Current and potential wildlife fatality hotspots along the Thousand Islands
Parkway in Eastern Ontario, Canada

by

Ewen Eberhardt, B.E.S (Hons.)

A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements of the degree of

Master of Science

Department of Geography and Environmental Studies

Carleton University

©

Ottawa, Ontario

Date 04.07.09

Abstract

The effects of roads on animal mortality are of increasing concern as environments are increasingly impacted by road development and traffic. This animal road kill study took place on the Thousand Islands Parkway, near St. Lawrence Islands National Park. The survey route was traveled by bicycle and over 6682 kills were located. There were 63 unique species identified, 3 were special concern and 2 were threatened as designated by the Committee on the Status of Wildlife in Canada. Data were analyzed using kernel density to visually identify hotspots, network K-function for statistical clustering, and roving window analysis to analyze relationships between road kill and various predictor variables including traffic volume. Although the landscape along the study route did not vary greatly, traffic volume was negatively associated with frog and toad kills, implying that populations have been depressed. Therefore, mitigation efforts should consider possible past habitats as well as current mortality hotspots.

Acknowledgements

I would like to thank Dr. Scott Mitchell for his supervision and Dr. Lenore Fahrig for helping guide the research and stimulate my interest in this subject area. Also, I would like to thank Parks Canada for funding this research. Specifically at Parks Canada, thanks go to Dr. Stephen Woodley, Josh Van Wieren and Marianne Kelly. Without the support of my family it would have been impossible to finish this research. This work also benefitted from NSERC Discovery Grant support to Dr. Scott Mitchell.

Table of Contents

Abstract	ii
Acknowledgements	iii
List of Tables	vi
List of Figures	vii
List of Appendices	x
1.0 Introduction	1
2.0 Examples of road kill studies	3
3.0 Review of wildlife species road kill	8
3.1 Point-by-point survey versus landscape modeling	9
3.2 Field data survey methods	11
3.2.1 Point-by-point survey data collection	11
3.2.2 Data recording	12
3.2.3 Predictor variable selection	13
3.3 Review of critical field equipment	13
3.4 Review of point pattern analysis and statistics	14
3.4.1 Kernel density	14
3.4.2 Network K-function	15
3.4.3 Statistical relationship techniques	16
4.0 Research questions	17
4.1 Predictions	17
4.2 Geographic context	18
5.0 Methodology	22
5.1 Data collection	22
5.2 Data analysis	30
6.0 Results	35
6.1 Summary of road kill	35
6.2 Spatial clustering of road kill by taxon	40
6.3 Significant relationships of taxon kill with predictor variables	56

6.4 Frog relationships of road kill with landscape spatial structure, controlling for traffic volume	62
7.0 Discussion.....	65
7.1 Error	69
8.0 Conclusions	72
9.0 References.....	74
10.0 Appendices	79

List of Tables

Table 1: Farmer (2007)'s predictor variables for species road kill study in two parks in Ontario, Canada

Table 2: Ramp et al. (2005)'s predictor variables from an animal road kill study in New South Wales, Australia

Table 3: Southern Ontario Land and Resource Information System (SOLRIS) land cover categories

Table 4: Independent landscape predictor variables (and source of information)

Table 5: Taxonomic study groups

Table 6: Taxon-specific results of wildlife road kill relationships with predictor variables (average of 10 random runs for 600 sites per taxon)

Table 7: Predictor variable correlation matrix from one random non overlapping selection of 626 neighborhoods

Table 8: Significant predictor variables for frog road kill, by road segment with traffic volume held out for the relationship

List of Figures

Figure 1: Study area map showing Algonquin to Adirondacks corridor; the large red arrow represents the A2A corridor between the two parks, the red circle represents the most narrow point of the corridor

Figure 2: Combined areas, standardized by road length, of wetland, water, and forest within 500 meters of the survey route, by road segment

Figure 3: Survey route: 37 km of parkway surveyed from A-B

Figure 4: Photograph from a road kill location of a 130 cm eastern rat snake May 26, 2008

Figure 5: Example of land cover categories using the Southern Ontario Land and Resource Information System along the western section of the study route

Figure 6: Traffic segments and counter locations along the study route

Figure 7: Example highlighting one 25 meter overlapping road kill analysis site and a 500 meter neighborhood on a background showing all 25 m sites and 500 m neighborhoods in the western area of the study area

Figure 8: Road kill species identification including total numbers killed

Figure 9: Total number of road kills collected by taxon including the category of unknown

Figure 10: Mean number of kills collected for 6 persistence test at time 0 and 24 hours later for a 10 km section of the survey route

Figure 11: Mean number of kills collected for 4 comparison tests between biking and driving for a 10 km section of the survey route

Figure 12: Density of frog kills using kernel range estimation (10 % category is high kill areas)

Figure 13: Density of toad kills using kernel range estimation (10 % category is high kill areas)

Figure 14: Density of salamander kills using kernel range estimation (10 % category is high kill areas)

Figure 15: Density of bird kills using kernel range estimation (10 % category is high kill areas)

Figure 16: Density of large mammal kills using kernel range estimation (10 % category is high kill areas)

Figure 17: Density of small mammal kills kernel range estimation (10 % category is high kill areas)

Figure 18: Density of snake kills using kernel range estimation (10 % category is high kill areas)

Figure 19: Density of turtle kills using kernel range estimation (10 % category is high kill areas)

Figure 20: Spatial clustering of frogs using Network K-function

Figure 21: Spatial clustering of toads using Network K-function

Figure 22: Spatial clustering of birds using Network K-function

Figure 23: Spatial clustering of large mammals using Network K-function

Figure 24: Spatial clustering of small mammals using Network K-function

Figure 25: Spatial clustering of snakes using Network K-function

Figure 26: Spatial clustering of turtles using Network K-function

Figure 27: Daily traffic volume for six road segments on the study route from traffic counters capturing hourly data for a duration of 121 days

Figure 28: Example of output for the frog kill model prediction in absence of population constraints by traffic volume, just east of Gananoque, the legend represents the estimated total number of frog kill for the survey duration given the effort of this study's survey

List of Appendices

Appendix 1: Road kill summary from the survey including: scientific name, common name, NatureServe Unique code, Provincial status, COSEWIC status and, number of recorded kills

Appendix 2: Taxon kill relationships with predictor variables from the average of 10 roving window analyses. Each analysis was calculated using multiple logistic regression using over 600 non-overlapping sites, across the study region.

