Management and Conservation

Road Kill Hotspots Do Not Effectively Indicate Mitigation Locations When Past Road Kill Has Depressed Populations

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ABSTRACT Negative effects of roads on wildlife include mortality caused by attempted road crossings. The most common method to choose locations for road kill mitigation is to identify hotspots of current road mortality. We evaluated the effect of traffic volume on current road kill hotspots. We used a road kill survey to test for differential traffic effects on road kill by taxonomic group, controlling for effects of habitat. Anuran road kill was negatively related, whereas bird road kill was positively related, to traffic volume. The negative effects of traffic on the birds are at broader spatial extents than we measured, and effective mitigation could be directed by hotspot analysis at this scale. Decreased anuran road kill with increasing traffic volume could be caused by road avoidance or depressed populations, but focusing mitigation efforts on anuran road kill hotspots may ignore populations that have been reduced by past traffic-related mortality. Road kill hotspot analyses should therefore be used with caution when evaluating mitigation options, since when past mortality reduces populations (e.g., Bouchard et al. 2009, in this region), current road kill numbers can be smallest in precisely the sites with the greatest historical road impact on the population size. Sites with high traffic volume in locations where wildlife habitat is near the road, and particularly where it straddles the road, will often correspond with road kill hotspots, but instances where there is good habitat but low current road kill can indicate particularly important locations for mitigation to restore populations.

KEY WORDS anurans, birds, hotspot, road ecology, road kill mitigation.

The effects of roads on natural environments are varied and complex (Forman et al. 2003). One of the most obvious of these is elevated wildlife mortality from collisions between vehicles and animals. Effective investment in mitigation of this impact requires knowledge of where and why road mortality has particularly large effects on wildlife populations. Many studies have already shown negative effects of roads on wildlife population size or occurrence. Fahrig and Rytwinski (2009) conducted a comprehensive review of papers up to 2008 that addressed the effects of roads and traffic on animal abundance. Across 79 studies of 131 species and 30 species groups, they found that both positive and negative effects of roads had been reported, but that the negative effects outnumbered the positive effects by a factor of 5, and the non-significant effects by a factor of 2. For many groups, the most likely explanation for these negative effects is road mortality (e.g., Rosen and Lowe 1994, Fahrig et al. 1995, Aresco 2005, Steen et al. 2006, Summers et al. 2011).

The most common current approach to identify sites for installation of structures to mitigate road mortality (fencing, wildlife passages) is to identify the hot spots of current road mortality (e.g., Ramp et al. 2005, Seiler 2005, Beaudry et al. 2008, Litvaitis and Tash 2008, Langen et al. 2009). Road mortality hotspots are typically located where wildlife habitats are near to or straddle the road, thus bringing wildlife in frequent contact with the road. As such, they can identify the most appropriate sites for mitigation in situations where the populations have not already been reduced by road mortality. However, if road mortality has already caused population reduction, current road kill hot spots could be poor indicators of the most effective mitigation sites (Fahrig et al. 2001). In this situation, appropriate mitigation sites would be those where habitat is available and road traffic volume is high, irrespective of actual road kill numbers. In fact, installing mitigation in sites with few road kills but high habitat availability and traffic could restore wildlife populations and might therefore be the most effective mitigation sites.

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We attempted to determine whether road kills are positively or negatively related to traffic volume. We reasoned that, all else being equal (i.e., controlling for habitat and road age), if current population size is unrelated to past road kill, road kill numbers should be greater in sites with higher traffic volumes. Alternatively, if animals avoid the road or if road mortality has reduced populations, current road kill numbers should be lesser in sites with higher traffic volumes. In the latter case, identification of potential mitigation sites should not be based on areas of current high road kill.

We used a data set that was collected in collaboration with the Saint Lawrence Islands National Park of Canada (SLINP), as part of a monitoring program on the Thousand Islands Parkway in Ontario, Canada. The data included 80 days of detailed road kill surveys on the parkway, and traffic levels within defined segments of the parkway. We tested for differential traffic effects on road kill numbers by taxonomic group, using associated land cover data to control for effects of habitat.

