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Spatial and temporal analysis of factors associated with urban deer–vehicle collisions

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Abstract: Increasing populations of white-tailed deer (*Odocoileus virginianus*) in urban areas have resulted in an increase in deer–vehicle collisions (DVCs). Deer–vehicle collisions represent a human–wildlife conflict of serious concern, given that they result, most notably, in significant risk to human safety, deer mortality, and costly vehicle damage. Although many communities have developed databases that track the frequency and location of DVCs, there is a need for analysis of the factors that affect DVC locations in urban areas. Data on deer movement patterns across roads in urban areas are valuable to reduce the occurrence of DVCs on existing roads and to assist planning of future urban road design and placement. Using DVC data from 2005 to 2009 provided by the Manitoba Public Insurance Corporation, we found that DVCs in Winnipeg, Canada, were not spatially or temporally random, and that human-induced deer movement patterns play a role in the frequency and location of DVC occurrence. Deer–vehicle collisions occurred more frequently near suburban areas and grasslands and were clustered near where people provided food for deer. A ban on feeding deer may help reduce the frequency of DVCs.

Key words: anthropogenic food sources, deer movement patterns, deer-feeding, deer–vehicle collisions, habitat selection, human–wildlife conflict, GIS, urban white-tailed deer

Vehicle accidents involving white-tailed deer (*Odocoileus virginianus*) occur at an alarming rate throughout North America and are considered a serious problem (Romin and Bissonette 1996, Bissonette et al. 2008). Deer–vehicle collisions may result in significant risk to human safety, deer mortality, and expensive vehicle damage (Finder et al. 1999). Conover et al. (1995) found that 92% of deer hit by a vehicle die. In the United States, estimates suggest that annually >1 million drivers are involved in DVCs, with more than 29,000 human injuries and 200 human fatalities (Conover et al. 1995) resulting in >$1 billion in vehicle damage (Conover 1997). In Canada, approximately 60,000 drivers hit deer each year, costing >$200 million annually (Transport Canada 2013).

In Manitoba, Canada, estimates suggest that nearly 300 people are injured annually, some seriously, in DVCs (Manitoba Public Insurance Corporation [MPIC] 2010). Today, MPIC, the sole vehicle insurer in Manitoba province, spends >$30 million per year on automobile insurance claims involving collisions with wildlife; 65% to 85% of these collision claims involve white-tailed deer (Province of Manitoba 2015)). The social costs associated with DVCs also are high and include human trauma, absence from work, and costs associated with those tasked with responding to such collisions (Hansen 1983).

The concept of cultural carrying capacity is defined as the maximum wildlife population that a society will accept within a given area (Decker and Purdy 1988, Riley et al. 2002). Cultural carrying capacity is difficult to determine, given that it is based on the views of stakeholders and that the threshold of acceptance is not static (Conover 2002). Stakeholders often do not see eye-to-eye on the acceptable wildlife population size or on the course of management action that should be taken to alleviate conflicts (Decker et al. 2001).

Wildlife acceptance capacity (Decker and Purdy 1988) has been applied to study overabundant white-tailed deer populations (Decker and Gavin 1987). Studies have explored human perceptions and attitudes with respect to deer-related vehicle accidents (Stout et al. 1993, Marcoux and Riley 2010). A quantitative human dimensions study, conducted within the city of Winnipeg, Canada, investigated resident opinions and tolerances toward the urban deer population; it identified DVCs as

Winnipeg residents' top deer-related concern (McCance 2009).

Table 1. The Canadian Land-Cover Classification (LCC) cover types for the city of Winnipeg study area by percentage of representation.

LCC cover type	Area (km^2)	% cover type
Annual crops	8.11	1.72
Broad leaf, dense	14.87	3.15
Cultivated agricultural land	81.91	17.34
Developed	252.99	53.54
Exposed land	1.34	0.28
Grassland	99.45	21.05
Herb	2.47	0.52
Mixed wood, dense	0.07	0.01
Water	11.20	2.37
Total	472.41	100

Numerous studies have investigated factors correlated with DVCs. The incidence of DVCs has been attributed to deer density (Widenmaier and Fahrig 2005, Sudharsan et al. 2006); season (Allen and McCullough 1976, Sudharsan et al. 2006, Ng et al. 2008); time of day (Marcoux et al. 2005); habitat type near roadways (Sage et al. 1983, Finder et al. 1999, Hussain et al. 2007); number of buildings (i.e., degree of development) near roadways (Neilsen et al. 2003, Hussain et al. 2007, McShea et al. 2008); traffic volume (McShea et al. 2008, Sudharsan et al. 2009); and roadway speed limits (Finder et al. 1999, Ng et al. 2008, Sudharsan et al. 2009).