Appendix 3: Frog kill relationships with predictor variables from each road segment from the average of 10 roving window analyses. Each analysis was calculated using multiple linear regression using non-overlapping sites across each road segment.

Appendix 4: Example logistical regression from one random non overlapping run of 626 sites for frogs for the whole study site

Appendix 5: Example linear regression from one random non overlapping run for 159 sites for frogs for road segment 1

1.0 Introduction

Biodiversity decline is a major issue in the 21st century. Over the last 5000 years the earth has been altered from natural to human dominated landscapes (Gutzwiller, 2002). Habitat destruction and modification by humans are the current leading causes of species extinctions. Maintaining biodiversity is important for numerous reasons including protecting healthy, functioning ecosystems that we, as humans, depend on, avoiding adverse implications for agriculture from loss of ecological services (e.g. pollination), and meeting the needs of the biomedical industry.

Road kill is one threat to biodiversity. The last century has experienced unprecedented growth in both road construction and automobile use. It has been estimated that roads have a direct ecological effect on over 20% of the United States alone (Forman, 2000). Road kill occurs when animals attempt to move across the road, generally during movements to breeding, wintering, or summering habitats, and are hit by vehicles (Aresco, 2005). Road kill is a function of various factors including animal movement patterns, driver behavior, and the structure of the road and landscape (Forman et al., 2003). In relation to conservation, it is reported that kill rates could be high enough to exceed natural causes of death from predation and disease (Forman et al., 2003).

Animal movement patterns are unique to each species; therefore, some species are more susceptible than others to being killed on a road. Small, slow moving organisms are at higher risk of road kill than larger species because of

their increased inability to avoid vehicles, their abundance, and lack of visibility to drivers (Ashley and Robinson, 1996). Studies have shown that amphibians, like the northern leopard frog (*Rana pipiens*), with a large home range (compared to other frogs) are more likely to come in contact with roads and have a greater chance of being killed (Carr and Fahrig, 2001). An animal can also be more exposed to road dangers due to certain habitat requirements, as seen with several species of turtles. The turtles come to the road edge to lay their eggs in the soft gravel, putting both the eggs and the adult female at risk of road kill (Forman et al., 2003).

Evidence suggests that in some areas that road kill has already significantly reduced local populations, in some cases resulting in local extinctions (Findlay and Bourdages, 2000). For example, increased traffic volume has been linked to areas that have lower amphibian road kill because the populations have been decimated (Fahrig et al., 2005).

After researching the relationship between high road kill zones and independent predictor variables, results can be modeled across the landscape to locate potential high road kill areas. This approach of finding current high road kill zones and modeling other locations with similar landscape configurations along the road could be the most effective means of mitigating road kill and restoring reduced populations.

Identification of high road kill zones is important for both conservation and motorist safety. The identification of landscape features related to hotspots can guide mitigation efforts and can, potentially, be applied in different geographic

locations. Standardized methodologies and data management systems should be used to gather data for each hotspot. The data and methods should be available for those that make decisions to mitigate wildlife road kill, both for conservation and motorist safety.

2.0 Examples of road kill studies

A range of studies has been conducted to determine various aspects of road kill. Given the variety, this review outlines a few of the studies that are particularly relevant to this research question.

Langen et al. (2007) evaluated animal road kill survey methods. One of their goals was to quantify the difference between driving, point counts and walking.

The driving method used two cars with 2 team members in each car. The study was conducted between the 13th of May and the 24th of July 2002, between 0503 and 1200 each day. They drove the study distance 23 times, with an average speed less than or equal to 46 km/hour. To measure inter-observer reliability, the 2 car teams drove on 11 pieces of the same road within 20 minutes of each other.

To evaluate the point count survey, locations were established at 2 mile intervals following the original starting site, which was always at the first highway sign after the origin of the highway. Each highway in the study area had at least 1 point count and a 50 meter transect was established at each point.

The walking survey established three transects varying from 910m to 385m. Transect locations were placed at known hotspots for road road kill. During 2002, each of the three transects were surveyed on 73 days. Inter-observer reliability was accessed by comparing results from the observers walking a 100 m stretch of road and comparing their results.

Comparing the tree methods, they found that driving surveys significantly underestimated overall road kill. More specifically, reptiles and amphibians were underrepresented, although they were able to identify an association between the locations of amphibian and reptile kills with proximity to wetlands. They further recommended that using a GPS would have rendered the extensive data collected by the surveys more useful because it would have allowed the use of a finer scale of spatial and statistical analysis.

Mazerolle (2004) researched the effects of traffic volume on amphibian abundance. He surveyed at night by driving, over an eight-year period (1995-2002), a 20 km stretch of road in Kouchibouguac National Park, New Brunswick. Mazerolle's research looked at the cumulative effects of traffic on the abundance of amphibians. He assessed the effects of small differences, 10-20 vehicles per hour, in traffic intensity and did not detect a trend of decreasing abundance of amphibian populations with traffic intensity. Overall, these results indicate that small increases in traffic intensity increased road kill but led to no change in abundance (Mazerolle, 2004). All driving was done alone in the dark and rain, which certainly would have affected his ability to detect road kill.