STUDY AREA

The Thousands Islands Parkway is located between Brockville and Gananoque in Ontario, Canada. Although SLINP is largely made up of islands in the St. Lawrence River, it includes land in the greater park ecosystem on the mainland, and the parkway provides tourist road access to this area and many of the marina facilities serving the rest of the park. Several key habitats occurred within the landscape, including areas of wetland that are prime habitat for rare or at risk species including the northern map turtle (*Graptemys geographica*) and stink pot turtle (*Sternotherus odoratus*). The region is also located in an important conservation corridor known as "Algonquin to Adirondacks" (A–A; Fig. 1). Conservation efforts in this corridor attempt to maintain or improve habitat connections between Algonquin Park in Ontario, Canada and Adirondack State Park in New York, USA.

The road was a 37-km, 2-lane highway with a speed limit of 80 km/hour through most of the route, with a 1-km section where the limit was 60 km/hour. As presented below, traffic volumes vary significantly with respect to location on the parkway. Although the parkway is owned and operated by an independent body, Parks Canada Agency is mandated to maintain and protect ecological integrity of the greater park ecosystem; therefore, the agency seeks to minimize wildlife mortality on roads in this important corridor.

METHODS

Data Collection

We traveled the 37-km survey route by bicycle early in the morning, but after dawn, on each of 80 days between 14 April and 16 October 2008, which in this region covers the active season for all species. We identified each vertebrate killed on the road as closely as possible to the species level,