Several management techniques have been suggested to mitigate, with varying success, the frequency of DVCs. Some of these techniques, aimed at reducing the occurrence of white-tailed deer on roadways, include deer population reduction (Brown et al. 2000, Riley et al. 2003); fencing (Puglisi et al. 1974, Falk et al. 1978, Feldamer et al. 1986, Putman 1997, Clevenger et al. 2001); underpasses and overpasses (Reed et al. 1975, Foster and Humphrey 1995, Rodriguez et al. 1996, Lehnert and Bissonette 1997, Putman 1997, Clevenger and Waltho 2000); intercept feeding (Wood and Wolfe 1998); whistles or repellents (Romin and Dalton 1992, D'Angelo et al. 2006); and reflectors (Schafer and Penland 1985, Romin and Dalton 1992, Vercautern et al. 2006). Other techniques have been aimed at improving a driver's ability to respond to deer on roadways. These techniques include such measures as reduced speed limits (Allen and McCullough 1976, Case 1978, Bashore et al. 1985); habitat modification (Putman 1997); improved lighting (Carbaugh et al.1975, Allen and McCullough 1976, Reed and Woodard 1981); and warning signs (Romin and Bissonette 1996, Sullivan et al. 2004).

The problem of DVCs in urban areas is a particular concern given high deer densities (Alverson et al. 1988) and high human population density with substantial levels of vehicular traffic (Squires 2002). Winnipeg has experienced a substantial increase in the number of motor vehicle accidents involving white-tailed deer over the past 3 decades. Winnipeg reported 48 DVCs in 1976 (Shoesmith and Koonz 1977), in comparison to the 464 DVCs reported in 2009 (MPIC, unpublished data). Huijser et al. (2009) estimate that the average DVC in Canada costs $6,600, suggesting that >$3.2 million is spent annually on collisions in Winnipeg alone. The need for direct management strategies to address DVCs is apparent and the cost-benefits of mitigation measures far exceed the costs associated with the status quo (Huijser et al. 2009). Within Winnipeg, a series of management techniques

Table 2: Time of day of DVCs from 2005 to 2009 within the city of Winnipeg.

Month	Sunrise to sunset	Other hours
Jan	18	98
Feb	28	59
Mar	25	78
Apr	30	109
May	38	79
Jun	42	89
Jul	43	77
Aug	40	74
Sep	31	123
Oct	110	165
Nov	148	244
Dec	58	157
Total	611	1,352

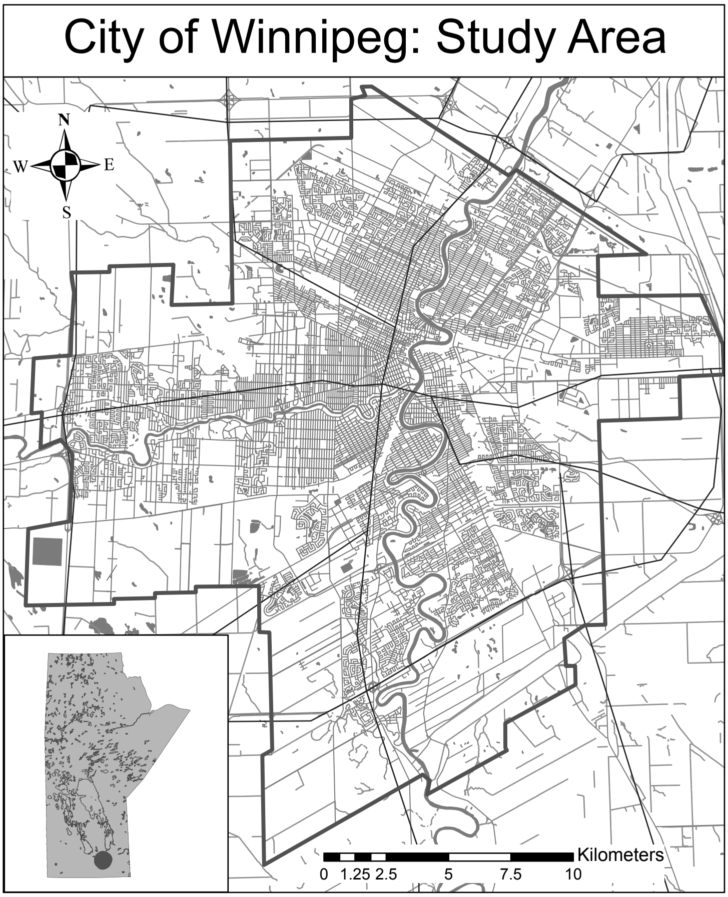

Figure 1. Map of the study area showing Winnipeg, major rivers, major roads, and residential road network. The black dot on the inset (bottom) is the location of the city relative to the province of Manitoba, Canada.

aimed at improving a driver's ability to respond to deer have been adopted to mitigate DVCs. These measures include warning signs, speed-limit enforcement, and improved lighting.