Fahrig et al. (2005) studied abundance of frogs in relation to traffic density. The study was conducted with sites in similar habitats but with differing traffic intensities. Live and dead frogs were counted per km and species abundance was calculated by estimating chorus intensities. Among the sites, the traffic intensities were grouped into three levels (annual daily average vehicle crossing): 500-3500, 5000-6000 and 8500-13000. They surveyed six times between 2030h and 2230h from the 25th of April to the 24th of May in 1993. They discovered a positive relationship between decreased number of dead amphibians and increased traffic intensity. This was counter to their hypothesis and raised the possibility that traffic intensity had already had a negative cumulative effect on the populations within the segments with higher traffic. They also found that abundance, as measured by chorus intensity, decreased with increased traffic intensity. The study suggested two means of reducing road kill: barriers and underpasses.

Ashley and Robinson (1996) studied wildlife road kill on the Long Point Causeway in Lake Erie, Ontario. The study focused on amphibians and reptiles, but data on other wildlife were also collected during the study. The causeway is 3.6 km long and the study was conducted during two different time periods, 1979-1980 and 1992-1993. They studied the relationship between roadside habitat and road kill using data collected from surveys conducted by bicycle or walking, three days a week between June and October. Kills were removed from the road after being identified to the lowest possible taxonomic group. The authors compared their study results from this wetland-dominated area, with

another study focused on a mixed hardwood habitat. They concluded road kill was greater along the wetland habitat and that amphibians and reptiles were the most vulnerable to being killed on the road by a vehicle collision. Amphibian kills were positively correlated with the proximity to wetlands and turtle kills were positively correlated with open water. Roadside habitat, time of day, traffic volume, seasonal patterns and life history were identified as the major associations with the susceptibility of a species to being struck by a vehicle. The authors discussed management considerations for road kill along wetlands. They also identified how difficult it was to assess the effects of kill on populations, but concluded that certain species numbers were probably being depressed through road kill.

Farmer (2007) studied the factors influencing road kill by collecting data in Long Point Provincial Park and Point Pelee National Park, in Southern Ontario. Data were collected for one season. Spatial and temporal factors were modeled to determine relationships between species road kill locations and other variables. The study examined each variable for significance and tried to determine which variables would make up the best model using genetic algorithms and hierarchical partitioning (Table 1). The study argues that reducing speed limits can reduce road kill.

Table 1: Farmer (2007) 's predictor variables for species road kill study in two parks in Ontario, Canada

<ul style="list-style-type: none"> • Road class with shade • Provincial Land cover • Environmental Land classification • Habitat Diversity • Curve 	<ul style="list-style-type: none"> • Rain • Road Speed • Traffic Volume • Max Temperature • Elevation • Shoulder Width • Intersection 	<ul style="list-style-type: none"> • Distance to cover • Road Density • Distance to water • Distance to wetland • Building density • Shoulder type
---	--	--

Ramp et al. (2005) used kernel density and the network K-function to find hotspots based on presence data. They also analyzed animal kill data for relationships to landscape predictor variables. Typically, landscape data are analyzed using a set distance from the road but this study used distances based on the home ranges of the five different species studied. They believed this was a better way of defining the environmental variables of concern.

Home ranges for the five study species were used as the neighborhood around each kill site. Based on the environmental variables chosen and the home range distances, models were developed to find road kill hotspots. Of the temporal variables, rainfall was the best predictor. Results demonstrated that spatial factors contributed more to the overall prediction of road kill than temporal factors. Distance to town and distance to water were the two spatial factors that best explained the most number of road kill.

Ramp et al. (2005) selected the variables listed in Table 2 using the criteria that they were:

1. Known from previous work to be related to fatalities,
2. Not factors that were specific to the study site,
3. Factors for which biologically important variation occurs over a scale that can be targeted in management, and
4. Factors not closely related to each other (to minimize co-linearity).

Table 2: Ramp et al. (2005)'s predictor variables from an animal road kill study in New South Wales, Australia

<ul style="list-style-type: none"> • Rainfall • Southern Oscillation index • Distance to the nearest town • Distance to the nearest gully 	<ul style="list-style-type: none"> • Elevation • Forest • Aspect • Curvature of the road
---	--

3.0 Review of wildlife species road kill

This study of wildlife road kill falls within the general research area of landscape ecology. For a study to be considered landscape ecology at least two key concepts need to be addressed and these concepts are used inconsistently within the field: landscape and landscape spatial structure (Wiens et al., 2007). Currently, there is debate as to the definition of 'landscape', as well as what constitutes 'landscape spatial structure'. For this research project, a 'landscape' is defined as 'a heterogeneous area, where the particular ecological question being asked determines the scale and description of that heterogeneity' (Fahrig, 2007). In this study, the landscape is comprised of the parkway and adjoining habitats and corridors that connect species to the parkway. Landscape spatial structure consists of landscape composition and configuration. For example, a

landscape's composition relates to the types of vegetative cover present, as well as the amount of each cover type. Landscape configuration could be spatial arrangement of the cover types within the landscape (Fahrig, 2007).

3.1 Point-by-point survey versus landscape modeling

Two main approaches can be used to identify areas of high wildlife road kill: point-by-point field data collection and landscape modeling. In most cases, the research question will determine which is the best method for conducting the study and certain studies will require a combination of the two approaches. Whichever approach is used, it is critically important that the research question is addressed in the least biased way possible and that financial and scale requirements of the project are met.

Point-by-point field data collection involves conducting road kill surveys in consistent, accurate and efficient ways. Consistency in methodologies between surveys is important if any comparisons are going to be made to other studies. Within a single survey, observer consistency needs to be evaluated to provide accurate reporting for the individual study (Langen et al., 2007). Accuracy in tracking the quantity of road kill sightings and accuracy of species identifications are equally critical. A unique aspect of road kill studies that needs to be accounted for is the variable persistence of carcasses of different species. For example, the leather from the turtles can be seen for weeks after being hit, while frog carcasses can disappear within hours (Langen et al., 2007). Depending on the spatial extent of the research area, different methodologies will be more or less efficient in addressing the issue of persistence.

Effort and timing are important factors in point-by-point surveys. Each species has different peak movement times that need to be considered. These movement patterns have various scales including daily and seasonal movements, and animals will also vary depending on weather conditions. Addressing these movement patterns is important in determining an accurate account of where animals are being killed and the relationships of these locations to landscape variables.