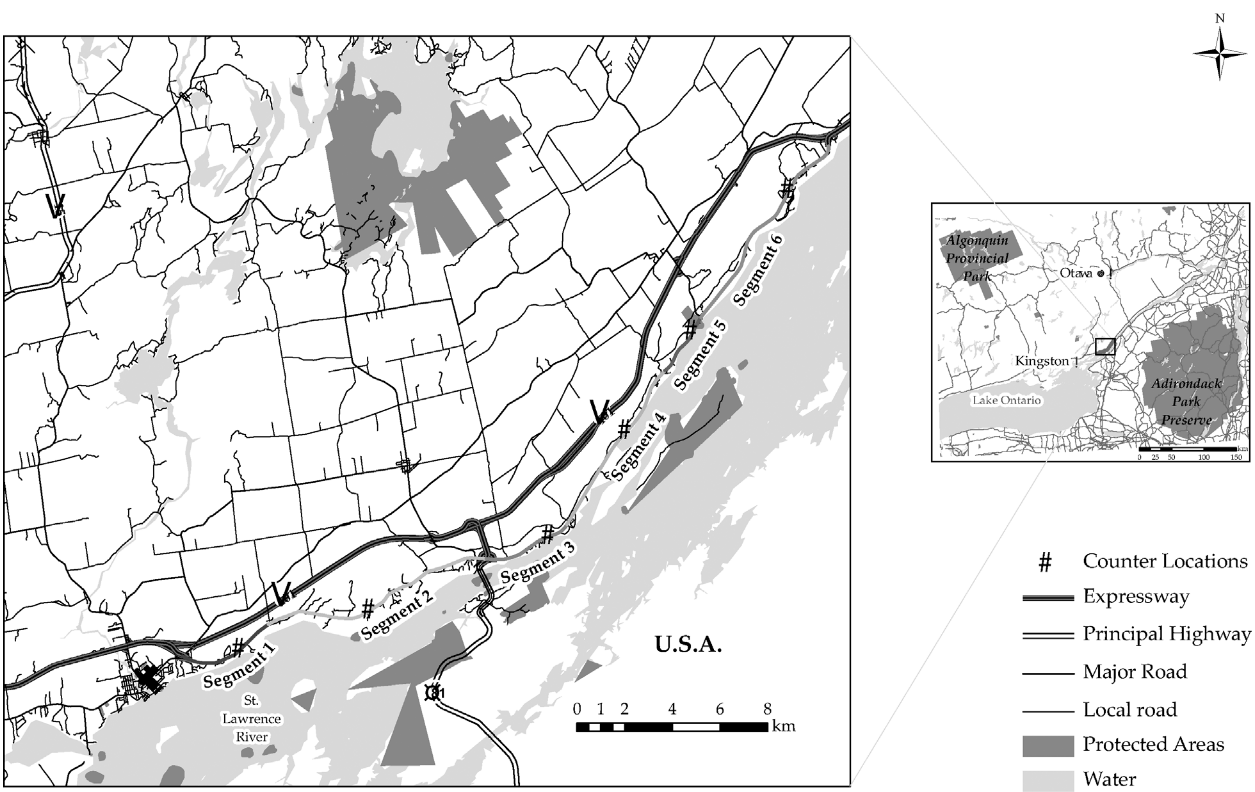

Figure 1. Location of study area, 2008. Key map shows relative location to Algonquin Provincial Park and Adirondack State Park in the Algonquin to Adirondack (A–A) conservation region; main map shows location of the installed traffic counters, the 6 traffic measurement segments on the Thousand Islands Parkway, Ontario, Canada and the highway connections between the busy multi-lane MacDonald-Cartier Freeway (Hwy 401) and a United States-Canada border crossing to I-81.

recorded its position on a hand-held computer with an integrated global positioning system (GPS), and then removed or flagged the road kill. At our request, local authorities did not conduct normal removal of road kill until we completed our surveys. To estimate persistence, or how long animals killed on the road remained there before being removed or cleaned by non-human means, over 6 test days we recorded all kills in a 10-km section, then returned to the same locations 24 hours later to check the detectability of the dead animal.

We installed 6 traffic counter units, 1 in each of the major road sections. We installed counters below the ground 0.5 m from the road and programmed them to capture vehicle crossings in both directions. We divided the road into the 6 segments based on the location of roads connecting the parkway to the parallel Highway 401, the busiest highway in our region (Fig. 1). In all analyses reported here, we used total vehicles per day passing through the segment, averaged over the study period.

In addition to our main predictor variable of interest (traffic volume), we collected information on other variables that might affect road kill numbers, so we could include these as covariates in our statistical models (below). We obtained landscape variables from the Southern Ontario Land and Resource Information System (SOLRIS version 1.2), a provincial land cover database with a resolution of 15 m and a positional accuracy of 30 m (Smyth 2008). From this database, we extracted estimates of built-up (urban features) area, building density, forest area, vacant land, water area, wetland area, and edge perimeter within 500 m of the parkway, all using the existing SOLRIS classes. We used Ontario Base Map data at a 1:10,000 scale to obtain an elevation model for the site. In addition, during our field surveys, we recorded the locations and characteristics (size, shape, integrity, and presence of water) of all 195 culverts that occur along the parkway.

Data Analyses

We conducted hotspot mapping using kernel density calculations on the road kill locations, in ArcGIS (version 9.3, ESRI, Redlands, CA). We calculated the network k-function (Ramp et al. 2005) with SANET (Spooner et al. 2004), providing significance analysis of spatial clumping with respect to distance. We used a roving window analysis to relate road kill numbers or presence–absence within 25-m windows to average daily peak road traffic in the road segment and landscape variables in the surrounding 500-m radius. Since the data were spatially dense along a single road, to decrease the potential for significance inflation from pseudo-replication, we adapted techniques from Holland et al. (2004) to conduct multiple candidate regression analyses on separate random non-overlapping samples of the full set of sites. We used the GRASS R interface (spgrass6 package version 0.6-27, http://cran.r-project.org/web/packages/spgrass6/index.html, accessed 15 Jul 2011) to randomly choose 10 independent subsets of the kill data (66–67 samples each) that had non-overlapping 500-m radius windows around the center of each kill measurement site. We performed generalized multiple linear regression on anuran (frogs and toads) mortality data because of the high data volume for that group, whereas we performed logistic regression on presence of kills data for all other groups, for each of the 10 subsets, against landscape data from 500-m windows around each kill measurement site. We tested average regression slopes from the 10 subsets for significant differences from zero, yielding an aggregate model for each taxon.

