit were considered. Tests of association displayed a strong relationship between DVCs and LCC. The development class had the largest positive association, while the disturbed forest class had the largest negative association. Contrary to other findings, streams were rarely associated with DVCs and the posted speed limit analysis showed no significant relationship with the spatial distribution of DVCs. It was concluded that deer behaviour is more influential in the occurrence of DVCs than is driver behaviour, due to the relationships established between DVCs and deer habitat. Although driver behaviour such as speeding or distraction may increase risk, collisions cannot occur where deer are not present. However, mitigation strategies should be targeted at modifying driver behaviour since such strategies are more economically feasible, effective, and accepted by society than are options for posting or controlling deer movements.

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INTRODUCTION

Motor vehicle accidents involving wildlife continue to become more prevalent across Canada (Vanlaar et al. 2012). The Canadian government has documented just under 40,000 wildlife-vehicle collisions in the year 2003 alone, which is the most recent data available for the country. In the same year, the number of reported collisions with wildlife in Ontario was approximately 14,000, the highest out of all provinces (Transport Canada 2020). These numbers are alarming and could be much higher due to unreported accidents.

White-tailed deer (*Odocoileus virginianus*) are the most common member of the cervid family found in North America, and more specifically Ontario (MNRF 2021). Within the province, they have an estimated population of 400,000 individuals (Vanlaar et al. 2019), meaning that they are likely to be involved in a large portion of wildlife-vehicle collisions. They are also a valued species in the hunting industry, and culturally significant for Indigenous communities who have hunted them for thousands of years (MNRF 2021). Due to the high abundance of deer, along with increasing anthropogenic expansion (i.e., roads), deer-vehicle collisions (DVCs) have become a frequent occurrence in the province.

DVCs pose a serious threat to the well-being of humans and deer. They most often result in minor injuries and costly vehicular damage; however, some have the potential to cause severe injury or death (Joyce and Mahoney 2001; Bissonette et al. 2008). In Ontario, four deaths and 596 injuries to people were reported for the year 2003 (Transport Canada 2020), and the financial costs resulting from vehicle damage has been estimated to be $2800 Canadian per accident (Vanlaar et al. 2012). By determining the spatial trends of DVCs in a localized area, mitigation strategies can be implemented in an appropriate fashion to reduce fatalities, injuries, and vehicle damage.

An investigation of spatial trends in DVC data from highways around Thunder Bay, Ontario was conducted using the Quantum Geographic Information System (QGIS). It was hypothesized that if the spatial distribution is related to deer behaviour, then they will occur more frequently than expected in areas associated with deer habitat compared to other areas. However, if DVCs are more related to driver behaviour, then there may be less (or no) association with deer habitat. It was predicted that deer habitat will have a closer relationship to the occurrence of DVCs than driver behaviour, but it is likely that both play some role in the occurrence of DVC events.

LITERATURE REVIEW

DEER IN HUMAN DISTURBED LANDSCAPES

As anthropogenic development continues to expand and modify the natural landscape, many animals have found ways to thrive in human disturbed environments (Gaughan and Destefano 2005; Duarte et al. 2015; Ciach and Fröhlich 2019). White-tailed deer fall into this category, having been found to use a wide range of environments altered by humans (Grund et al. 2002; Etter et al. 2002). One study found a 17.5-fold increase in white-tailed deer when comparing periods of pre- and post-industrial development in Alberta, Canada (Latham et al. 2011), suggesting that these deer thrive human disturbed environments. It has also been shown that deer are not forced into human disturbed environments but rather choose to reside there based on attractive factors such as increased resources or decreased predation (Gaughan and DeStefano 2005).

One of the most notable changes to the landscape that humans have caused in the past few centuries is the vast expansion of agricultural land. When forested land was intensely cleared for crop production and other land uses, large tracts of open land were left behind that present high-quality habitat for deer (VerCauteren 2003). In addition, these habitats have become easier for deer to access since riparian corridors are allowed to become more mature. Streams and rivers would naturally change course quite often depending on the extent of spring run-off; however, dams and water flow diversions eventually restrict this pattern by regulating the flow of water, which is also often less than normal (Nilsson and Berggren 2000). Such changes have led deer to disperse into areas that they would not normally be able to reach due to the lack of suitable cover along streams (VerCauteren 2003).