Previous research has shown that DVCs are not temporally or spatially random (Bashore et al. 1985, Finder et al. 1999). Gaining more knowledge of the factors that influence deer movement onto and across roadways is needed to guide potential management strategies to mitigate DVCs on existing roads and to plan future road design and placement (Finder et al. 1999). In this study, we examined factors that contribute to the frequency of DVCs within Winnipeg. Our research further explored the temporal occurrences of urban DVCs by month, day of the week, and time of day in which they occurred (Table 2). We also investigated whether DVCs were spatially auto-correlated within Winnipeg, and we examined the land-cover classification (Table 1) variables associated with high-risk DVC roadways. In combination with these analyses, our study examined the relationship between DVCs and urban deer density. Finally, we investigated whether a positive correlation exists among deer movement, DVC occurrence, and residential feeding sites. Analysis of the factors associated with DVCs may identify opportunities where direct management strategies can be best applied to reduce DVC frequency.

Methods

Winnipeg spans approximately 464.01 km² at an average elevation of 240 m. The city is located in the Red River Valley and is characterized by rich, deep soils, flat topography, and a native tall-grass prairie ecosystem (Scott 2007; Figure 1). The city has a humid continental climate (Koppen climate classification), with summers typically humid and hot, and temperatures rising to 35° C. Winters are typically dry and cold, with temperatures falling to -35° C (Environment Canada 2012). The human population of Winnipeg was 730,000 during 2010 (Census of Canada 2011).

White-tailed deer have been an integral part of the Winnipeg's landscape for >100 years (Goulden 1981). Historically, white-tailed deer were observed in small numbers in wooded areas along the Assiniboine and Red rivers and the Charleswood area of the city up until the mid-1970s, with a population estimate of 200 deer at that time (Shoesmith and Koonz 1977). Since then, however, the white-tailed deer population has been increasing. An aerial survey in February 2006 recorded >1,700 deer within Winnipeg and its near surrounding area (Hagglund 2006). Manitoba Public Insurance Corporation provided the DVC data analyzed in this study. Deer–vehicle collisions were recorded as home addresses and street intersections. For this study, all reported DVCs for the city from 2005 to 2009 were geo-located using ArcGIS 9.3 and projected to NAD83 Zone 14 North.

Our study investigated the temporal occurrence of DVCs within Winnipeg. The 1,963 DVCs reported within the city from 2005 to 2009 were separated by month, day of week, and hour of the day in which they occurred. Chi-square testing was used to determine whether DVCs occurred more frequently during certain months and days of the week. Further, the hours of the day were separated into those that fell within an hour of sunrise and within an hour of sunset hour blocks with those that did not. These hours were selected based on the sunrise and sunset times for Winnipeg (World Clock 2015). Using the combined total DVCs/hour for all data from 2005 to 2009 (1,963 collisions), the number of DVCs to fall within an hour of sunrise and sunset were tallied and compared to the number of DVCs to fall within remaining hours of the day. Paired *t* tests were conducted to assess whether a statistically significant higher number of DVCs occurred during sunrise and sunset. To explore the relationship of the DVCs with respect to each other (spatial auto-correlation), an average nearest neighbor calculation on the 2005 to 2009 DVC data was conducted. Using uniform cells sized at 2.5-×-2.5-km grid blocks overlaid on the total area of the city space, Moran's I, a cross-product statistic was carried out to determine whether DVCs were spatially auto-correlated (Dale et al. 2002). A Moran's I index value near >1 indicates positive auto-correlation (clustered relationship) and near <1 indicates dispersion. To investigate whether DVCs occurred more frequently near certain land-cover types a spatial join was conducted in ArcGIS 9.3 between the 2005 to 2009 DVC locations and the Canadian Land-Cover Classification (LCC) layer. The LCC is a national land-cover spatial database developed by the Canadian federal government with data integrated from the major federal departments involved in land management in Canada, such as Agriculture and Agri-Foods Canada, Canadian Forestry Service, and the Canadian Center for Remote Sensing, developed at a 25-m resolution. This is the best available land-cover layer available for the city of Winnipeg (Table 1).

Figure 2. GPS-collared buck.