We performed spatial analyses in ArcGIS and GRASS (version 6.4, http://grass.osgeo.org, accessed 18 Apr 2010), and completed statistical analyses in R (version 2.13.1, http://cran.r-project.org, accessed 15 Jul 2011).

RESULTS

We located 6,682 kills, including 63 species, of which 3 were of "special concern" and 2 were "threatened" as designated by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Road kills by species group were 5,468 frogs/toads, 11 salamanders, 244 snakes, 128 turtles, 212 birds, 165 small mammals (chipmunks [*Tamias stratus*], mice [*Peromyscus maniculatus*], minks [*Neovison vison*], moles [*Parascalops breweri*], shrews [*Sorex cinereus*], squirrels [*Sciurus carolinensis* and *Tamiasciurus hudsonicus*], weasels [*Mustela frenata*]), 27 large mammals (beavers [*Castor canadensis*], foxes [*Vulpes vulpes*], porcupines [*Erethizon dorsatum*], raccoons [*Procyon lotor*], skunks [*Mephitis mephitis*]), 399 unknown, and 28 other (invertebrate or fish).

A large number of killed animals were likely missed by our surveys; our persistence tests showed that across all species, of the kills counted during the initial survey at time 0, only 37% persisted until the follow-up survey 24 hours later. We used this to make simple estimates of total kills across the season. Assuming uniform mortality throughout the day, and that all species could be identified at some point during a 24-hour period, a worst case estimate is that on average we only detect 37% of the actual mortality; therefore, the total observed kills can be adjusted up to 18,059 kills, or 226 kills/day. Further, assuming that this rate of kill applies on all non-survey days across the 186-day period, there could have been as many as 42,036 kills across the entire survey route and duration, or 5.1 kills per km per day.

The traffic volume along the 6 road segments varied between an average of 1,838 and 3,644 events per day for the 121 days that we collected hourly traffic data. Traffic volume in the eastern sections of the survey route was half that of the western sections (Table 1).

We found distinct clusters of kill zones, and these differed among taxa (hot spots of frogs and birds shown in Figs. 2 and 3; see supplementary material for all other groups and clustering analyses, available online at www.onlinelibrary.wiley.com). Most of the identified frogs and toads were located in the eastern, less traveled half of the parkway (79%, or 4,310 out of 5,468 kills, were found in road segments 3–6).

We developed multiple regression models of the effect of traffic on road kills while controlling for covariates (Table 2) only for anurans, birds, and small mammals because of insufficient data for the other groups. Anuran road kills (total

Table 1. Average daily traffic volumes on each segment of the Thousand Islands Parkway, 8 June 2008 to 8 October 2008, length of each segment, and segment averages of habitat variables measured in 500-m buffers around 25-m roving window locations along the parkway.

Segment	Average traffic volume (vehicles per day)	Length (m)	Mean habitat variables: Wet edge (m)	Built-up area (m^2)	Wetland area (m^2)	Distance to nearest culvert (m)
1	3,664	4,227	1,277	10,825	47,930	56
2	2,941	10,013	1,153	7,946	71,386	47
3	2,334	3,816	1,571	22,803	82,244	49
4	1,958	7,695	954	5,180	3,086	133
5	2,080	2,751	1,301	14,170	28,528	124
6	1,838	9,188	1,321	34,935	37,335	150

kills) consistently showed a strong negative relationship with traffic volume (max. daily vehicles, averaged over the study period). We found a weaker positive relationship with the amount of wet edge within the 500-m window (the average standardized regression coefficient was approx. half the magnitude of that for traffic volume, and was only selected in the models for three data subsets; $P = 0.002$). The presence of bird kills had a positive relationship with traffic, as well as with built-up area and wetland areas within the 500-m window. The only consistent predictor of small mammal mortality was a negative effect of distance to culvert; both positive and negative habitat influences were found in all traffic segments (Table 1).

