Road Mortality of Reptiles and Other Wildlife at the Ojibway Prairie Complex and Greater Park Ecosystem in Southern Ontario

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The Ojibway Prairie Complex in Windsor contains the largest protected tallgrass prairie ecosystem in Ontario and supports numerous species at risk. Despite its ecological significance, it is crossed by multiple high-traffic roads. Road mortality is a major threat to endangered species in Canada, particularly reptiles. The main goal of this study was to describe the nature and extent of vertebrate road mortality, with a focus on reptiles, on roads bisecting the Ojibway Prairie Complex, and the Greater Park Ecosystem, in Windsor and LaSalle, Ontario. A systematic road mortality survey was conducted by bicycle along seven roads (12.5 km) in 2010, 2012, and 2013. Also, opportunistic observations (n = 103) spanning over 30 years were assembled from a variety of sources. In total, 2083 vertebrates (49 species), including 446 reptiles (11 species), were recorded "dead on road" during systematic surveys. The highest diversity of reptiles was recorded on Matchette Road, whereas the highest rate of reptile mortality was recorded on Malden Road. Reptile species at risk were killed on all roads surveyed. Combining systematic and opportunistic data, we found seven reptile species at risk: Butler's Gartersnake (*Thamnophis butleri*), Eastern Foxsnake (*Pantherophis vulpinus*), Eastern Massasauga (*Sistrurus catenatus catenatus*), Blanding's Turtle (*Emydoidea blandingii*), Eastern Musk Turtle (*Sternotherus odoratus*), Northern Map Turtle (*Graptemys geographica*), and Snapping Turtle (*Chelydra serpentina*). Reptile road mortality "hotspots" occurred where each road is intersected by a naturalized utility right-of-way. Our results can be used to focus mitigation efforts in space and time to reduce mortality rates and enhance connectivity in the Ojibway Prairie Complex and Greater Park Ecosystem.

Key Words: Reptiles; vertebrates; species at risk; road mortality; Ojibway Prairie Complex; Windsor; LaSalle; utility right-of-way

Introduction

Our understanding of the negative impacts of roads on wildlife is increasing. In Canada, road mortality is now considered a major threat to the persistence of endangered species, particularly reptiles (e.g., Row *et al.* 2007). Road mortality surveys have been used in areas of ecological importance to identify the nature and extent of wildlife road mortality (Ashley and Robinson 1996; Vijayakumar *et al.* 2001; Smith and Dodd 2003; Langen *et al.* 2007; Coelho *et al.* 2008; Shepard *et al.* 2008), and to measure the effectiveness of mitigation measures (Dodd *et al.* 2004; Aresco 2005; Baxter-Gilbert *et al.* 2015).

The Ojibway Prairie Complex (OPC), in extreme southwestern Ontario, is recognized as a Carolinian Canada Signature Site (Johnson 2005); it contains the largest protected tallgrass prairie remnant in Ontario, (Rodger 1998). This "complex" of tallgrass prairies, savannahs, forests, and provincially significant wetlands supports a multitude of regionally, provincially, and globally significant species of flora and fauna, some of which are found nowhere else in Canada (City of Windsor 2013). Furthermore, as many as 10 reptile species listed federally as at risk have been recently documented in the OPC and the surrounding greater park ecosystem (City of Windsor 2013; COSEWIC 2015).

Situated within an urban landscape, the OPC and Greater Park Ecosytem is surrounded and fragmented by residential, industrial, commercial, and agricultural lands as well as an extensive network of local, collector and arterial roads, in addition to a newly built provincial highway. Many species of wildlife, including at-risk reptiles, have been observed killed on these roads over the previous three decades (P. Pratt, unpublished data). These data were collected opportunistically, and no attempt has been made to document road mortality in this region systematically.

The main goal of this study was to describe the nature and extent of vertebrate road mortality, with a focus on reptiles and species at risk, on roads bisecting the OPC and Greater Park Ecosystem in the city of Windsor and the town of LaSalle. Our objectives were to identify which vertebrate species are killed on roads, estimate road mortality rates for each group, and identify spatial and temporal patterns of vertebrate road mortality.

Methods

Systematic Road Mortality Surveys

Seven collector and arterial roads in the study landscape were surveyed (Figure 1; Table 1). They were divided into two groups, reflecting different survey effort: in section B, all amphibians, birds, mammals, snakes, and turtles found dead on a road were recorded systematically, whereas, in section A, only dead snakes and turtles were recorded systematically. Also, more surveys were conducted in section B (n = 157) than in

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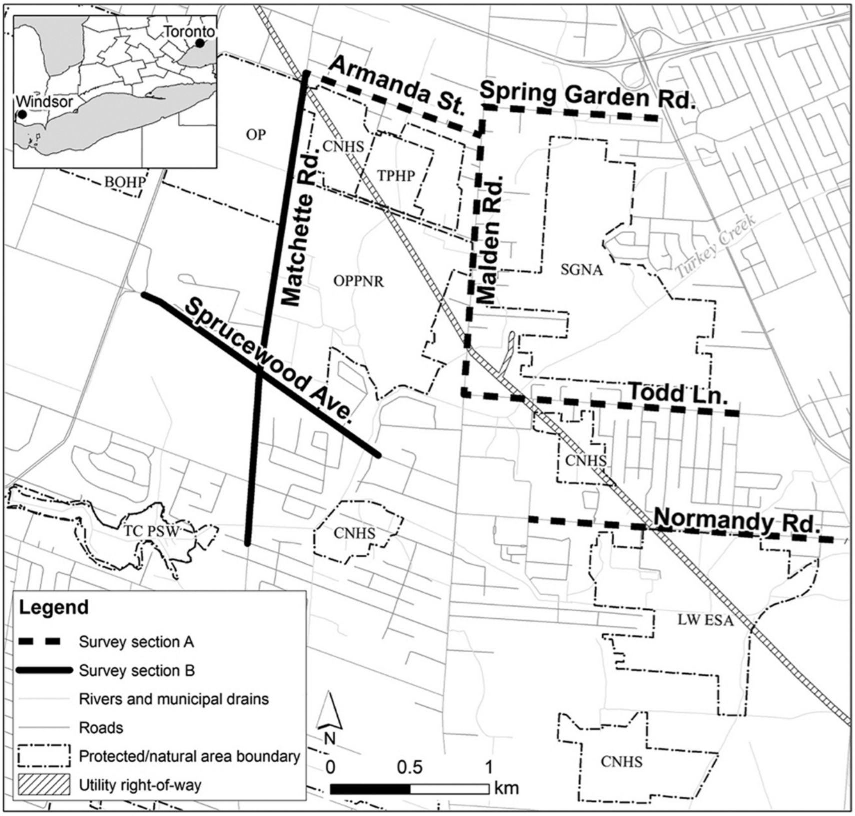