Landscape models, i.e. models relating species abundance to habitat qualities that vary in space, are useful to establish “hotspots” of abundance. The models can then be used to predict other hotspots in similar environments, or under different scenarios. Important variables in road kill landscape models include, but are not limited to: land cover, distance to open water and land use. In order to develop these types of models empirical data from studies in similar landscapes can be used and the results of modeling can be verified against actual road kill data (Ramp et al., 2005).

Determining whether to use a point-by-point survey or landscape modeling approach depends on the research question being asked. If the research question is designed to find the local distribution of road kill and landscape relationships, collecting field data is the preferred option; however, if the goal is to test and refine predictive models or to identify at small scales potential areas to investigate, landscape modeling is a preferred option (Ramp et al., 2005). This study incorporates the two methods in its aim to assess the current effect of

road kill on different species and to predict previous hotspots where populations have been lowered.

3.2 Field data survey methods

Identifying wildlife road kill hot spots can be accomplished through a variety of methods. These methods will have very important effects on the results. Beyond data collection, the way data are recorded is critical. The survey methods and data collection techniques should be driven by the research question.

3.2.1 Point-by-point survey data collection

Road kill data are typically collected using one of the following techniques: driving surveys, walking surveys or point counts. Each of the three methods has positive and negative features in relation to consistency, accuracy and efficiency.

Driving surveys cover more ground in a shorter period of time than other methods like walking; however, spotting road kill from a moving vehicle can be difficult. At a minimum, each survey team should consist of one driver and one spotter. Car speed needs to be kept low to spot road kill and once a kill is located, the team must stop for identification. By having multiple driving teams survey the same piece of road, results can be compared to ensure a high degree of accuracy. Lack of detection of road kill, particularly for small species, can lead to detection bias (Langen et al., 2007).

Walking surveys cover the least amount of ground per unit of time and require the most amount of physical labor. Walking surveys are the most

accurate at finding road kill. The limitations on how much time they take and the amount of distance covered make walking surveys a more viable option for the study of previously identified high concentration zones (Langen et al., 2007).

A point count method of collecting data involves selecting points along a road network and measuring road kill within a specified radius of that point. Points can either be randomly selected or established at equal intervals. At each point, a transect is delineated for a set distance in both directions (Langen et al., 2007). If the goal is to identify hotspots along a specific route, point counts could easily misrepresent what is occurring on the ground.

3.2.2 Data recording

Survey data can be recorded in a variety of ways to analyze road kill zones. The two most common methods are to record the numbers of road kill within a set distance of road and the other is by capturing spatial (e.g. latitude and longitude) coordinates for each location.

The majority of road kill papers reviewed calculated kills per kilometer (km) to assess the geographic component (Ramp et al., 2005; Mazerolle, 2004; Carr and Fahrig, 2001). This method of data recording does not allow the data to be analyzed using spatial point pattern statistics. Although there are few studies that collected precise geographic coordinates, those studies that did were able to use a large suite of spatial statistics during analysis (Ramp et al., 2005; Farmer, 2007). Given the small range of some species, capturing geographic locations appears to be the preferred recording method if the research question relates directly to these points.

3.2.3 Predictor variable selection

Collecting information on pertinent variables is an important aspect of a road kill study. The selection of variables should be determined by the taxon being studied, the research question and the specific landscape parameters present at the study site. Predictor variables could include factors such as proximity to water, area of habitat, elevation, and traffic volume.

3.3 Review of critical field equipment

The collection of species road kill data requires a variety of tools and technologies. Simple identification, measurement, and cleaning tools are necessary as well as more sophisticated instruments to determine geographical coordinates of road kill locations (global positioning system) and capture the volume of traffic.

Global positioning system (GPS) technology determines geographical coordinates through triangulation of measured distances between known and unknown points. The system calculates distances using radio signals sent between satellites and the GPS receiver. The satellite positions and the distances between them are known and by using this information, the receiver calculates where it is on the ground. Distance is determined by the length of time that the radio signals take to reach the receiver. Each satellite's unique 'pseudo-code' identifies it and its location. The delay is then multiplied by the speed of light to calculate distance.

There are a variety of ways to capture traffic data including manual counts, pneumatic tube and magnetic devices. Pneumatic tubes cross the roadway and

are attached to counters that register the change in pressure when a vehicle runs over the tube. Magnetic counters use technology to detect changes in magnetic state when large ferrous metal objects cross the sensing area, distorting the earth's magnetic field. For both these technologies, remote units can be installed below or above the ground and depending on the configuration and site selection the units can capture vehicles going in all directions.

3.4 Review of point pattern analysis and statistics

There are a variety of point pattern analyses and standard statistics that can be used to investigate road kill data to identify clustering visually and statistically as well as identifying relationships between road kill sites and predictor variables. Depending on the data collected and the focus of the study, techniques such as kernel density, network K-function and regression can be employed.

3.4.1 Kernel density

Kernel density is a moving window function, which weights points within the influence of the function by their distance to where the density is being calculated (Mitchell, 2005). The size of the kernel determines the area of influence. In order to use kernel density to identify high road kill zones, only presence data are needed (Ramp et al., 2005). Kernel density provides a good tool to visually identify clustering.

3.4.2 Network K-function

The K-function describes the dispersion of point features over a range of spatial scales (Ripley, 1976). The analysis examines the number of features or data points within defined distances and compares the number of features within these defined distances to multiple simulations of random distributions. This process identifies spatial clustering at various scales (Spooner et al., 2004). The analysis identifies whether or not points are significantly clustering compared to random distributions. Due to edge effects however, the patterns that result from this analysis are potentially misleading (Mitchell, 2005). Using the traditional K-function on networks can also lead to inappropriate results (Okabe and Yamada, 2001), but the network K-function modifies the statistic to work with distances along a network instead of in all directions.