We joined the DVC point features to the LCC land-cover data layer. We determined the DVC adjacent to the closest cover type to assess if the observed frequencies and the closest adjacent land-cover types differed from random expectation using 10,000 random points generated along city roadways (Table 1). In order to assess similarities and differences between random points and GPS data, often five times the number of GPS data points is generated as random points for comparative analysis (Johnson and Gillingham 2005). The same methods of analysis were repeated using 10,000 random points along the greater Winnipeg area roadways to determine whether the summary results from the DVC data were independent of what would be observed if the distribution of values were random. To explore the relationship of deer count observations (Hagglund 2006), Moran's I was conducted on the deer count observation layer (based on the 2006 aerial survey conducted by Manitoba Conservation and Water Stewardship).

We conducted a geographic spatial regression analysis in ArcGIS 9.3, using projected data to investigate the correlation between DVCs and deer observations within each 2.5-×-2.5-km grid blocks. The geographic weighted regression

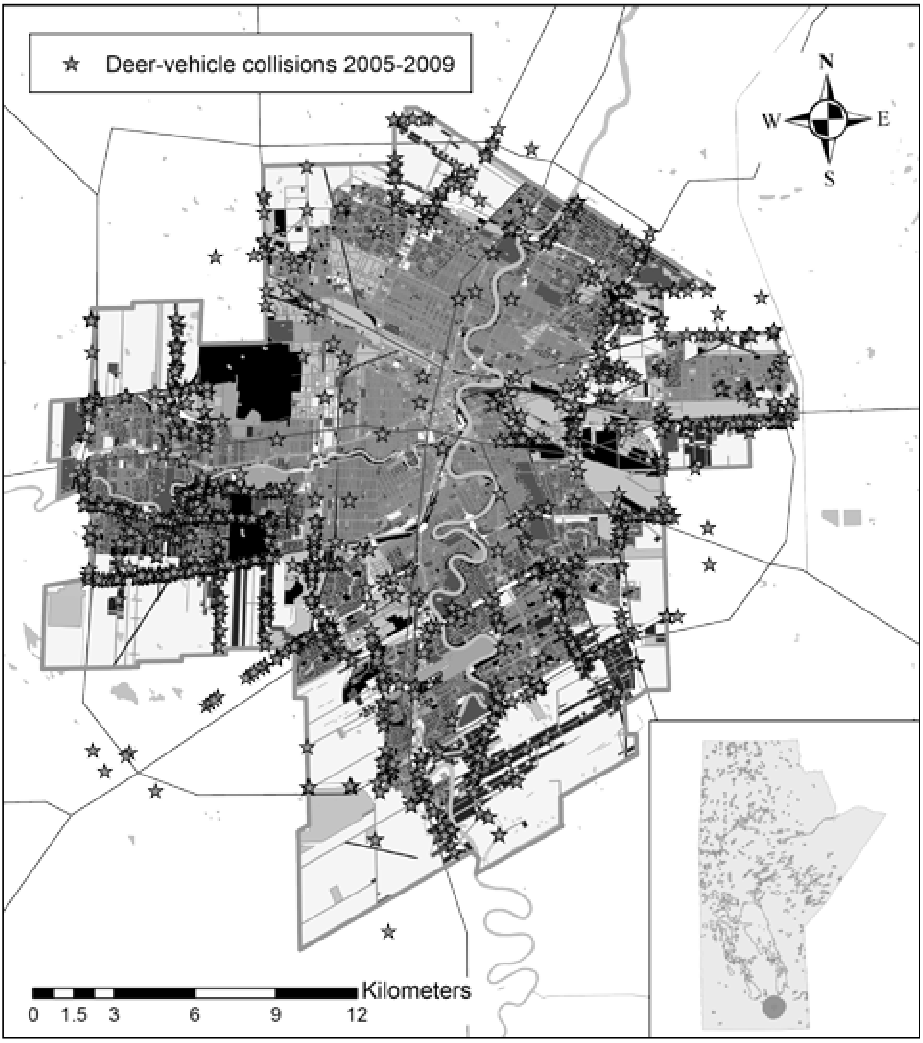

Figure 3: Reported DVCs in Winnipeg from 2005 to 2009 (black stars), black lines indicate roadways, and developed areas are represented in light grey. The grey dot illustrated on the inset represents the location of the city relative to the province of Manitoba.

model in ArcGIS 9.3 represents a local form of linear regression used to model spatially varying relationships (Environmental Research Institute Inc., Canada [ESRI] 2015). Given that standard deviation measures the spread or dispersion of a set of data (Mitchell 2002), the geographic weighted regression built a local regression equation for each feature in the dataset.