DISCUSSION

We found a strong negative relationship between traffic volume and anuran road kills. This is consistent with Fahrig et al. (1995) who found fewer anuran road kills (but greater per capita road kill mortality) on roads with greater traffic volumes. Although concurrent population data were not available in the immediate study area, given that the main effect of roads on anurans is mortality and not road avoidance (Bouchard et al. 2009), this result suggests that the populations are likely depressed surrounding the western half of the parkway. In any case, it indicates that road kill hotspots should not be used to identify the best locations for road mitigation for anurans. An alternative approach is to locate mitigation measures where traffic volume is greatest and where anuran habitats are adjacent to the highway or, more importantly, where these habitats occur on both sides of the highway. According to our model results in the study area, these would be locations with wetland edges straddling the road, in the western part of the parkway where peak traffic volumes are greatest. Again, this is not where they would be sited if road kill hotspots were used, since the

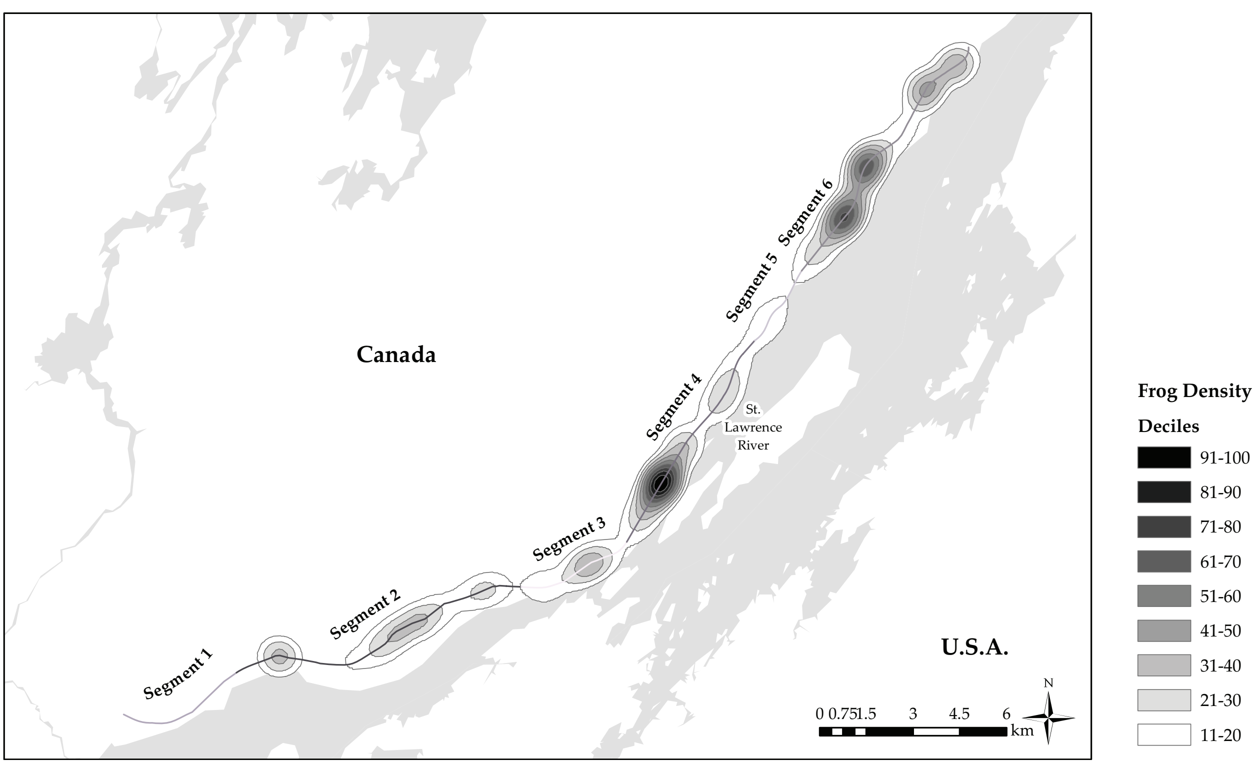

Figure 2. Distribution of frogs killed on the Thousand Islands Parkway, Ontario, Canada in 2008, and road segments used for collecting traffic data; hotspots identified using deciles of road kill density; numbers in legend refer to deciles of road kill density (i.e., 91–100 means greatest density of road kills).