Human disturbance from forestry-related activities have also benefitted deer. Extensive areas of forest are cut down every year to supply timber demands, resulting in large expanses of early successional forests (VerCauteren 2003; Laurent et al. 2020). The young forests that regenerate after clearing contain forage that deer prefer in summer months, leading them to move into these areas (Latham et al. 2011; Laurent et al. 2020).

Similarly, residential areas offer another suitable habitat for deer. They have fertilized grass lawns and various gardens containing attractive food, providing deer with high-quality habitat especially in the winter (Etter et al. 2002; Gaughan and Destefano 2005). People living in residential areas also provide supplemental food for deer, which has allowed some populations to reach levels that would not occur naturally in the wild. Deer can become habituated to areas since they know people are providing food, causing them to frequently return (McCance et al. 2015).

The final factor that contributes to the higher observations of deer in human disturbed habitats, as well as to higher frequency of DVCs, is the increase in road density that has occurred over time. Nichols et al. (2014) suggest that common deer behaviour near roads includes foraging and movement to habitat on the other side of the road. Deer have also been observed to walk along the road, presumably to find an ideal location to cross (Donaldson et al. 2016). A case can also be made for the higher use of roads or roadsides by many wildlife species because they serve as efficient transportation routes that require less energy expenditure than traversing through dense forest (Grund et al. 2002). The following section will discuss the spatial trends of DVCs that is not limited to features of deer habitat in human-disturbed landscapes.

SPATIAL TRENDS IN THE OCCURENCE OF DVCs

Many previous studies have shown that DVCs are not spatially random (Finder et al. 1999; Found and Boyce 2011a; Gunson et al. 2011). Several spatial factors have been suggested for the clustering of DVCs, including proximity to forest cover, riparian corridor and road intersections, gullies along roads (Finder et al. 1999), high landscape diversity, increased vegetation density beside roads (Found and Boyce 2011), supplemental feeding areas (McCance et al. 2015), and salty water along the roadside (Fraser 1979). These factors are all related to habitat preferences of deer, which includes areas along roadways (Found and Boyce 2011a). Increased occurrences of DVCs were found to be related generally to proximity to forest cover (Finder et al. 1999; Meisingset et al. 2014). Hegland and Hamre (2018) showed that when there is no forest cover along the road, DVC frequency decreased by 50% because deer use the forest for bed sites, escape from predators, and food resources (Found and Boyce 2011a). Occurrence of forest cover also has the potential to hide deer from a driver's view, leaving the driver with little time to avoid hitting the animal (Finder et al. 1999). Roads that pass-through areas with high landscape diversity have been associated with more frequent DVCs, particularly where forest patches and open fields such as crop land or parks are near each other (Found and Boyce

2011a). This type of heterogenous environment provides deer with suitable forage and cover from predators.

Areas with riparian corridors that intersect with roads have increased numbers of DVCs. The reason is that deer and many other animals use riparian corridors as travel routes to move between habitats for different activities more easily (Finder et al. 1999). Hubbard et al. (2000) discovered that bridges predict an increased likelihood of DVCs because they are associated with both deer and human travel corridors. Aquino and Nkomo (2021) similarly documented that animals moving through natural corridors such as streams and forest edges near roads have a higher chance of being hit by a vehicle. Gullies and ditches that run along roadsides have a similar effect. They increase the probability of DVCs because they can lower the visibility of deer to oncoming drivers and/or funnel deer to roads (Finder et al. 1999; Nichols et al. 2014).

Because herbivores need to consume sodium that they often do not obtain in sufficient quantities from plants, they often seek mineral licks or other sources of salt (Hill et al. 2021). Salts used to eliminate ice on roads can collect in pools along roadsides and attract deer (Feldhamer et al. 1986; Hill et al. 2021). Fraser (1979) observed deer drinking salty water beside a road; the deer were reluctant to move even when oncoming vehicles were just 30-40 m away, and some even ran in front of vehicles. In Thunder Bay, small herds of deer on the road have been seen licking the pavement, even as cars passed by in the opposite direction (personal observation).

MITIGATION STRATEGIES

Several mitigation strategies have been proposed that aim to modify the behaviour of either deer or humans to reduce the number of DVCs (Mastro et al. 2008; Nichols et al. 2014). Modifications to human behaviour include lowering speed limits, erecting road warning signs, maintaining vegetation, installing roadside lights, and increasing the offerings of DVC awareness or education programs (Putnam 1997; Meisingset et al. 2014; Nichols et al. 2014; Hegland and Hamre 2018). Decreasing speed limits in areas with high DVCs can be effective (Ng et al. 2008; Meisingset et al. 2014). When drivers travel at slower speeds, they have more time to react to seeing deer on or near a road, and they have shorter stopping distances. Where decreasing a speed limit permanently is not possible, temporary reductions during high-risk times for DVCs can be implemented. One issue with this strategy is that not everyone follows posted speed limits, so reducing speed limits can have limited effects (Nichols et al. 2014).