As a part of a larger research initiative involving white-tailed deer within Winnipeg, we trapped deer with a modified version of Clover Box Traps (Clover 1954) within high densities of deer located in the southwest portion of the city. We collared deer with Lotek Wild Cell GSM collars, (Newmarket, Ontario, Canada; Figure 2) from March 2010 to January 2013 ($n = 18$). The GPS collars were programmed to take a latitude and longitude location f-point every 2 hours. Deer movement data from March 10, 2010, to March 31, 2011, were mapped using ArcGIS 9.3. Deer home-range size was determined using Hawth's tools by calculating the minimum convex polygon for each animal. This research received Animal Ethics Approval from the University of Manitoba, Protocol number F09-034.

Preliminary spatial analysis of deer movement indicated that collared urban deer were spending a considerable amount of time

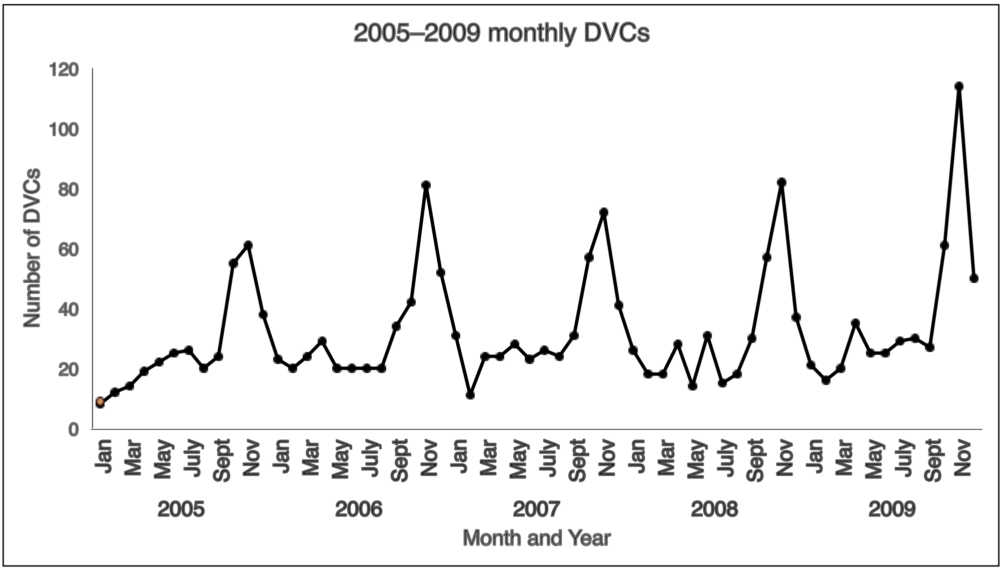

Figure 4: Monthly occurrence of DVCs (total number/month) from 2005 to 2009 within Winnipeg.

Table 3. Frequency DVCs in Winnipeg in relation to nearest land-cover class (LCC) type between 2005 and 2009. Zero implies that, for that cover type, all DVCs were closer to other land-cover classes.

Land-cover class	Year					Total	Random
	2005	2006	2007	2008	2009		
Annual crops	12	3	0	0	0	15	193
Broad leaf dense	6	5	4	5	2	22	309
Cultivated agricultural land	22	21	17	11	16	87	1,789
Developed	207	270	260	224	316	1,277	5,146
Exposed land	0	2	1	1	2	6	36
Grassland	69	90	121	139	128	547	2,224
Herb	3	0	0	0	0	3	58
Water	1	1	0	0	0	2	242
Other	4	0	0	0	0	4	3
Total	324	392	403	380	464	1,963	10,000

visiting a few residential properties multiple times per day. All of these collared animals (n = 18) were year-round residents within the city, with no seasonal migration events (McCance 2014). We isolated the residential properties showing the greatest density of deer locations per m^2 of property for the first 6 months that the deer were collared. We approached the registered owner of the residential property showing the greatest density of deer location points per m^2 for each collared deer to explore further why a select number of residential properties were visited often by the collared white-tailed deer. We asked property owners to participate in a one-on-one personal interview (n = 14). However, only 11 owners agreed to participate. We used a critical case-study approach that was semi-structured, and we adopted a directive style (Denzin and Lincoln 2003). The interviews were conducted to assess whether residents were engaged in actions that may be attracting deer or whether their residential property offered deer protective cover.