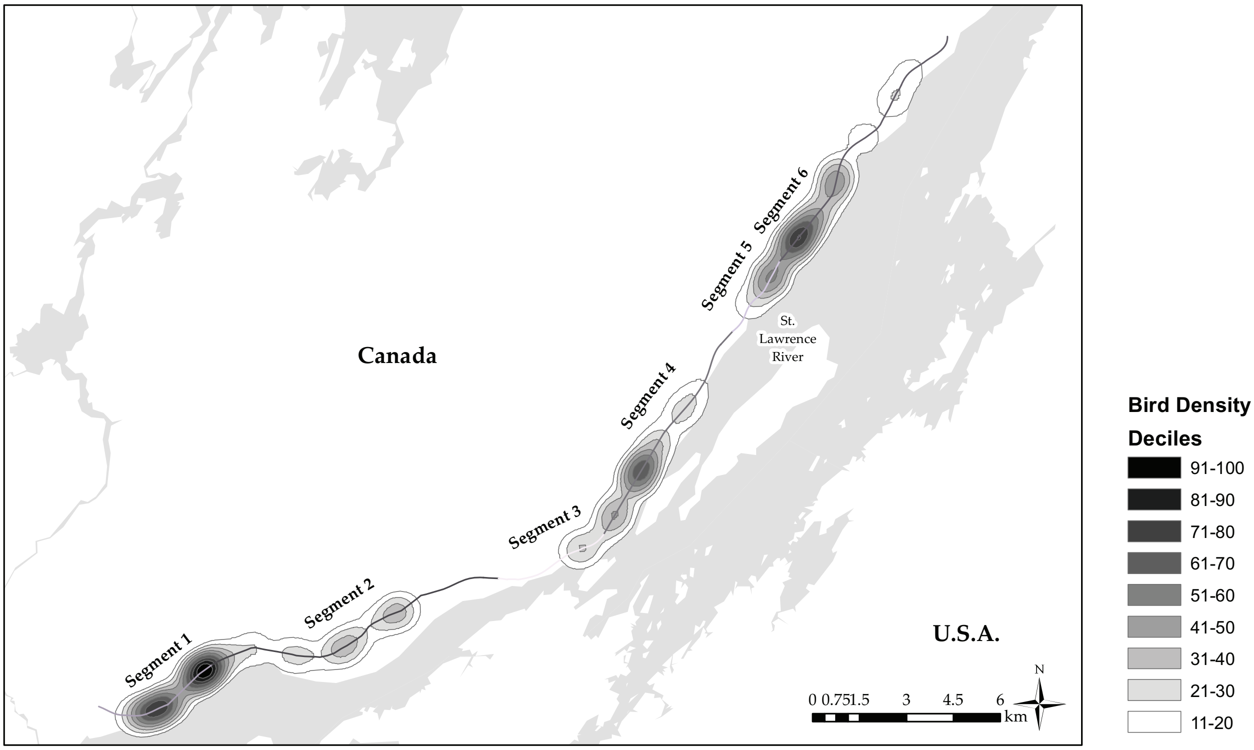

Figure 3. Distribution of birds killed on the Thousand Islands Parkway, Ontario, Canada in 2008, and road segments used for collecting traffic data; hotspots identified using decile ranges of road kill density; numbers in legend refer to deciles of road kill density (i.e., 91–100 means greatest density of road kills).

hotspots occur predominantly on the eastern sections (segments 3–6) of the parkway. Summarized habitat variables show that the western segments with high traffic have as much wet edge and even more wetland area as other segments (Table 1). We confirmed this qualitatively by ground experience, and by looking at aerial photographs (see Supplementary Material, available online at www.onlinelibrary.wiley.com).

In contrast to the anurans, we found a positive relationship between bird kills and traffic volume. Several authors have suggested that road mortality can affect bird population abundances, both at small extents within a breeding season (Mumme et al. 2000, Kuitunen et al. 2003, Summers et al. 2011) or over large areas (Orłowski 2005, 2008). Our study indexed road kill at a relatively local scale (within 25-m diameter areas), but the surveys included data well beyond the end of the breeding season. The positive relationship between road kill numbers and traffic volume suggests that over these spatial and temporal scales, birds are sufficiently mobile that local, short-term depressions due to mortality are replenished by other birds moving into or through the same area. The negative effects of this road mortality on bird populations are likely observed over a larger area than the 500-m radius of our analysis. These results imply that the most effective mitigation sites for birds would likely correspond to the bird road kill hotspots.