Road signs are used to alert drivers when there is an increased risk of deer crossing the road, prompting them to be more aware of their surroundings and to slow their vehicle speeds down. They are usually placed along segments of roads that are known to have frequent DVCs. Standard signage is the simplest form with no lights or other eye-catching additives; they typically remain along the road permanently (Found and Boyce 2011b; Nichols et al. 2014). Enhanced signs are more animated than standard signs to increase driver awareness of a potential DVC hotspot, and occasionally sport text that provides driving safety tips (Nichols et al. 2014). Such signs are placed, usually temporarily, along sections of roads that have increased DVCs during certain times of the year (Sullivan et al. 2004). The overall effectiveness of road signs in reducing DVCs has been extremely variable but some road signs have been shown to be better than others (Putnam 1997; Sullivan et al. 2004; Found and Boyce 2011b; Nichols et al. 2014). Standard and even enhanced road signs permanently in place are thought to be the least effective because drivers become desensitized to them, resulting in no long-term behavioural changes (Putnam 1997; Sullivan et al. 2004). Temporary road signs placed along roads with high frequency of road crossings can be much more effective. Sullivan et al. (2004) found that temporary road signs reduced DVCs by an estimated 50%. Although the success of road signs is highly variable, the low cost of their implementation has resulted in signage being one of the most common approaches to DVC reduction (Putnam 1997).

Maintenance of roadside vegetation to increase driver visibility of deer along roads is another variably successful mitigation strategy to reduce DVCs. When drivers can see oncoming deer from further distances, they have more time to react and avoid hitting the deer (Gunson et al. 2011; Nichols et al 2014). However, removing vegetation can increase the presence of deer because of the new foraging opportunity created with new vegetative growth. Thus, means maintenance along roads must have to occur frequently to improve visibility while limiting appealing regrowth and at the same time discourage vegetative regrowth. Another method to increase driver visibility is to put lights along roads that have high DVC risk, but there is limited knowledge on the effectiveness of this strategy (Nichols et al. 2014; Mastro et al. 2008). However, Ciach and Fröhlich (2019) showed that artificial lighting reduced the probability of roe deer (*Capreolus capreolus*) occupying urban areas with suitable habitat.

Educational programs can be employed to increase driver awareness of DVCs and in turn reduce them (Joyce and Mahoney 2001; Riley and Marcoux 2006). Many people think that DVCs are unavoidable, but this is not the case (Riley and Marcoux 2006). By educating the public about how to avoid DVCs and the appropriate actions to follow when involved in one, officials can reduce DVCs and their consequences (Riley and Marcoux 2006). Joyce and Mahoney (2001) suggest that long-term programs would be more effective in changing driver behaviour compared to sporadic, short-term programs because long-term programs are more likely to create better driving habits. Examples of driver awareness programs include radio broadcasts, newspapers, and social media (Joyce and Mahoney 2001; Riley and Marcoux 2006). Another interesting method is to incorporate information about DVCs into new-driver training programs (Joyce and Mahoney 2001). Since anyone who drives a vehicle can be involved in a DVC, multiple methods of knowledge transference are most effective (Riley and Marcoux 2006).

The mitigation strategies aimed at modifying deer behaviour intend to keep deer off roads. They include fencing (Feldhamer et al. 1986; Clevenger et al. 2001), overpasses and underpasses (Donaldson and Elliot 2021), mirrors/reflectors (Nichols et al. 2014), and reductions in deer abundance (Schwabe et al. 2002). Fencing can be an effective way to reduce DVCs because fences prevent deer from crossing roads. However, fences are sometimes viewed as more of a deterrent than an impermeable barrier because some deer can find ways around or over them (Putnam 1997). Fences need to be built at an appropriate height to be most effective; for example, 2.7 m fencing to keep deer away from roadsides better than a 2.2 m fencing (Feldhamer et al. 1986). Fence maintenance is an important consideration because gaps can be created from eroding land or degrading materials. A major concern regarding fence construction along roads is its length. Fence ends have been shown to be areas of high DVCs because deer attempting to cross will walk along the fence until there is an opening (Clevenger et al. 2001). Another issue with fences is that they cause additional habitat fragmentation for all wildlife species (Mastro et al. 2008). A final problem that fences introduce is the entrapment of deer beside the road that do find their way across the fence, which increases the likelihood of their crossing the road (Putnam

1997). When fences are constructed in combination with deer overpasses or underpasses, they are more successful (Rosa 2006). The fence prevents deer from entering the road, while the man-made corridor allows them access to habitat on the other side.