The K-function measures all point to point distances, where a radius t is centered on each point and the number of points in the radius t are counted (Spooner, 2004). As the circle radius t changes, patterns can be detected as the observed patterns differ from expected patterns.

$$\lambda K(t) = E(\#(\text{Events within distance } t \text{ of an arbitrary event}))$$

$\#$ = number of events

$E()$ = normal expectation operator

λ = mean number of events per unit area

(for further details see Bailey and Gatrell 1995)

If K significantly deviates from complete spatial randomness the points are dispersed or clustered (Spooner, 2004). If K is above the upper 95 % level this

indicates that clustering is an important factor. If clustering is an important factor the data can be further analyzed to find relationships between kill locations and independent variables. Conversely if the observed values are no different than random values it would be difficult to link kill locations to landscape variables.

3.4.3 Statistical relationship techniques

Regression is a way of explaining a response variable with single or multiple independent variables (Freund et al., 2003). The systematic part of the variability is called the regression equation (Freund et al., 2003). A popular multiple linear regression technique is called least squares, which fits the best line between variables while minimizing the square of the residuals (Freund et al., 2003). The residuals are the difference between the best fit line and each predicted (y) value. Linear regression uses continuous data for the response and the data need to be normally distributed. If the response data are nominal, logistical regression techniques are used.

To make inferences about a model that was developed using regression analysis, the relationships between the predictor variables need to be understood, which can be quite difficult (McNally, 2002; Guthery and Bingham, 2006). The regression technique is generally used by ecologists or biologists for two purposes. The first is to assess the amount of variance in the dependent variable which can be attributed to each predictor variable. Secondly, the analysis is used to find the 'best' predictive model (McNally, 2002). The individual coefficients of a multiple regression model can be interpreted for direct

effects on the response variable when the other predictor variables are held constant (McNally, 2002).

4.0 Research questions

The aim of this research was to determine where along the Thousand Islands Parkway between Brockville and Gananoque, Ontario the current high vertebrate wildlife road kill zones are, and what the associations are between wildlife kills and hypothesized predictor variables (e.g. roadside vegetation, open water, wetlands, and traffic volume). If traffic volume affects abundance of amphibian road kills, can the variable be controlled for, in order to locate areas of low kill but high kill potential? This approach of finding current high wildlife kill zones and modeling for other similar landscape configurations along the parkway could be the best way to mitigate future road kill and help restore reduced populations. The goal was not to analyze individual species road kill patterns but a range of taxon road kill patterns.

4.1 Predictions

The research was designed to test the following predictions:

- there will be significant spatial and visual clustering of road kill, by taxon, and this clustering will be related to preferred habitat;
- statistically significant relationships will exist between high road kill zones, by taxon, and predictor variables

- traffic volume along the study route will be relatively consistent; therefore, traffic volume won't predict frog high kill zones

4.2 Geographic context

The Thousands Islands Parkway runs between Brockville and Gananoque in Ontario, Canada. The Parkway is located in an important conservation corridor known as Algonquin to Adirondacks (A to A) (Figure 1). There has never been a wildlife road kill study along this roadway, which bisects the conservation corridor at its most narrow point (Figure 1). St. Lawrence Islands National Park is situated in the middle of the A to A axis. The study area incorporates the section of the Parkway parallel to the densest portion of islands and the narrowest point in the A to A conservation corridor.

St. Lawrence Islands National Park is managed by Parks Canada. Parks Canada's mandate includes protecting and ensuring ecological integrity for present and future generations. To meet this goal, managers of National Parks must work within the greater park ecosystem to preserve and protect integrity. The park protects land on both sides of the parkway; therefore, it is important to understand more about the effects of road kill.

Figure 1: Study area map showing Algonquin to Adirondacks corridor; the large red arrow represents the A2A corridor between the two parks, the red circle represents the most narrow point of the corridor (base map courtesy of Google Maps, 2008)

The landscape cover along the length of the study area was relatively consistent (Figure 2); the combined areas of water, wetland and forest for six segments of the parkway, controlling for segment length, was relatively constant.

Figure 2: Combined areas, standardized by road length, of wetland, water, and forest within 500 meters of the survey route, by road segment

There is not a lot of curvature in the road as the parkway closely follows the St. Lawrence River (Figure 3). Within the landscape, there are also several key habitats, for example there are many areas of wetland that are prime habitat for several rare or at risk species including: the common map turtle (*Graptemys geographica*), considered provincially vulnerable in Ontario and imperiled in Quebec, and the stink pot turtle (*Sternotherus odoratus*), considered vulnerable in Ontario and critically imperiled in Quebec. The black rat snake (*Elaphe obsoleta obsoleta*) is considered vulnerable in Ontario and endangered nationally and has been observed on and along the parkway.

Figure 3: Survey route: 37 km of Parkway surveyed from A-B (base map courtesy of Google Maps, 2008)

The Thousand Islands Parkway is a paved, two lane road which has very little variation in elevation. The speed limit is 80 km/h throughout the survey route, except for a one kilometer section where the speed limit is 60 km/h. Road kill has been identified as one of the major problems for certain species including many types of turtles in this area (Bradford, 2003). As much as 50% of deaths, for certain species, have been attributed to road kill in this area (Bradford, 2003).

Understanding the effects of road kill on this study site has particular significance because of its location within the Algonquin to Adirondack (A2A) corridor. The conservation of this corridor is an attempt to maintain or improve the habitat connections between Algonquin Park in Ontario, Canada and Adirondack State Park in New York, USA. The extra resilience of being

connected is important for populations to maintaining biodiversity. The entire A2A corridor provides North-South passageways that are being threatened by continued development and therefore fragmentation.

5.0 Methodology

The research questions for this study include the need to determine road kill density patterns, identify significant spatial clustering and test for relationships between road kill and predictor variables. Based on these requirements, the chosen approach was to conduct a point-by-point road kill survey. A pedal bicycle was used to travel the 37 km survey route daily at a slow enough pace (approximate average speed of 15 km/hr) so as to avoid underestimating road kill. Spatial and statistical modeling were used to analyze relationships between taxon-specific kill zones and predictor variables.