Using the Home Range Extension Function in ArcGIS 9.3 (Rodgers et al. 2007), the high-density, core-use areas (using adaptive kernel density analysis and assessing core areas

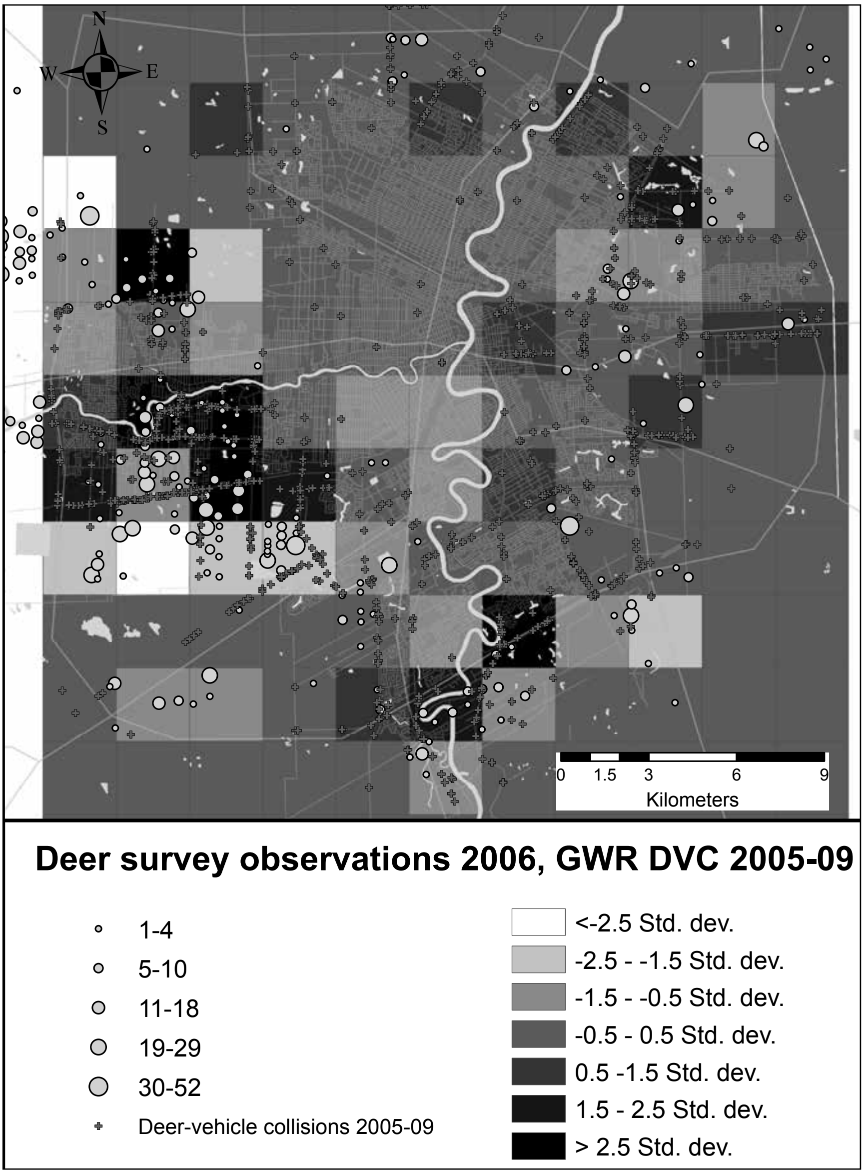

Figure 5. Deer survey grid block areas within Winnipeg, illustrating the correlation between DVCs and deer observations within each block for 2006. (GWR = graphic weighted regression; Std. dev. = standard deviation.)

between the 10 to 70% isopleth) for the deer were mapped in relation to the confirmed cases of DVCs and the confirmed cases of anthropogenic food sources. The latter were identified through personal interviews to assess the locational correlation among deer movement, DVCs, and anthropogenic food sites. We used ArcGIS 9.3 to measure the distance between the DVCs and feeding sites. We then compared these distances to those between DVC sites and 55 random locations. We used Hawth's Tools of the 11 GPS-collared deer and the confirmed feed sites associated with these deer, confirmed by the open-ended interviews. A distance-to-feature analysis was conducted between the DVC and the feed site location in comparison to the DVC location and 55 random locations. We used a Wilcox Rank Sum test (R Version 3.0.1) to determine whether DVCs occurred in closer proximity to the feed sites than to the random locations. This research received ap-proval from the Joint-Faculty Research Ethics Board at the University of Manitoba, Protocol number J2009:116. Data gathered from these interviews were transcribed and analyzed.