The use of mirrors and reflectors to reduce DVCs has been highly contested (D'Angelo et al. 2006). They work by reflecting light from a vehicle onto the road, which is supposed to alert the deer and cause them to move away (Nichols et al. 2014). Due to the way that these reflector's function they can only be used at night. One study found that DVCs decreased by 32% when reflectors were used, and that they significantly lowered the amount of high-risk road crossings by deer (Riginos et al. 2015). Contrastingly, D'Angelo et al. (2006) conducted a study in which four colours of light reflectors were implemented with no effect on reducing DVCs for any of them. Thus, the effectiveness of reflectors in reducing DVCs still requires further research with more rigorous study designs.

When high numbers of deer are present in a localized area, there is an increased probability of DVCs occurring, leading people to suggest that reductions in deer abundance through hunting, culls or relocations can decrease DVC occurrence in these situations (Shwabe et al. 2002; Hedlund et al. 2004). However, local people or animal rights groups may be opposed to deer reduction methods of this kind.

METHODS AND MATERIALS

This study focused on exploring spatial factors that potentially influence the occurrence of DVCs on several highways around the city of Thunder Bay. Data on all recorded wildlife-vehicle collisions from 2011-2021 was provided by the Ministry of Transportation Ontario. The date, time, weather, road conditions, latitude, and longitude of all collisions were provided. There was a total of 1,332 DVCs documented, but 231 of them were removed from the dataset since they occurred on highways passing through the suburbs or inner city. This is because the analysis was aimed at DVCs occurring on rural highways. Segments of the following eight highways were included: the Trans-Canada Highway (Highway 11 & 17), Highway 61, Highway 130, Highway 527, Highway 588, Dog Lake Road (Highway 589), Highway 590, and Highway 591. The GPS location of each DVC was displayed using the Quantum Geographic Information System (QGIS) 3.28, projected in NAD83 UTM Zone 16 North. All other datasets were obtained through OntarioGeoHub.

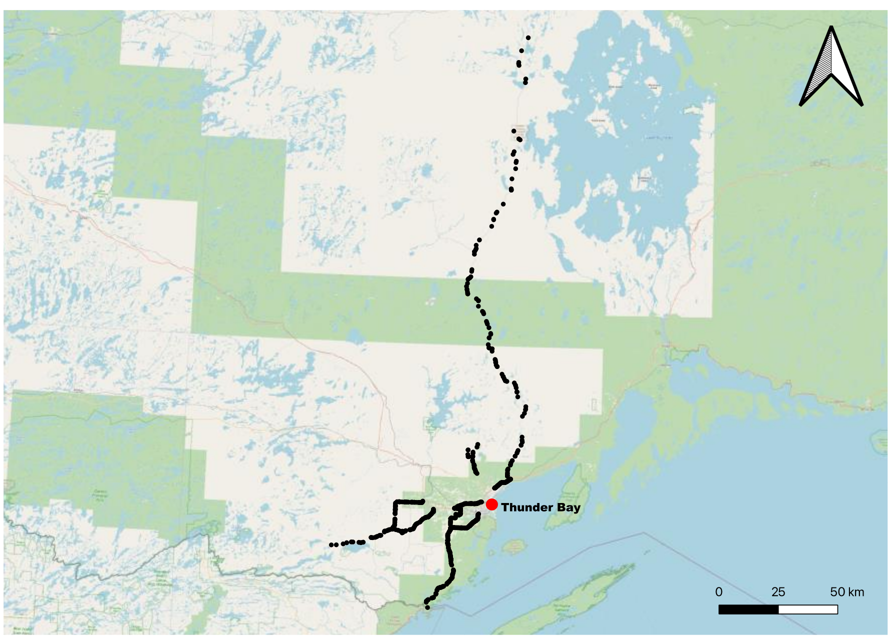

Figure 1. Locations of all DVCs occurring on highway segments around Thunder Bay, ON from 2011 to 2021.