FIGURE 1. Map of the Ojibway Prairie Complex and Greater Park Ecosystem study area showing approximate boundaries of protected areas and roads surveyed for dead vertebrates during 2010–2013. BOHP = Black Oak Heritage Park, CNHS = Candidate Natural Heritage Site, LW ESA = LaSalle Woods Environmentally Significant Area, OP = Ojibway Park, OPPNR = Ojibway Prairie Provincial Nature Reserve, SGNA= Spring Garden Natural Area, TC PSW = Turkey Creek Provincially Significant Wetland, and TPHP = Tallgrass Prairie Heritage Park.

TABLE 1. Length, traffic intensity, and adjacent land use for roads surveyed during a systematic road mortality study in the Ojibway Prairie Complex and Greater Park Ecosystem in Windsor and LaSalle, Ontario, from 2010 to 2013.

Length of survey route (km)	Road (length surveyed, km)	Estimated average annual daily traffic*	Adjacent land use†
Section A (7.85)	Armanda Street (1.17)	2200 (2006 data)	91% res, 9% row
	Spring Garden Road (1.09)	2500 (2005 data)	81% res, 8% ins, 8% row, 3% com
	Malden Road (1.82)	8654 (2006 data) 8000 (2013 data)	67% res, 19% row, 6% com, 6% nat, 2% ins
	Todd Lane (1.74)	9580–12 027 (2006 data) 15 236 (2008 data)	85% res, 11% row, 4% rec
	Normandy Road (2.03)	6619–8744 (2006 data)	70% res, 18% nat, 6% rec, 4% row, 2% ins
Section B (4.75)	Matchette Road (3.00)	6836–9300 (2006 data)	54% res, 38% nat, 6% row, 2% rec
	Sprucewood Avenue (1.75)	4619–6235 (2006 data) 5700–9402 (2008 data)	58% res, 25% rec, 12% nat, 5% row

*Sources: Dillon Consulting (2007, 2009); P. Bouliane, personal communication, 2014; County of Essex (2014).
†Sources: City of Windsor (2007); Town of LaSalle (2014). "Adjacent land use" is estimated using a GIS by dividing the length of road frontage for a given land use or zoning designation (both sides of the road) by the total length of road frontage (i.e., double the road length). Note: com = commercial, ins = institutional, nat = natural heritage/environment, rec = recreational, res = residential, row = opened and unopened road right-of-way.

section A (n = 135). Results for snakes and turtles from both sections were pooled.

Roads were surveyed by bicycle at speeds of 12–17 km/h on 3 days a week (on average every other day, except section A was surveyed on average every 4 days in 2010) for 52 non-consecutive weeks. Three technicians conducted road surveys: surveyor 1 in 2010–2013, surveyor 2 in 2012, and surveyor 3 in 2013. Surveys took place from May to mid-August in 2010 and 2013 and from late-August to October in 2012 and 2013. (Data from a single late-April survey are combined with May data.) The posted speed limit on all roads surveyed was 50 km/h. The survey route was traveled in a loop such that both lanes of each road were surveyed and it took about 3 h to complete a full survey. Surveys were always conducted with the flow of traffic; however, for each survey we alternated between completing section A or section B first. Most surveys (> 70%) were completed between 1100 and 1700. When all effort is combined, we surveyed the equivalent of almost 1800 km of roads, an average of 300 km/month (range 244–382 km/month).

For each specimen found dead on a road, the following data were recorded: UTM coordinates (accuracy of 5–10 m), road name, and location on road (yellow line, centre of lane, white line, or shoulder). During periods of high amphibian mortality, UTM coordinates were not recorded for these species; rather, these were tabulated by pre-defined road segment. Species, age class, and sex were also recorded when possible; however, many amphibians (54%), birds (46%), and mammals (31%) could not be identified to species. Photographs were taken of all species listed as at risk by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2015).

To avoid duplication of records, all dead specimens were removed from the road and discarded in adjacent vegetation or roadside swale. When physical removal was not possible (because of carcass condition or safety concerns), specimens were left in situ and the white line adjacent to the carcass was marked with a water-resistant cattle marker or lumber crayon. These marks continued to be visible for at least a week after marking, which was generally sufficient to allow for the specimen to be removed from the road by other means. Carcass persistence rates were not estimated. All animals encountered alive on roads were noted and either left in situ (if on the road shoulder) or helped across the road in the direction in which they appeared to be traveling.

Opportunistic Data Collection

Observations of snakes and turtles on roads, dead or alive, were also solicited from various local naturalists (including the authors) and organizations to assemble a dataset of opportunistic records. Opportunistic data were kept separate from those collected during our surveys. Observations in this dataset spanned over 30 years (1984–2014) and included records of snakes and turtles found dead (n = 106) and alive (n = 17) on roads in the study landscape. Many observations were provided by staff at the Ojibway Nature Centre. In most cases, records were verified by qualified personnel. All results reported here are based on our systematic data, unless otherwise specified.