5.1 Data collection

To identify high road kill zones along the study route, a survey was conducted between April 14, 2008 and October 16, 2008. These dates were chosen because the majority of road kill occur during movements to breeding, wintering, or summering habitats and these dates incorporate these periods. The data were collected for a total of 80 days.

Removal of road kill animals was coordinated with local authorities. The data were collected in the early morning, on average four days a week, to

minimize loss of data due to removal of road killed animals by other sources (predation, general public).

Persistence, or a dead animal's resistance to decay from environmental exposure or removal, was calculated for different species. This was determined by travelling 10 km by bike and recording the positions of kill, but not removing them. After 24 hrs, the same route was travelled and previously recorded kills were identified and recorded. This was conducted 6 separate times and an average persistence by species was calculated.

During the field season, 2960 km were surveyed by pedal bicycle (Figure 3) and 6682 mortalities were recorded. The location of each fatality was determined within 3-5 meters using a differentially corrected Global Positioning System (GPS) receiver (Trimble Nomad) with a mobile GIS (Environmental Systems Research Institute (ESRI) ArcPad, version 7.1). The field mapping tools expedited the process of recording information in the field and reduced transcription errors. Mortalities were identified to the species level where possible, and once counted, were removed from the road or flagged with paint. Kills of particular interest were photographed and linked to the geodatabase. An example photograph of a 130cm eastern rat snake (which is a COSEWIC threatened species) is shown in Figure 4.

Figure 4: Photograph from a road kill location of an eastern rat snake (130 cm length), May 26, 2008

Once the field data were collected, a Geographic Information System (GIS) database was developed for the study area. All of the road kill and other predictor variables were imported to or created within this system. Landscape variables originated primarily from the Southern Ontario Land and Resource Information System (SOLRIS version 1.2), a new provincial land cover database, with a positional accuracy of 30m and a pixel size of 15 meters (Smyth, 2008). SOLRIS represents a spatial layer of land cover inventories (Figure 5). Table 3 shows the classes that SOLRIS used to represent the land cover.

Table 3: Southern Ontario Land and Resource Information System (SOLRIS)

land cover categories

Land Cover	
<ul style="list-style-type: none"> • Open Cliff and Talus • Alvar • Open Shoreline • Open Bluff • Open Sand Barren and Dune • Treed Sand Barren and Dune • Open Tallgrass Prairie • Tallgrass Savannah • Tallgrass Woodland • Forest • Coniferous Forest • Mixed Forest 	<ul style="list-style-type: none"> • Deciduous Forest • Plantations - Tree Cultivated • Hedge Rows • Transportation • Extraction • Built-up Area Pervious • Built-up Area Impervious • Swamp • Fen • Bog • Marsh • Open Water • Undifferentiated

Figure 5: Example of land cover categories using the Southern Ontario Land and Resource Information System along the western section of the study route

The final predictor variables were selected based on previous research recommendations and focused on habitat and human use (Table 4).

Table 4: Independent landscape predictor variables (and source of information)

Independent variables
<ul style="list-style-type: none"> • Built up Area (SOLRIS categories: 44 and 45) • # Buildings (Ontario Base maps 1:10k) • # Culverts (Field Data) • Elevation (Ontario Base maps 1:10k) • Forest Area (SOLRIS) • Traffic Volume (Field Data) • Undifferentiated Area (SOLRIS) • Water Area (SOLRIS category: 66) • Water Edge (SOLRIS) • Wetland Area (SOLRIS categories: 50 to 63) • # Wet Culverts (Field Data)

All of the landscape variables were aggregated for a 500 meter neighborhood around each analysis site. Built-up area represents human developed structures such parking lots. Elevation, calculated as the average height above sea level within each 500m neighborhood, was chosen because the St. Lawrence River runs parallel to the study route and certain taxa might try to access the river at low elevation. Water edge is calculated from the length of the boundary of water within the area. Water, wetland, and forest areas represent

the sum of the areas within the neighborhood. The undifferentiated area in SOLRIS is a catch all for leftover groups, which in many cases include fields and grassy areas around houses.

Based on previous research, traffic volume was considered a potentially important predictor variable, specifically for amphibians (Fahrig, 2005). Traffic volume along the study route was recorded using six remote counting devices (TrafX Research Gen III, Canmore, AB). TrafX counters use microelectronic technology to detect changes in magnetic state within 6m (20ft) of the counter (TrafX Research, 2008) . The unit's main parts consist of a quartz clock, memory and a low-field geomagnetic sensor. The counters capture traffic 'events', which occur when a vehicle passes the counter. Changes are only detected for ferrous metal objects, which distort the earth's magnetic field. The change in state registers an event into the unit's memory along with a time stamp from the quartz clock. The units were installed below the ground 0.5m from the road and were programmed to capture events going in both directions. The study route was divided into six segments to analyze differences in traffic volumes along the study route. The division of the segments was based on traffic flow to and from Highway 401, which parallels the parkway (Figure 6).

Figure 6: Traffic segments and counter locations along the study route

Culverts were also considered a potentially important predictor variable and, therefore, specific surveys of culverts along the parkway were initiated. Culverts are important for wildlife because they can operate as tunnels under roads. They are generally placed for drainage and, therefore, often link wet vegetated ditches and other wetlands. These linkages often create vegetated pathways to and from the culvert locations and other natural landscape covers. Data were gathered concerning the shape, size (cm), location and presence /

absence of water in each of the 195 culverts. Culverts were located using the GPS receiver and photographs were taken from one end of each culvert.

5.2 Data analysis

A variety of analysis techniques were used to identify taxon-specific high road kill zones and their links to predictor variables. The road kill data were divided into nine different taxonomic groups (Table 5). These groups were analyzed separately because of their significantly different life history characteristics and the potential need for unique mitigation strategies. Also, priority might be placed on some type of wildlife mitigation over others therefore having the data broken apart into these groups might help in future efforts. For example, turtles travel at different rates of speed and through different habitat than white tailed deer; therefore, grouping data into easily identifiable units ensured any analyses would represent that unit's mobility and potentially habitat preferences. Data analysis for specific species beyond the units identified in Table 5 could be further refined because exact species names were recorded whenever possible. Spatial analyses were performed in ArcGIS (ESRI, version 9.3) and statistical analyses were completed in JMP (Statistical Analysis System (SAS), version 7.0.2).