To investigate the potential association of LCC with DVCs, the Ontario Land Cover Compilation v.2.0 (OLCC v 2.0) was used. The OLCC V. 2.0 is an updated land cover classification that has incorporated the Provincial Land Cover Database (2000 ed.), Far North Land Cover (Version 1.4), and the Southern Ontario Land Resource Information System (Version 1.2) into one classification scheme. It includes 29 land cover types and has a range of 1:50,000 – 1:100,000 for different levels of spatial analysis. The complete list of land cover classification can be found within the Ontario Land Cover Compilation Data Specifications, Version 2.0 (OMNRF 2014).

There was a total of 13 land cover classes (LCCs) represented within the study area. Bogs, swamps, sand/gravel/mine tailings/extraction, open water and unknown/other LCCs were removed from the analysis due to their irrelevance to deer habitat or lack of sufficient coverage in the study area. In addition, sparse treed, deciduous treed, mixed treed, and coniferous treed LCCs were compiled into one class named 'forest.' The remaining classes included disturbance, development, and agriculture.

Within QGIS, dissolved buffers with a radius of 75 m were generated around all points identifying DVCs. This radius was chosen to ensure that more than just the development LCC was detected within them since it frequently dominates areas along roads. The zonal histogram tool was used to determine the number of pixels of each LCC that occurred within the buffer. Random points were generated to allow for comparisons between DVC data and randomly distributed data. For proper comparative analysis between case and random points, it has been suggested that five times the number of case points should be incorporated in the random set (Johnson and Gillingham 2005). The Chi-square Test of Independence was then performed to investigate which LCCs were associated with DVCs, positively (more than expected from random) or negatively (less than expected from random). The equation used for Chi-square testing is as follows:

$$X^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

where X^2 is the Chi-square value, O is the count of observed LCC in the buffered areas around points indicating DVCs, and E is the expected LCC distribution for the random case from occurrence in the buffered random points in the study area. Each of the eight highways and its associated DVCs were analyzed separately.

To explore the relationship between stream crossings and DVCs, the Ontario Hydro Network (OHN) – Watercourse vector dataset created by the Ontario Ministry of Natural Resources and Forestry (OMNRF) was used. This layer includes natural and anthropogenic areas of flowing surface water. The clip tool was applied with the OHN – Watercourse layer as the input layer and the DVC buffer as the overlay layer to determine the number of streams that occurred within 75 m of the collision. The number of streams associated with a DVC was compared to the total number of streams that occurred within 75 m of either side of the road.

To compare the association of DVCs to driver behaviour, an exploration of the speed limits was chosen. The Ontario Road Network (ORN) Road Net Element vector dataset developed by the OMNRF was used for this analysis. The intersection tool was used to determine the speed limit associated with each DVC. The fraction of DVCs within each speed zone was compared to the total fraction of the highway with the same posted speed limit. The speed-zone analysis could be undertaken only for two of the eight highways, because the other six lacked posted speed limits other than the maximum (80 km/h on rural highways and 90 km/h on the Trans-Canada Highway).

RESULTS

ASSOCIATION OF DVCS WITH LAND COVER CLASSES

There was generally a strong relationship between LCCs and DVCs. The Chi-square Test of Independence produced a statistic with $p<0.01$ for associations of certain LCCs with DVCs on all highways. The associations varied among the highways, but disturbed habitats and areas classed as development were frequently associated (Table 1). There was often a negative association between DVCs and the forest LCC. Only Hwy 589 and Hwy 591 had slightly more than expected DVCs occurring near forests, and forest was never the largest case for an association. The disturbance LCC was the largest case for association in three out of seven highways. Two of these (Hwy 589 and Hwy 591) displayed a negative association of DVCs with disturbance, and one was a positive association (Hwy 11 & 17). Two additional highways had more than expected DVCs occurring near disturbance (Hwy 527 and Hwy 590) but were not considered the largest association.

The development LCC expressed the largest association for three out of eight highways. Hwy 527 had a negative association between development and DVCs, while Hwy 130 and Hwy 61 had a positive one for the development LCC. There were three additional instances where this LCC had more than expected DVCs. Land cover classed as agriculture had the largest association with DVCs for two out of four highways (Hwy 588 and Hwy 590). There were more than expected DVCs for this LCC on three of the highways.