Data Analysis and Mapping

Mortality rates are reported either as number of dead on road (DOR) individuals per 100 km surveyed (e.g., [446 DOR /1798 km surveyed] × 100 = 24.8 DOR/100 km surveyed) or as number of DOR individuals per km per survey (e.g., [446 DOR] / [11.5 km per survey, on average] / [157 surveys] = 0.25 DOR/km/survey). Rates per month or per survey road were calculated in the same way, but using only the relevant subset of the data. Frequency estimates (DOR/km/survey) are assumed to be representative of daily mortality rates (i.e., DOR/ km/day) for birds, mammals, snakes, and amphibians, as other research has shown that most carcasses of these animals remain on the road for only one day (Enge and Wood 2002; DeGregorio *et al.* 2011; Santos *et al.* 2011). For turtles, however, per survey rates may not be synonymous with daily rates as some investigators have found most specimens remain on the road for two or more days (Langen *et al.* 2007; Santos *et al.* 2011).

To determine whether there were significant differences in the numbers of dead animals recorded per taxon across calendar months (data pooled by month, regardless of year), we made comparisons using a χ^2 goodness-of-fit test using SPSS 22.0 (IBM, Armonk, New York, USA). Departures from expected equal frequencies across all months were determined by residuals that were greater or less than the critical value of ± 1.96. When a significant difference from an expected frequency was found, pairwise goodness-of-fit tests were performed to determine which months were significantly different from the others. Sample sizes were too low to compare monthly mortality rates for at-risk turtles.

Scientific names of all reptiles and amphibians follow Crother (2012). Maps were produced in ArcGIS version 9.1 (ESRI, Redlands, California, USA). All distances were determined using the "Measure" tool in ArcGIS.

Spatial Analysis

The distribution of reptile road mortality events was analyzed using Siriema version 1.1 (Coelho *et al.* 2006). Roadkill data were weighted for species at risk (SAR) using the following scheme based on the COSEWIC (2015) list: non-SAR/not at risk = 1, special concern = 2, threatened = 3, endangered = 4 (Table 2); thus, "hotspots" (and any future mitigation efforts) would be biased toward such species. (A sensitivity analysis on Malden Road demonstrated that the location

TABLE 2. Vertebrates found during a systematic road mortality survey in the Ojibway Prairie Complex and Greater Park Ecosystem in Windsor and LaSalle, Ontario, from 2010–2013.

Species (COSEWIC status)*		Opportunistic data†	Systematic data: 2010 (May–mid-Aug.)	2012 (Late Aug.–Oct.)	2013 May–(mid-Aug.)	2013 (Late Aug.–Oct.)	Total
REPTILES							
Eastern Foxsnake (END; Carolinian pop.)	*Pantherophis vulpinus*	DOR + AOR	6	29	8	7	50
Eastern Massasauga (END; Carolinian pop.)	*Sistrurus catenatus catenatus*	DOR	0	0	0	0	0
Northern Brownsnake (NAR)	*Storeria dekayi dekayi*	DOR	61	64‡	4	11	140
Northern Red-bellied Snake	*Storeria occipitomaculata occipitomaculata*	—	12	4	1	3	20
Butler's Gartersnake (END)	*Thamnophis butleri*	DOR	8	10	0	1	19
Eastern Gartersnake	*Thamnophis sirtalis sirtalis*	DOR + AOR	42	45‡	29	11	127
Unidentified snake	*Thamnophis* sp.	—	0	9	0	0	9
Unidentified snake	—	—	7	8	2	2	19
Snapping Turtle (SC)	*Chelydra serpentina*	DOR + AOR	4‡	11	2	1	18
Midland Painted Turtle	*Chrysemys picta marginata*	DOR + AOR	17‡	6	10	0	33
Blanding's Turtle (THR; Great Lakes /St. Lawrence pop.)	*Emydoidea blandingii*	DOR + AOR	1‡	1	0	0	2
Northern Map Turtle (SC)	*Graptemys geographica*	DOR + AOR	2	0	3	0	5
Eastern Musk Turtle (SC)	*Sternotherus odoratus*	—	1	0	0	0	1
Red-eared Slider	*Trachemys scripta elegans*	DOR + AOR	1	0	2	0	3
All reptiles (11 species in surveys)			**162**	**187**	**61**	**36**	**446**
AMPHIBIANS							
American Toad	*Anaxyrus americanus*	—	166	4	101	22	293
Green Frog/Bull Frog	*Lithobates clamitans, L. catesbeiana*	—	133	1	3	1	138
Northern Leopard Frog (NAR: eastern populations)	*Lithobates pipiens*	—	60	9	40	61	170
Unidentified amphibians	—	—	674	16	12	0	702
Total amphibians (4 species)			**1033**	**30**	**156**	**84**	**1303**
BIRDS							
Red-winged Blackbird	*Agelaius phoeniceus*	—	5	0	9	0	14
Mallard Duck	*Anas fulvigula*	—	1	0	0	0	1
Ruby-throated Hummingbird	*Archilochus colubris*	—	0§	0	0	0	0
Northern Cardinal	*Cardinalis cardinalis*	—	0	0	4	1	5
American Goldfinch	*Carduelis tristis*	—	1	0	0	0	1
Rock Dove	*Columba livia*	—	0§	0	0	0	0
Gray Catbird	*Dumetella carolinensis*	—	0	0§	0	0	0
Baltimore Oriole (including one unidentified *Icterus* sp.)	*Icterus galbula*	—	3	0	0	0	3
Tree Swallow	*Iridoprocene bicolor*	—	1	0	0	0	1
House Sparrow	*Passer domesticus*	—	3	0	7	7	17
Black-capped Chickadee	*Poecile atricapillus*	—	0	0	1	0	1
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	—	3	0	0	0	3

TABLE 2 *(continued)*. Vertebrates found during a systematic road mortality survey in the Ojibway Prairie Complex and Greater Park Ecosystem in Windsor and LaSalle, Ontario, from 2010–2013.