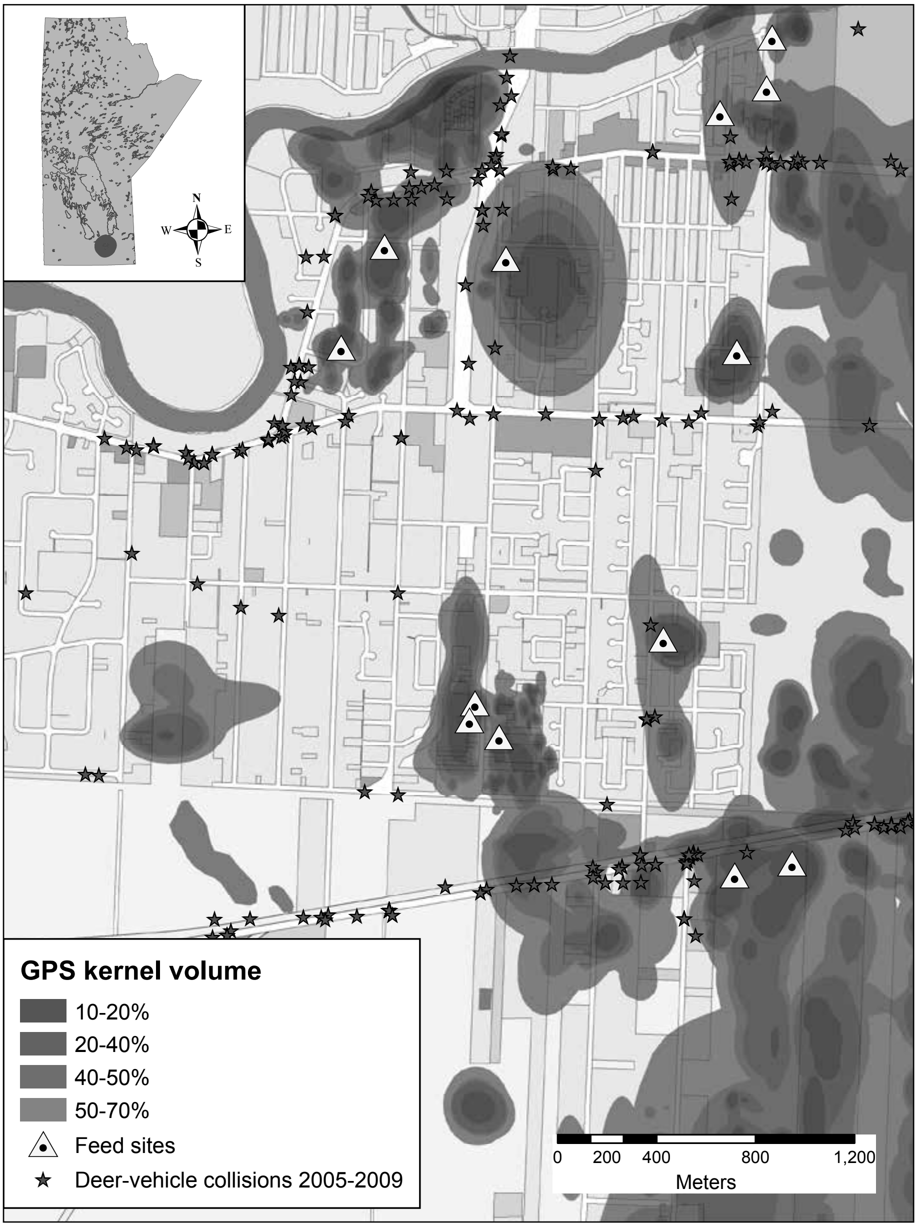

Figure 6. GPS-collared deer-density cores in relation to DVCs and anthropogenic food sites.

Results

There were 324, 392, 403, 380, and 464 DVCs annually reported to MPIC between 2005 and 2009 respectively (1,963 total; Figure 3). Occurrence of DVCs peaked during fall, coinciding with the deer rutting season. There were not any significant differences among days of the week (Figure 4).

Thirty-two of the DVCs occurred during the hour of sunrise and the hour of sunset. If the DVCs were evenly distributed over the 24 hour period of a day, each hour would account for 4% of the total number of DVCs. More DVCs occurred within an hour of sunrise and sunset than during the remaining hours of the day ($P = 0.003914$).

Based on average nearest-neighbor tests, DVCs were clustered and not randomly dispersed with a Z score of -57.54, observed mean distance/expected mean distance of 0.28, and a significance level of 0.01. Given the average nearest neighbor index (average nearest

Table 4. City of Winnipeg GPS-collared deer movement data in relation to land-cover class.

Land-cover class	Fall	Spring	Summer	Winter	Total
Annual crops	249	449	169	133	1,000
Broad leaf, dense	3,410	5,803	3,898	5,651	18,762
Cultivated agricultural land	944	1,251	2,936	254	5,385
Developed	3,476	2,171	2,110	4,562	12,319
Exposed land	230	131	157	250	768
Grassland	6,768	4,867	4,069	7,287	22,991
Herb	148	252	150	272	822
Mixed wood, dense	44	3	7	134	188
Water	91	68	79	157	395
Total	15,360	14,995	13,575	18,700	62,630

neighbor ratio) was <1, the pattern exhibits clustering. Similarly, using the 2.5-×-2.5-km grid block approach, DVCs were clustered, with a Moran's I index of 0.47, Z score of 8.14 and significance level of 0.01.