Small mammal road kills did not show any significant relationship with traffic volume. This is consistent with the many studies showing that small mammals generally avoid moving onto the road surface (Mader 1984, Swihart and Slade 1984, Burnett 1992, Ford and Fahrig 2008, McGregor et al. 2008), and that small mammal populations are therefore not negatively affected by road mortality (Johnson and Collinge 2004; Rytwinski and Fahrig 2007, 2011;

Table 2. Consistently significant relationships between standardized road mortality[a] on the Thousand Islands Parkway, Ontario, Canada in 2008 and traffic or habitat variables identified as a significant predictor in at least 3 of the 10 subsets of our data, all of which had to have a regression coefficient with the same sign (i.e., all positive or negative slopes).

Taxon	Variable	No. of subsets significant (out of 10)	Standardized regression coefficient ± 1 SD	t (μ <> 0)	P-value (1-tail)
Anurans	Daily average maximum traffic	10	−19.591 ± 3.457	−17.920	<0.001
	Wet edge	3	9.941 ± 7.490	4.197	0.002
Birds	Built-up area	3	12.518 ± 12.187	3.246	0.005
	Daily average maximum traffic	3	4.009 ± 2.609	4.860	<0.001
	Wetland area	4	13.519 ± 10.181	4.199	0.002
Small mammals	Log distance to nearest culvert	4	−4.275 ± 3.526	−3.834	0.002

[a] Mortality for anurans measured as total recorded kills, mortality for all other groups measured as presence or absence of kills, all within 25-m road segments.

Bissonette and Rosa 2009). The negative effect of distance to the closest culvert on small mammal mortality could suggest that more mammals are attempting to cross the road in the vicinity of culverts, but that they are not using the culvert to cross the road. This lends support to the idea that many animals move along waterways and that appropriate mitigation for small mammals may be culvert designs allowing dry passage of small mammals (reviewed in Glista et al. 2008).

MANAGEMENT IMPLICATIONS

We conclude that caution should be exercised in the use of road kill hotspot analyses for identification of appropriate sites for road mitigation. In particular, when past mortality reduces populations, current road kill numbers can be smallest in precisely the sites with the greatest road traffic volumes. For animals prone to population declines due to road mortality, rather than focusing on road kill hotspots for mitigation placement, we recommend priority should be on sites with high traffic in locations where wildlife habitat is near the road, and particularly where it straddles the road. Although these sites will often correspond with road kill hotspots, instances where they do not coincide can indicate particularly important locations for mitigation to restore populations that have been reduced by road mortality.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's web-site.

Figure S1. Density of frog kills using kernel range estimation (10 % category is high kill areas).

Figure S2. Density of toad kills using kernel range estimation (10 % category is high kill areas).

Figure S3. Density of salamander kills using kernel range estimation (10 % category is high kill areas).

Figure S4. Density of bird kills using kernel range estimation (10 % category is high kill areas).

Figure S5. Density of large mammal kills using kernel range estimation (10 % category is high kill areas).

Figure S6. Density of small mammals kills using kernel range estimation (10 % category is high kill areas).

Figure S7. Density of snake kills using kernel range estimation (10 % category is high kill areas).

Figure S8. Density of turtle kills using kernel range estimation (10 % category is high kill areas).

Figure S9. Spatial clustering of frogs using Network K-function.

Figure S10. Spatial clustering of toads using Network K-function.

Figure S11. Spatial clustering of birds using Network K-function.

Figure S12. Spatial clustering of large mammals using Network K-function.

Figure S13. Spatial clustering of small mammals using Network K-function.

Figure S14. Spatial clustering of snakes using Network K-function.

Figure S15. Spatial clustering of turtles using Network K-function.