Species (COSEWIC status)*		Opportunistic data†	Systematic data: 2010 (May–mid-Aug.)	2012 (Late Aug.–Oct.)	2013 May–(mid-Aug.)	2013 (Late Aug.–Oct.)	Total
Ring-necked Pheasant	*Phasianus colchicus*	—	0	1	0	0	1
Common Grackle	*Quiscalus quiscula*	—	0§	0	0	0	0
Eastern Bluebird (NAR)	*Sialia sialis*	—	0	0	1	0	1
Chipping Sparrow	*Spizella passerina*	—	0§	0	0	0	0
European Starling	*Sturnus vulgaris*	—	3	0	12	2	17
Carolina Wren	*Thryothorus ludovicianus*	—	0	0§	0	0	0
House Wren	*Troglodytes aedon*	—	2	0	0	0	2
American Robin	*Turdus migratorius*	—	2	0	24	1	27
Mourning Dove	*Zenaida asiatica*	—	1	0	0	0	1
Unidentified birds	—	—			70	89	289
All birds (21 species)			**95**	**9**	**67**	**13**	**184**
MAMMALS							
Short tailed Shrew	*Blarina brevicauda*	—	3	1	0	0	4
Virginia Opossum	*Didelphis virginiana*	—	1	2	1	1	5
Domestic Cat	*Felis catus*	—	0	0	0	2	2
Woodchuck	*Marmota monax*	—	0	2	0	0	2
Striped Skunk	*Mephitis mephitis*	—	4	5	0	0	9
Meadow Vole	*Microtus pennsylvanicus*	—	3	0	0	0	3
Muskrat	*Ondatra zibethicus*	—	1	0	0	0	1
White-footed Mouse	*Peromyscus leucopus*	—	0	1	0	0	1
Raccoon	*Procyon lotor*	—	4	2	1	1	8
Eastern Gray Squirrel	*Sciurus carolinensis*	—	3	1	9	11	24
Eastern Cottontail Rabbit (most probable species)	*Sylvilagus floridanus*	—	2	5	7	3	17
Eastern Chipmunk	*Tamias striatus*	—	14	0§	5	4	23
Unidentified Bat	—	—	1	3	0	0	4
Unidentified small mammals (Shrews, voles, mice, etc.)	—	—	20	6	2	3	31
Unidentified mammals	—	—	5	11	0	0	16
All mammals (13 species)			**61**	**39**	**25**	**25**	**150**
Total vertebrates (49 species)			**1351**	**265**	**309**	**158**	**2083**

*Source: COSEWIC (2015). END = endangered, THR = threatened, SC = special concern, NAR = not at risk.
†Incidental observations of snakes and turtles on roads: DOR = species found at least once dead on road; AOR = species observed at least once alive on road.
‡Snake or turtle species observed AOR at least once during a survey in that time period.
§Bird or mammal observed DOR in Section A during systematic surveys, but whose numbers were not tallied.

of mortality hotspots was sensitive to the SAR weighting.)

The Siriema analysis consisted of two steps (Coelho *et al.* 2008). First, Ripley's *K* function is used to test for significant spatial aggregations of road mortality events ($L(r)$ values) on each study road, and, if found, to determine at which spatial scales (i.e., radius length) such aggregations occur. Second, using a relevant radius length from step one as an input, hotspot analysis is used to identify the relative locations along each road where significant spatial aggregations occur (N_{events}-$N_{simulated}$). We used a linear, as opposed to a two-dimensional, *K*-function and hotspot analysis (Coelho *et al.* 2006) because all roads are linear (except for a minor curve on two of the roads), and no major differences were detected during an initial analysis of a sample of roads using both methods.

For the Ripley's *K*-function analysis, we used a 95% confidence interval (CI), an initial radius of 0.025 km, a radius step of 0.025 km, and 100 simulations. For the hotspot identification, we used a 95% CI, 100 simulations, 500 road divisions, and two radii for each road: a radius for which the greatest intensity of spatial clustering was reported (from Ripley's *K*) and a radius of 0.050 km. Two radii identified as having significant aggregations were used (one relatively longer than the other), so that results could better inform placement of both fine-scale (e.g., ecopassages) and broad-scale (e.g., barrier fencing or traffic calming) mitigation strategies (Coelho *et al.* 2006). Only roads with significant spatial aggregations of road mortality (based on Ripley's *K* analysis) were subjected to hotspot identification. For north–south roads, kilometre 0.00 was set at the southern end and for east–west roads, kilometre 0.00 was set at the western end.

Results

Species Composition of Road Mortality

Overall, 2083 vertebrates of 49 species were found dead during systematic surveys. This includes four species of amphibians, 21 species of birds, 13 species of mammals, five species of snakes, and six species of turtles (Table 2). Eastern Gartersnakes (*Thamnophis sirtalis sirtalis*) and Northern Brownsnakes (*Storeria dekayi dekayi*) made up the majority (70%) of snakes recorded, while Midland Painted Turtles (*Chrysemys picta marginata*) and Snapping Turtles (*Chelydra serpentina*) accounted for the majority (82%) of turtles. On average, dead snakes were observed seven times more frequently than dead turtles (Table 3).

Just over a fifth (21%) of all dead snakes and turtles were SAR. Six such species were found in this study: Blanding's Turtle (*Emydoidea blandingii*), Eastern Musk Turtle (*Sternotherus odoratus*), Northern Map Turtle (*Graptemys geographica*), Snapping Turtle, Butler's Gartersnake (*Thamnophis butleri*), and Eastern Foxsnake (*Pantherophis vulpinus*). Butler's Gartersnakes, Eastern Foxsnakes, and Snapping Turtles made up the vast majority (92%) of SAR records. On average, dead SAR snakes were observed twice as often as SAR turtles (Table 3). An additional SAR, the Eastern Massasauga (*Sistrurus catenatus catenatus*) was found dead opportunistically during the study period (Table 2). Seven provincially listed snakes and turtles were observed dead at the OPC and Greater Park Ecosystem, and, of these, three species appeared to be disproportionately represented.