Table 5: Taxonomic study groups

Taxonomic Study Groups		
<ul style="list-style-type: none">• Frog• Toad• Salamander	<ul style="list-style-type: none">• Bird• Mammal Large• Mammal Small	<ul style="list-style-type: none">• Snake• Turtle• Unknown

Once the spatial data were collected and divided, kernel density analysis was used to calculate density of road kill zones. Kernel density analysis was performed using the Animal Movement Software developed by Hooge (2002)(Animal Movement Extension, version 2.0). The analysis was specifically useful in visually inspecting and identifying areas of high kill density. The kernel density method creates a density map on a planar surface but in this case all of the kills are located along a network. It would be preferable to create a density surface on the network but given that the road was relatively linear and the toolsets were available the kernel density was used.

For the kernel density analysis, the bandwidth, or search distance, was set to 500m for all taxa (Ramp et al., 2005). This bandwidth was used because it corresponds to the neighborhood window used in the subsequent relationship analysis, which was considered suitable because of the mitigation potential at that scale. The software calculates a number for each cell from the average of all the cells in the bandwidth. The range of values from the density analysis was divided into intervals of 10. All of the values are then organized into the intervals and then mapped as polygons. The software was then used to build probability polygons representing the histogram of intensity for each taxon (Spooner et al., 2004).

To determine whether the wildlife kill points were significantly spatially clustered along the survey route, network K-function analyses were employed (Spatial Analysis on a Network (SANET), version 3.0). Each taxon's point distribution was compared to 100 Monte Carlo simulations (Spooner et al., 2004).

Various search radii (100m, 500m, 1000m, 2000m) for the network K-function analysis were explored and 1000 meters was selected because analyses at all these radii lead to very similar results and at that radius the processing time was reasonable. With the 1000 meter interval it was easy to identify where the clustering was occurring. The regular K-function analyzes point distribution for a planar surface but given this statistic was being used determined significance of clustering along a road network the Network K-function was utilized.

To determine significant relationships between road kill and predictor variables, three major analyses were performed. First, the predictor variables for the whole study route were analyzed for significance within each taxon using logistic regression. Secondly, because of the known susceptibility of frogs to traffic volume and the large amount of data, each road segment was analyzed independently to find common predictor variables among segments while controlling for traffic volume using linear regression. Lastly, a model was developed for potential frog high kill zones using the variables that were found to be significant when traffic volume was controlled. All non-spatial statistics (i.e. landscape variable analysis) were calculated with the JMP statistical package (SAS Institute Inc., Version 7.0.2)

There were 1481 overlapping 25 meter sites along the study route. Each site overlapped by 12.5 meters on to the next site (Figure 7).

Figure 7: Example highlighting one 25 meter overlapping road kill analysis site and a 500 meter neighborhood on a background showing all 25 m sites and 500 m neighborhoods in the western area of the study area

The 25 meter sites were used to calculate from the GPS survey data if kill(s) had occurred or not in that geographic area. Each of the 25 meter sites was buffered to create 500 meter neighborhoods to calculate landscape predictor variables. The 500 meter neighborhood scale represents a good scale to easily identify areas of concern along the study route for possible consideration in future road work. Once on the ground, it is easy to visualize and interpret the

results of a 500 m neighborhood to identify precise areas of potential road kill mitigation. All of the relationship analyses were calculated using a roving window analysis, between road kill mortality at the 25 meter sites and landscape variables within the 500 meter neighborhoods.

Random, non-overlapping samples of 25 meter sites were taken ten times and kill-landscape variable relationships were analyzed for each taxon (Jenness Random Selection, version 1.0). There were about 626 sites in each random selection. Holland et al. (2004) identified advantages to a similar analysis design: the technique maximizes the use of the data from the site level and the analysis includes many regressions so site selection is not affected by a particular site. The average from the logistical regressions of the slope of ten random runs for each taxon was analyzed for significance. Logistic regression was used because many groups only had presence/absence data available..

All of the variable distributions were plotted and visually analyzed. Built-up area, number of buildings, undifferentiated area and water area were log transformed to meet the requirements of normality for the analysis. All independent variables were analyzed for correlations to understand the multicollinearity problem between variables and all variables were below a correlation coefficient of 0.7, a cutoff used by Clevenger et al. (2003).

To further analyze the non-traffic related relationships between frog kill and landscape predictor variables, each road segment was analyzed for the same predictor variables as the previous analysis, but in absence of the effect of traffic volume (the variable was removed from the regression analysis).

Appendix 3 lists the number of sites in each of the road segments. The analysis used the same non-overlapping roving window analysis approach described above which averaged the slopes for 10 runs and analyzed for significance but used linear regression because there was sufficient frog road kill data within the 25 m sites to use abundance data instead of presence/absence. Once the important landscape predictor variables were identified, a model was created using the average slopes and then linked back to the original 25 m sites for visualization.

6.0 Results

6.1 Summary of road kill

During the survey period, 2960 km were covered by pedal bicycle and 6682 wildlife road kill were identified on the 37 km survey route. Among the 6682 road kill counted, 63 unique species were identified, and of these three were designated by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) to be of special concern and two were threatened. Figure 8 portrays the total kill by species common name where possible, and the grouping where exact identification was impossible. The total number of kills, scientific name, common name, provincial status (S-rank), COSEWIC status and NatureServe unique identifier, are provided in Appendix 1.

Figure 8: Road kill species identification including total numbers killed

The road kill data were aggregated into eight taxon groups including: frogs (5416 kills), salamanders (11 kills), toads (52 kills), birds (212 kills), large mammals (27 kills), small mammals (165 kills), snakes (244 kills), and turtles (128 kills) and unknown (Table 5). The largest road kill group was frogs which represented 81% of all kill points (Figure 9), followed by snakes which accounted for 4% of kills.