Table 1. Observed and expected percent of land cover area per class for each highway.

Highway	Chi-Square	Forest	Disturbance	Development	Agriculture
		Land Cover Class (%)			
Hwy 11 & 17	Observed	54	10	35	-
	Expected	56	8	36	-
Hwy 61	Observed	45	1	43	10
	Expected	55	3	32	10
Hwy 130	Observed	38	-	42	18
	Expected	45	-	31	18
Hwy 527	Observed	51	38	9	0
	Expected	52	33	15	0
Hwy 588	Observed	82	8	3	7
	Expected	84	11	2	4
Hwy 589	Observed	83	0	13	-
	Expected	80	6	14	-
Hwy 590	Observed	96	1	0	3
	Expected	97	1	1	1
Hwy 591	Observed	75	7	18	-
	Expected	71	19	10	-

STREAMS

Fewer than expected DVCs were associated with streams (Table 2). Only two highways displayed more than 50% of the total number of streams occurring along the highway as associated with DVCs. The average percent of streams associated with DVCs was 34%.

POSTED SPEED LIMIT

Only two highways (Hwy 130 and Hwy 588) were used in the posted speed limit analysis because they had more than one posted speed limit. Chi-square testing was not used to analyze this data because it did not have large enough (>5%) expected values. Speed limit was not associated with the occurrence of DVCs (Table 3).

Table 2. Percent of streams associated with DVCs for each highway.

Highway	Stream (%)
Hwy 11 & 17	60
Hwy 61	45
Hwy 130	20
Hwy 527	14
Hwy 588	32
Hwy 589	24
Hwy 590	60
Hwy 591	17

Table 3. Percent of DVCs occurring under different posted speed limits.

		Posted Speed Limit (%)			
Highway		50	60	80	90
Hwy 130	Observed	-	48	52	-
	Random	-	48	52	-
Hwy 588	Observed	1	3	96	-
	Random	2	5	94	-

DISCUSSION

A case can be made for both deer and driver behaviour having an influence on the occurrence of DVCs. Our findings suggest that deer behaviour in Thunder Bay seems to play a more important role in predicting the occurrence DVCs.

DEER BEHAVIOUR AND DVCS

White-tailed deer have become more adapted to human disturbance and have learned to exploit disturbed areas (Etter et al. 2002). Deer are known to make use of residential areas for cover during the winter and exploit food from bird feeders, gardens and intentionally installed feeding stations (Fineder et al. 1999; McCance et al. 2015; Duarte et al. 2015). This association with people may explain the reason for a large association between DVCs and the ‘development’ LCC found in this study. In addition, Gaughan and DeStefano (2005) explain that lack of predators and hunting in residential areas can also contribute to higher deer densities, which can cause increased DVC frequency in these areas.

However, in contrast to what was expected, the ‘disturbance’ LCC was often largely negatively associated with DVCs. OMNRF (2016) describes the ‘disturbance’ LCC as an area of natural or anthropogenic disturbance having occurred within the past 10-20 years, meaning that the area is likely early successional forest in the Thunder Bay area. White-tailed deer and other North American ungulates use this kind of habitat in the summer to graze on forages such as grass, clover, and other broad-leaved plants (Voigt et al. 1997). VerCauteren (2003) argued that logging activities can produce a range of successional phases, all of which translate into prime deer habitat for all seasons. However, the negative association presumably of early successional forest with DVCs in this study is similar to the findings of Hegland and Hamre (2018), where it was determined that a high portion of open land reduced the occurrence of DVCs. The effect is attributable to the likely increase of visibility for deer and drivers in this type of landscape. Furthermore, there is a possibility that less favourable browse is regenerated or replanted in these areas around Thunder Bay, leading deer to use more attractive areas for food found in agricultural or residential areas.

The 'forest' LCC was almost always negatively associated with DVCs. In contrast, forest cover has been found to predict the occurrence of DVCs in other areas (Putnam 1997; Finder et al 1999; Found and Boyce 2011a). One explanation for the difference is that forest makes up a large portion of the total land cover in Thunder Bay, the majority (>50%) of the calculated cover (buffers around random points) along six out of eight highways. Since there is abundant forest cover, deer may be less willing to risk crossing a road to reach it as compared to other, less common LCCs that deer utilize. Deer are also known to have specific habitat requirements that differ between seasons. According to the Forest Management Guidelines for white-tailed deer habitat, coniferous forest is necessary for winter survival, but adjacent young successional forests are also required to build up energy reserves to prepare for the lack of energy-rich forage during the winter (Voigt et al. 1997). Given that the forest LCC in this study was a combination of all forest types (sparse, conifer, deciduous and mixed) and the absence of calculation relating to edge contrats or other metrics of habitat configuration, the analysis may have missed this important distinction.