Temporal and Spatial Patterns of Road Mortality

Mortality rates differed significantly between months for amphibians ($\chi^2 = 1483.12$, df = 5, $P < 0.001$; peak in July–August), birds ($\chi^2 = 73.87$, df = 5, $P < 0.001$; peak

TABLE 3. Vertebrate mortality rates recorded during a systematic road mortality survey in the Ojibway Prairie Complex and Greater Park Ecosystem in Windsor and LaSalle, Ontario, from 2010 to 2013. Rates for amphibians, birds, and mammals are based on data from Section B only; rates for all other groups are based on combined data from both sections.

Vertebrate group	Average mortality rate, no./100 km	Above average mortality rates by month, no./100 km						Above average mortality rates by road, no./100 km*†				
		May	Jun	Jul	Aug	Sep	Oct	Nor	Mal	Mat	Spr	Tod
Amphibians	176.2	—	—	607.2	192.3	—	—					
Birds	24.7	32.3	48.0	40.4	—	—	—			n/a		
Mammals	20.1	—	26.9	24.4	23.0	—	—					
Snakes	21.4	—	—	—	36.2	26.3	28.7	—	52.3	—	—	—
Turtles	3.4	6.0	5.9	—	—	4.1	—	—	—	7.2	4.7	—
Species at risk												
All†	5.3	—	6.3	—	—	9.1	7.1	—	9.4	7.4	—	—
Snakes	3.8	—	—	—	—	6.6	6.3	4.0	7.0	5.3	—	3.9
Turtles†	1.4	—	3.2	—	—	2.5	—	—	2.5	2.1	1.8	—

*Nor = Normandy Road, Mal = Malden Road, Mat = Matchette Road, Spr = Sprucewood Avenue, Tod = Todd Lane.
Above average mortality rates for snakes, turtles, and species at risk were not observed on Spring Garden or Armanda roads.
†χ^2 tests were not conducted.

in May–July), snakes ($\chi^2 = 98.5$, df = 5, $P < 0.001$; peak in August–October), SAR snakes ($\chi^2 = 32.8$, df = 5, $P < 0.001$; peak in September–October), and turtles ($\chi^2 = 24.71$, df = 5, $P < 0.001$; peaks in May–June and September), but not for mammals ($\chi^2 = 6.08$, df = 5, $P = 0.299$). Temporal patterns remained after controlling for the number of kilometres surveyed per month (Figure 2, Table 3).

Turtle mortality was hatchling-biased in May and September (67% and 62%, respectively), but not in June (13%). Over half (62%) of all dead SAR turtles were found in June and September, whereas most dead non-hatchlings (70%) were found in June. Snake mortality was adult-biased (88%) in August, whereas, in September and October, mortality was more evenly represented by younger age classes (55% and 67%, respectively). Over half (65%) of SAR snake mortality was observed in September and October. Above average mortality rates for SAR turtles and SAR snakes, combined, were observed on Malden and Matchette roads (Table 3). The highest diversity of dead snakes and turtles (11 species) and SAR (six species) were observed on Matchette Road. Three SAR (Butler's Gartersnake, Eastern Foxsnake, and Snapping Turtle) were each observed at least once during all months and on most roads.

Road Mortality Hotspots

Significant aggregations of snake and turtle road mortality events were detected at multiple scales on five of seven roads: Matchette, Malden, Spring Garden, Todd, and Normandy roads (Table 4, Figure 3). Aggregation intensity was highest at the scale of 0.300 km to 1.050 km for each of these five roads (Table 4). Significant aggregations were also detected at the scale of 0.050 km for all five roads except Spring Garden Road. Significant dispersion was detected only on Matchette Road (Table 4, Figure 3).

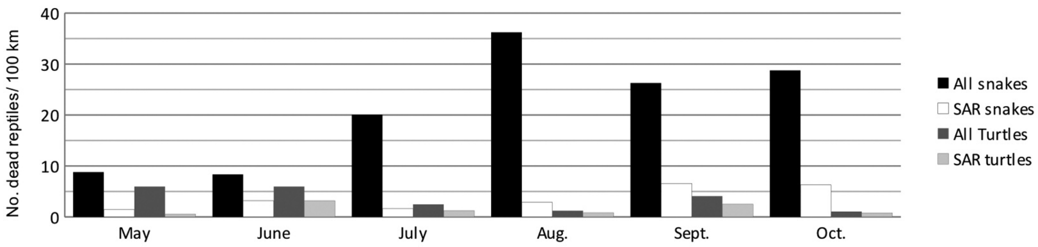

FIGURE 2. Mortality rates recorded during 52 non-consecutive weeks from 2010 to 2013 on seven collector and arterial roads in the Ojibway Prairie Complex and Greater Park Ecosystem in Windsor and LaSalle, Ontario.

TABLE 4. Radii with significant aggregations and dispersions (to the nearest 0.025 km) and locations of hotspots (to the nearest 0.050 km) determined during a reptile road mortality study in the Ojibway Prairie Complex and Greater Park Ecosystem, Windsor and LaSalle, Ontario, from 2010 to 2013.

Road	Radii with significant* aggregations, km	Radii with highest aggregation intensity, km	Radii with significant* dispersions, km	Length (and relative location) of road mortality hotspots* with greatest intensity, km	
				Finer scale (0.050 km radii)	Broader scale (radii varies)
Malden Road	0.025–1.375 1.475–1.550	1.050 1.125	n/a	0.150 (km 0.200 – km 0.350)	0.400 (km 0.000 – km 0.400); 0.250 km radius
Matchette Road	0.025–1.400	0.825	1.675–2.725	0.200 (km 2.750 – km 2.950)	1.000 (km 2.000 – km 3.000); 0.825 km radius
Normandy Road	0.025–1.225	0.850	n/a	0.300 (km 0.550 – km 0.850)	0.600 (km 0.650 – km 1.250); 0.450 km radius
Todd Lane	0.025–0.600	0.300	n/a	0.200 (km 0.250 – km 0.450)	0.650 (km 0.000 – km 0.650); 0.300 km radius
Spring Garden Road	0.225–0.325 0.375–0.400 0.450–0.500	0.475	n/a	n/a	n/a

*Based on a 95% confidence interval.