Most (93%) of the DVCs during 2005 to 2009 occurred adjacent to developed or grassland-cover types (Table 3). The LCC layer and the random points comparison indicated that the 3 habitat types in closest proximity to the random points were developed land (51.5%), grasslands (22%), and cultivated agricultural land (17.9%).

There was a statistically significant difference between DVC proximity to the various LCC types compared and the random points (χ^2 = 422.02, df = 8, P = 0.0001). Results support that DVCs have a higher probability of occurring near developed land or grassland land-cover types. The locations of white-tailed deer within Winnipeg were clustered at the time they were identified during the 2006 deer survey using a Moran's I index of 0.11, a Z score of 5.37, and a significance level of 0.01 (Figure 5).

Collared deer spent considerable time frequenting developed landscapes and grasslands found on vacant tracts of public property behind residential housing within Winnipeg (Table 4). Deer location points in ArcGIS 9.3 indicated that deer were visiting a select number of residential properties multiple times a day, traveling across busy roadways as they moved from protective cover to visit these select few residential properties. Results of the personal interviews suggested that all (100%) of these selected residential properties where deer showed the highest number of location points were associated with an intentionally supplied anthropogenic food source. These residents were either offering food to deer daily all year or providing protective cover adjacent to the food source. During the winter months, these residents were feeding >30 white-tailed deer per day.

High-use core areas were centered on confirmed cases of anthropogenic food sources. We found an association between high-use areas and supplied anthropogenic food sources, as well as increased prevalence of DVCs. In most instances, DVCs along roadways are often also proximal to feeding sites (Figure 6). Results of Wilcon Rank Sum Test, comparing the distance of DVCs to the confirmed feeding site locations in comparison to random locations indicated that the DVCs were closer to the confirmed feed sites than random locations would be. The mean distance of the DVCs to feeding sites was 289.85 meters, with a standard deviation of 133.21, median of 403.12 compared to the random locations that had a mean distance from the feed sites of 459.38, standard deviation of 256.18. The P value was <0.05 and closer for DVC occurrence locations to the feed sites compared to the random locations.

Discussion

October, November, and December were the 3 months when most DVCs occurred. This timeline is consistent with the months that deer are actively breeding (Goulden 1981). During fall, males are travelling farther to find females in estrus, and males looking to breed may "push" females (Beier and McCullough 1990). Similar findings in regard to DVC occurrences during the fall months were documented in Iowa by Hubbard et al. (2000) and in Edmonton, Alberta, Canada, by Ng et al. (2008).

We found a higher occurrence of DVCs during sunrise and sunset. This is not surprising given that white-tail deer are most active during dawn and dusk (Beier and McCullough 1990). Our results are consistent with the earlier works of Bashore et al. (1985), Hubbard et al. (2000), and Nielsen et al. (2003). We documented that DVCs were not spatially random within the city.

Most DVCs in our study area were adjacent to developed or grasslands cover types. Sudharsan et al. (2009) and Myers et al. (2008) found that a higher probability of DVCs occur near heavily populated and agricultural areas. Deer–vehicle collisions were associated with grasslands and wooded areas (Myers et al. 2008). Similarly, other researchers have found a higher occurrence of DVCs near woodlots (Finder et al. 1999, Hussain et al. 2007). However, in our study, increased numbers of DVCs were more associated with developed land cover than woodlots, suggesting perhaps that, for Winnipeg's urban deer, protective cover and food requirements are being met readily within developed landscapes.

We also found that deer density is heavily influenced by sites where people provide food for them. Deer–vehicle collisions were clustered around these feeding sites. Sudharsan et al. (2009) also found connectivity between high DVC roadways and landscape types where deer access a food source; however, in their research, these collisions were associated with agricultural crops.

Management implications

Our the results indicate that urban DVCs are positively correlated to deer density, certain land-cover types, and that they occur more frequently during certain times of the day and months of the year. Deer–vehicle collisions are often located near where people intentionally feed deer. Therefore, the human behavior of providing anthropogenic food sources to urban deer may be influencing DVC location and frequency in Winnipeg. Management strategies, such as a feeding ban, aimed at reducing the availability of intentionally supplied anthropogenic food within the city may be useful. Management strategies should be specifically designed to focus during the times of day and year when a higher number of DVCs occur. Localized management near key habitat types that are associated with higher numbers of DVCs should be considered.

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