The 'agriculture' LCC was the least represented cover type along highways in the study area. However, two highways showed this LCC as having the largest positive association with DVCs comparing other LCCs. Agricultural areas have been shown to increase the frequency of DVCs (Meisingset et al. 2014). Moreover, Hata et al. (2021) suggest that agricultural crops allow deer to grow bigger and increase their reproductive success. Perhaps deer in Thunder Bay are making a trade-off between safety and food by taking a larger risk crossing the road to access higher quality food. There may also be more dispersing juvenile deer in spring along agricultural land where it abuts roads (Hubbard et al. 2000).

Contrary to what was expected, there was a weak association between occurrence of roadside streams and DVCs. Riparian corridors are usually used by many wildlife species for efficient transportation between habitat patches (Finder et al. 1999; Aquino and Nkomo 2021). It is possible that not all streams were suitable for deer to use in the Thunder Bay study area, given that an appropriate amount of mature vegetation growth adjacent to the stream is needed for cover to avoid predation while travelling along stream corridors (VerCauteren 2003). In addition, different outcomes may have occurred for alternate spatial analyses, such as measuring the distance of each DVC to the nearest stream, to provide more insight into relationships between DVCs and stream corridors.

DRIVER BEHAVIOUR AND DVCs

The influence of driver behaviour in the occurrence of DVCs was not able to be confirmed in this study due to data deficiencies. However, some broad conclusions were drawn to consider how driver behaviour may influence DVCs in Thunder Bay.

The LCC analysis showed that DVCs were positively associated with the class representing developed land, largely residential areas in the immediate vicinity of Thunder Bay. This association could be related to driver distractions, as drivers may be more flustered in areas with artificial lighting and increased noise and movement by people and their pets or livestock. This study also showed no association between posted speed limit and DVCs for two highways.

However, this outcome is likely due to the limited number of highways that had more than one posted speed limit, which restricted the sample size and accuracy of results. In other regions, speed limits are associated with the risk of DVCs: when drivers are going faster, they have decreased reaction time and more distance to travel when attempting to stop (Meisingset et al. 2014; Aquino and Nkomo 2021). More information on driver behaviour is needed to accurately compare the influence of driver and deer behaviour on DVCs.

MITIGATION STRATEGIES

Although deer behaviour appears to be more influential in the occurrence of DVCs in Thunder Bay, mitigation strategies should focus on modifying human behaviour to reduce them. Options for managing deer behaviour such as fence and overpass construction and maintenance is very costly (Putnam 1997; Joyce and Mahoney 2001). Other methods like reflectors have displayed inconsistent results in their effectiveness (D'Angelo et al. 2006; Riginos et al. 2015). Finally, deer culls are probably an unpopular option among most residents and could potentially cause more problems than they solve. Instead, officials should consider more effective and economically feasible solutions that target human behaviours. After all, it is much easier to communicate with and modify the behaviours of people than it is to control the behaviours of wildlife such as deer. This can include the erection of temporary signage or reduced speed limits in areas with more frequent DVCs during high activity season such as spring and fall (Sullivan et al. 2004; Meisingset et al. 2014). In addition, the city of Thunder Bay should incorporate DVC awareness training into their driver education programs to inform people about how to limit the risk of DVCs occurring.

CONCLUSION

This study concluded that deer behaviour was able to predict DVC occurrence in Thunder Bay, while more information is needed to properly assess driver-related behaviours. The associations found between DVCs and LCCs showed that DVCs occur in areas associated with presumed deer habitat, while less evidence was found to support driver behaviour as influential to DVCs. However, there are many spatial factors that come into play when predicting DVC occurrence such as road characteristics or landscape heterogeneity, which were not analyzed in this study. Moreover, the underreporting of all wildlife-vehicle collisions means that the full display of spatial interactions cannot be observed. Further studies using the same data should be conducted to consider the temporal aspect of DVC occurrence in Thunder Bay which would complement the findings produced in this study. To efficiently reduce the risk of DVCs in Thunder Bay, mitigation strategies targeted at improving driver's behaviour should be employed.

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