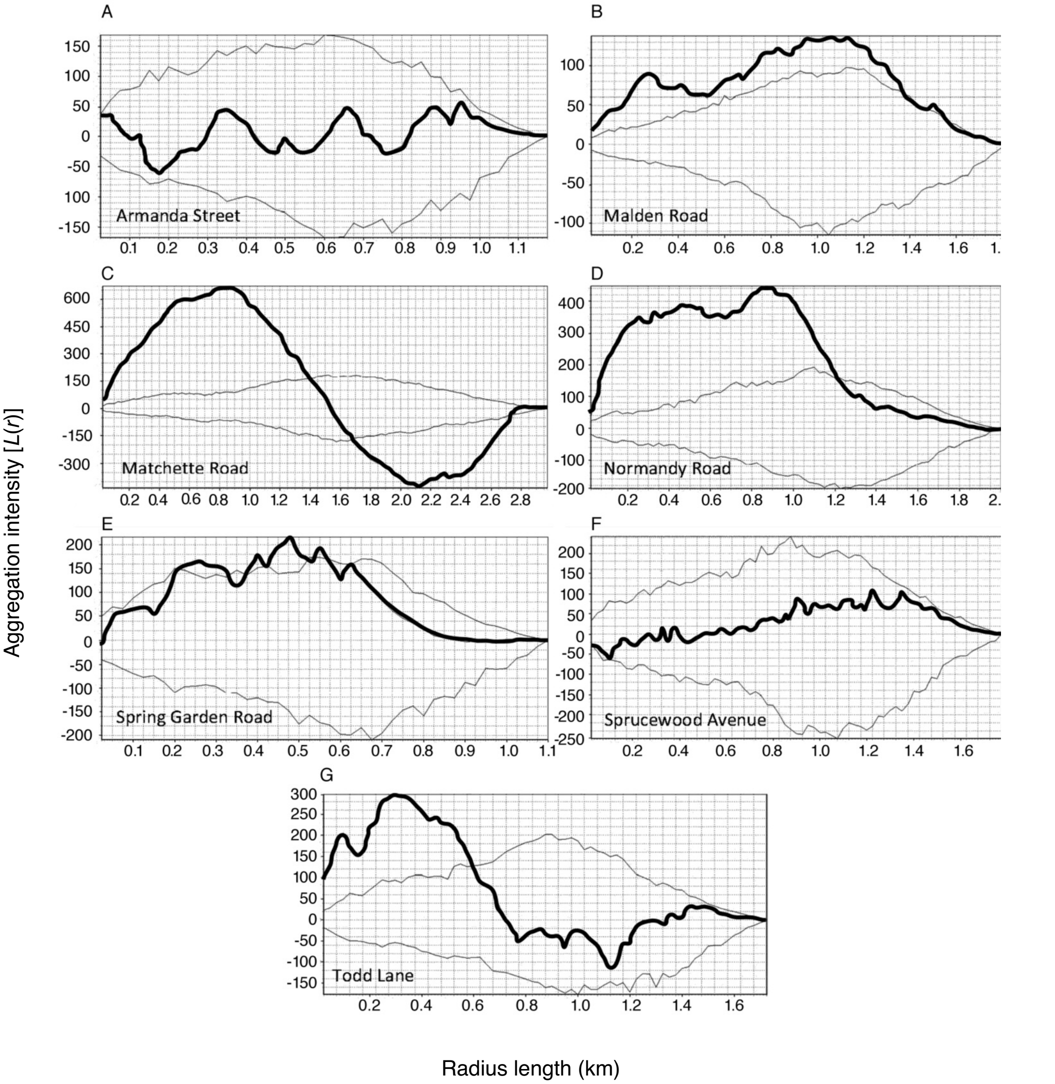

FIGURE 3. Ripley's *K* analysis for significant spatial aggregations of reptile road mortality events recorded on seven roads during a systematic road mortality study in the Ojibway Prairie Complex and Greater Park Ecosystem in Windsor and LaSalle, Ontario. In each graph, aggregation intensity [$L(r)$] is a function of radius length [r (km)], and 95% confidence limits are represented by the two light black lines. Significant aggregations of road mortality events occur where the bold black line exceeds the upper confidence limit.

Results of hotspot analysis were aberrant for Malden, Normandy, and Spring Garden roads when using the radii with the highest aggregation intensity for each of these roads (1.050 km, 0.850 km, and 0.475 km, respectively). Subsequent analyses were conducted for Malden and Normandy roads using the radii of the next smallest "peaks" in $L(r)$ from the Ripley's *K* analyses (0.250 km and 0.450 km, respectively; Figure 3). Spring Garden Road was dropped from further analysis after trials with four radii continued to produce aberrant results.

Snake and turtle road mortality hotspots appeared to be associated with the presence of a utility right-of-way that bisects the study landscape (parallel natural gas and high-voltage hydro transmission lines) and crosses four study roads (Matchette, Malden, Todd, and Normandy; Figures 1, 4). For each of these four roads, and at two scales of analysis, the highest intensity road mortality hotspot occurred in close proximity to where each road intersects the right-of-way (Figure 4). Depending on the scale of analysis used, approximately a third (33/82 or 40%) to half (45/82 or 55%) of all SAR records from the four roads were observed within hotspots (a combined length of 0.850–2.650 km; Table 4, Figure 3).

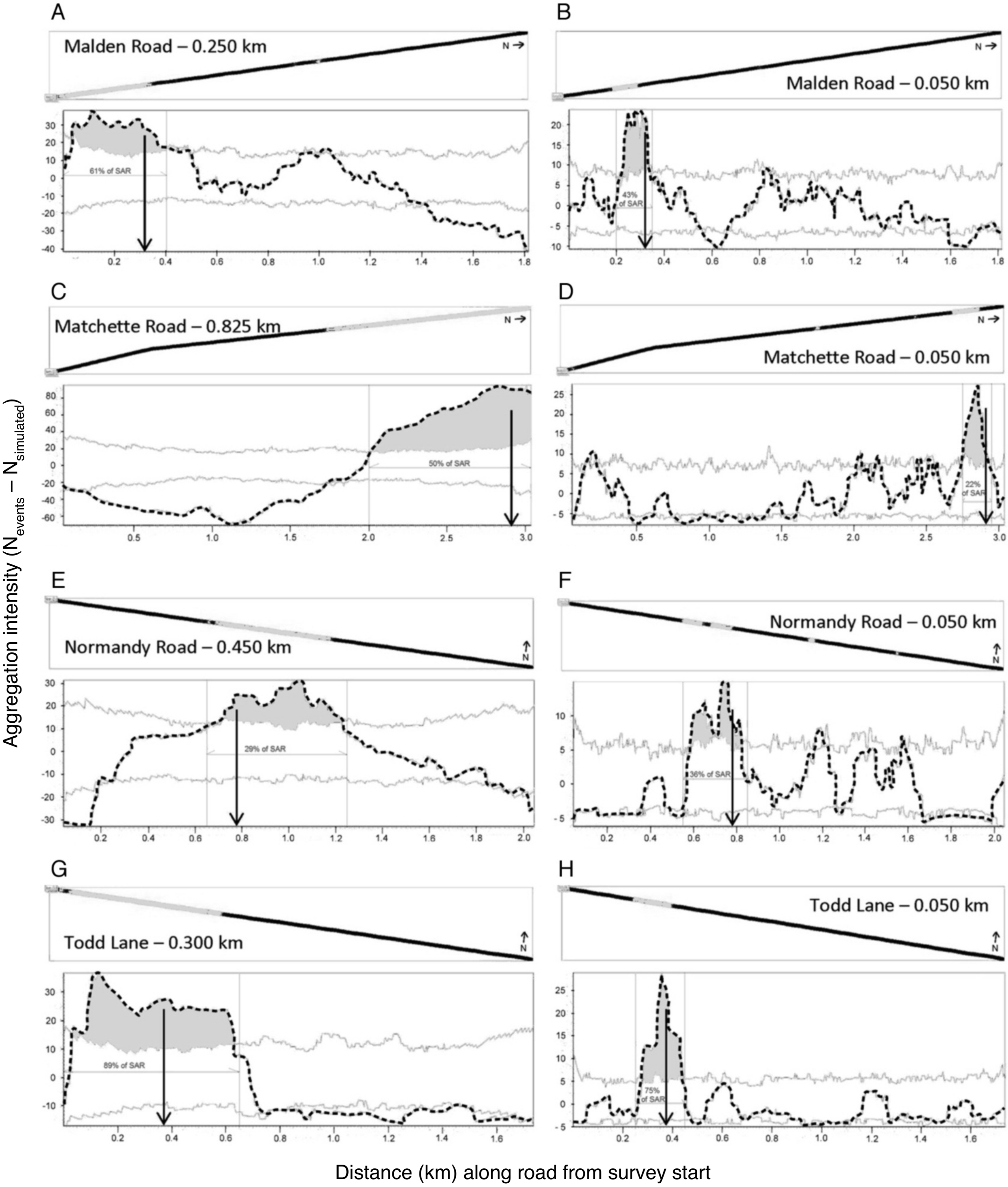

FIGURE 4. Hotspot analysis for significant spatial aggregations of reptile road mortality events recorded on four roads in the Ojibway Prairie Complex and Greater Park Ecosystem in Windsor and LaSalle, Ontario. In each graph, aggregation intensity ($N_{events} - N_{simulated}$) is a function of distance (km) along road from survey start (i.e., km 0.0), and 95% confidence limits are represented by light gray horizontal lines. Significant aggregations of road mortality events (i.e., hotspots) occur where the bold dashed line exceeds the upper confidence limit. Aggregations of greatest intensity are highlighted in light gray, and their approximate extent (to the nearest 0.05 km) is indicated by the light gray vertical bars. The proportion of species at risk (SAR) observations that occur within the hotspots (i.e., within the gray bars) is indicated. Above each graph, roads are depicted as a solid black line and segments with significant aggregations of road mortality events are represented in light grey. The scale of analysis (i.e., radii) is indicated next to each road name. Black arrows indicate the approximate location of the utility right-of-way intersection with each road. (Note: for Normandy Road, 50% of SAR records occured between km 0.550 and km 1.250)

Discussion

Limitations of this Study

We recognize three major limitations to our study: underestimation of the number of species found dead as well as mortality rates; overgeneralization of temporal patterns; and under-representation of spatial aggregations of roadkill.

Ours is not a comprehensive list of all vertebrates killed on roads in and surrounding the OPC. Considering the short time frame of our study, the fact that a large proportion (41%) of specimens we collected were not identified to species, and that we only recorded 17% of the approximately 301 vertebrate species known locally (City of Windsor 2013), it is likely that additional species are being killed on roads in the study landscape.

There is no doubt that the rates of road mortality that we observed are underestimates of the true mortality rates in the study landscape during our study. There are a number of reasons for this. First, most animals killed on roads are removed or obliterated within a day by scavengers, high traffic volumes, or other forces (Kline and Swann 1998; Clevenger *et al.* 2001; Hels and Buchwald 2001; Enge and Wood 2002; Smith and Dodd 2003; DeGregorio *et al.* 2011; Santos *et al.* 2011; Farmer and Brooks 2012), which could result in road mortality being underestimated by a factor of 12–16 (scavenging: Slater 2002, as cited by DeGregorio *et al.* 2011). Second, surveying by bicycle led to slight underestimates of mortality rates of small snakes compared with surveying on foot (S. Boyle, personal communication, 2013). Third, we did not survey for carcasses in roadside swales, where some animals killed on roads likely ended up (e.g., Dodd *et al.* 2004). Fourth, we did not estimate or correct for differences in detection rates between observers (i.e., observer bias). Finally, we surveyed only the arterial and collector roads in the study area, not the multiple "local" roads, on which Eastern Foxsnakes have been confirmed killed in 2010, 2012, and 2013 (P. Pratt, unpublished data).

The temporal patterns in road mortality that we observed after pooling data from all three survey years may not be representative of within-year patterns. However, more in-depth analyses of the data are hindered by unequal survey effort within years and, in 2013, a series of temporary road closures on our study roads. Regardless, the patterns we observed for snakes and turtles are consistent with the biology of these two faunal groups. For example, high mortality of turtles in May and June can be explained by adult dispersal during nesting and emergence of hatchlings that overwintered. Also, high mortality of turtles and snakes from August to October can be explained by emergence of neonates as well as snake dispersal to hibernation sites.

Additional aggregations of road mortality may remain undetected in the study landscape because of scavenging pressure, low sample size, or short length of study. Some hotspots could be "masked" if scavenging pressure is relatively high in those areas. After placing fresh snake carcasses, DeGregorio *et al.* (2011) found they were removed more often in certain habitat types (forested versus dune habitats). Also, Santos *et al.* (2011) found that lower traffic rates facilitate scavenger access to carcasses. Although scavengers are present in the study landscape (see Table 2), we did not conduct tests to determine how scavenging pressure is distributed along our study roads. Hotspots were not identified on three roads — Sprucewood, Armanda, and Spring Garden roads — likely because of low sample sizes. Furthermore, our analysis was conducted using data from only two full May–October periods, which might not be sufficient to identify all hotspots. Additional spatial aggregations may become apparent with a larger dataset that spans a longer time.

Impacts of Roads on Ojibway Prairie Vertebrates

Roads are a conspicuous cause of anthropogenic mortality of vertebrates, especially snakes and species at risk, in the OPC and Greater Park Ecosystem. The average snake road mortality rate of 0.21/km/day (assuming [384 DOR snakes] / [11.5 km per survey, on average] / [157 surveys]) is higher than those reported at other Ontario sites: 0.06/km/day at the Long Point Causeway, Port Rowan (Ashley and Robinson 1996), 0.15/km/day at Rondeau Provincial Park and Point Pelee National Park combined (Farmer and Brooks 2012), and 0.19/km/day at Dyer's Bay, Northern Bruce Peninsula (Reed and Mackenzie 2010).

We confirmed that seven reptile SAR are being subjected to road mortality at the OPC and Greater Park Ecosystem, and that mortality occurs on all major, and some local, roads in the focal area. During our study, we estimate that SAR were being killed on roads across the OPC at a minimum average rate of 19 individuals a month (assuming: [5.3 DOR/100 km surveyed] × [11.5 km surveyed/survey day, on average] = [0.61 DOR/day] × [30.7 days/month]). The population-level impacts of the rates of road mortality experienced by SAR in general, and each species in particular, remain unknown. Regardless, road mortality undoubtedly places additional pressure on small populations of reptiles already experiencing a wide range of threats and stressors as a result of inhabiting an urban landscape (Mitchell *et al.* 2008). Furthermore, management documents for at least two of these species highlight the need to address road mortality and habitat fragmentation across their range (Parks Canada Agency 2013; OMNR 2011).

A precedent has already been set for mitigating road mortality at protected areas across Ontario. For example, using today's SAR designations for reptiles (COSEWIC 2015), the diversity of SAR affected by roads at the OPC (seven) is equal to or greater than that observed at Long Point Provincial Park (seven SAR: Ashley and Robinson 1996), Rondeau Provincial Park (seven SAR: Farmer and Brooks 2012), Point Pelee National Park (four SAR: McKay and Brown 2007;

Farmer and Brooks 2012), and Bruce Peninsula National Park (four SAR: Eco-Kare International 2010; Reed and McKenzie 2010). Efforts to mitigate road mortality are complete or underway in all four of these parks. Our results provide insight into where and when similar mitigation efforts would have the greatest impact in terms of reducing road morality at the OPC and Greater Park Ecosystem.

Management Considerations

Mitigation measures would produce the greatest benefit for SAR and other reptiles if they are prioritized at locations where SAR road mortality is highest or during periods of peak mortality rates, or both. Our results suggest that the following four roads should be targeted: Malden, Matchette, Normandy, and Todd. At a minimum, the installation of physical mitigation structures (e.g., barrier walls or fencing), 150–300 m in length, at the intersection of each of these roads and the utility right-of-way, for a total of 850 m, would target road sections where, collectively, over a third of SAR mortality was recorded. If these structures were extended to 400–1000 m, depending on the road, for a total of 2650 m, mitigation measures would target road sections where just over half of all SAR mortality was recorded on these roads. Furthermore, there is an opportunity for mitigation measures along the four roads mentioned above to contribute not only to reducing road mortality, but also to increasing landscape connectivity for snakes and turtles.

The utility right-of-way that bisects the study landscape is managed to prevent development of a forest canopy, thus providing a continuous corridor of suitable open habitat for snakes, particularly in areas dominated by residential development or dense forest. Results from this road mortality study, in combination with previous habitat suitability modeling for Eastern Massasauga (Choquette 2011) and radiotelemetry data on Eastern Foxsnakes (S. Marks, personal communication, 2013), suggest that the right-of-way is either used as a movement corridor or has potential to function as a corridor for SAR snakes in the study area. Considering the importance of protecting and restoring connectivity in this fragmented landscape, mitigation work done on roads in the vicinity of the utility right-of-way should combine efforts to reduce road mortality and increase connectivity (e.g., diverting animals to newly installed, or existing culverts, with the use of barrier fencing).

In addition to permanent solutions, and to address the widespread nature of SAR road mortality, temporary mitigation measures (e.g., seasonal road closures, seasonal speed limit reductions, etc.) could be used during peak mortality periods for certain taxa and age classes, at a minimum, in June, September, and October, when relatively high mortality rates of snake and turtle SAR were observed. Efforts could be further extended to include May and August to cover additional periods of high turtle and snake mortality. Finally, the potential benefits to all vertebrate groups of permanent road closures or traffic speed reductions should not be overlooked (see Martinson 2009; Farmer and Brooks 2012).

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