Figure 9: Total number of road kills collected by taxon including the category of unknown and other (e.g. non vertebrate butterfly)

Persistence rate was calculated 6 times, each one over a 24 hour time period, along a 10 km stretch of road. Of the kills counted during the initial survey at time 0, only 37% persisted until the follow up survey 24 hours later (Figure 10). Therefore a total kill estimate for the duration of the study, 186 days, is 35140 kills. This estimate is based on the average kill per day (79) adjusted to account for the average species persistence rate (37%) for non survey days (17081) and the adjusted actual kill for survey days (18059). The estimated kill divided by the number of survey days is 189 kills per day, or 5.1 kills per km per day. The accuracy of this estimation is limited to the ability to measure persistence, assumes a uniform mortality likelihood through the day, and does not account for species that are killed and disappear in less than a 24 hour time period. A kill could disappear due to a variety of factors, including removal by scavengers, damage from subsequent vehicles, or wet weather conditions.

Figure 10: Mean number of kills collected for 6 persistence tests at time 0 and 24 hours later for a 10 km section of the survey route

It has been documented that driving versus walking results in different road kill results (Langen et al., 2007); however, there are not published materials showing the difference between those methods and using a pedal bike. The ten kilometer distance was travelled on four separate occasions to determine the difference between biking and driving. First the route was travelled by car and then as soon as possible afterwards by bike, both times locating kills using the same protocol. As Figure 11 shows, driving detected 74% less road kill than biking.

Figure 11: Mean number of kills collected for 4 comparison tests between biking and driving for a 10 km section of the survey route

6.2 Spatial clustering of road kill by taxon

Kernel density analysis demonstrated that each taxon group exhibited some form of clustering which illustrated high kill density zones. Visual inspection of the resulting maps shows that east of Rockport and east of Mallorytown Landing were high road kill zones for seven of the eight taxon groups.

High frog kill density areas were all located in the eastern part of the study area at the following three locations: Jones Creek, east of Mallorytown Landing and east of Rockport. Of these, the highest kill density was situated in the zone east of Rockport. There were only three medium frog kill density zones west of the Hill Island Bridge (Figure 12).

Toad kill density followed a similar pattern to the frog kill density. High kill zones were located in the eastern section of the study area and the three zones identified as having high frog kill density also had high toad kill. The lowest of the three areas for toad kill is east of Rockport. There is only one high toad density zone in the western section of the study area, west of Hill Island Bridge (Figure 13).

Kernel density analysis identified the highest salamander kill density site as the area close to Jones Creek, which is located in the eastern part of the study area (Figure 14).

Areas of bird kill did not follow the same geographic trend as frogs, toads and salamanders; they were more evenly distributed along the study route. Four areas were highlighted by the kernel density analysis including: east of Mallorytown Landing, Rockport, Landon's Bay and just east of Gananoque. High bird kill density zones were spread over longer distances than the amphibian frog and toad kill zones (Figure 15).

Large mammal high kill density zones were compact compared to the bird locations. The four areas highlighted were Mallorytown Landing, Rockport area, Glenhouse Resort and west of Landon's Bay (Figure 16).

Small mammal kill zones occurred throughout the study area. The highest density zone occurred near Rockport (Figure 17).

Snake kill zones were dispersed throughout the study area (Figure 18), and the highest kill density area was located east of Rockport. This zone is 4 km in

length and pronounced. There is a visual consistency when looking at locations of high frog kill zones and high snake kill zones.

Compact turtle kill zones also occur throughout the study area (Figure 19). The highest turtle kill zones take place in the western section of the study area. The two highest areas are associated with Landon's Bay and east of Gananoque.

Figure 12: Density of frog kills using kernel range estimation (10 % category is high kill areas)

Figure 13: Density of toad kills using kernel range estimation (10 % category is high kill areas)

Figure 14: Density of salamander kills using kernel range estimation (10 % category is high kill areas)

Figure 15: Density of bird kills using kernel range estimation (10 % category is high kill areas)

Figure 16: Density of large mammals kills using kernel range estimation (10 % category is high kill areas)

Figure 17: Density of small mammal kills using kernel range estimation (10 % category is high kill areas)

Figure 18: Density of snake kills using kernel range estimation (10 % category is high kill areas)

Figure 19: Density of turtle kills using kernel range estimation (10 % category is high kill areas)

The network K-function analysis determined whether the kill points along the survey route were clustered or random in nature. Contrary to the hypothesis, not all taxa exhibited significant spatial clustering. The taxa that appear to be randomly distributed were small and large mammals.

Figures 20 through 26 plot $K(t)$ of the observed survey data by taxon against complete spatial randomness (CSR) determined by Monte Carlo simulations. If observed $K(t)$ is higher than the upper 95% window around the CSR the data are determined to be significant clustered at that spatial scale.

Frog kills were clustered at all spatial scales (Figure 20). The SANET tool has limitations on the number of points that can be processed. The frog kill dataset, due to its size, was the only taxon in which the analysis could not be completed on the raw data. Instead, ten random samples were taken and the average results are presented in Figure 20.

Toad kills clustered throughout the study range as well, with a curious dip at the 5 km scale (Figure 21). The dip in the observed features does not go below the level of CSR, therefore toads appear to be clustering at all spatial scales.

Bird kill showed significant clustering up to the 5 km spatial scale (Figure 22). Past the 6 km scale the bird data showed significant dispersion.

Large and small mammal kill presented complete spatial randomness (Figure 23 and 24). There were a few spikes in large mammal kill densities, but they were not above the upper 95% limit of the random distribution. Observed small mammal kill almost exactly followed the CSR curve.

Observed snake kill showed clustering at all scales (Figure 25).

Turtle kill shows clustering up to the 7 km scale and CSR at broader scales (Figure 26).

Figure 20: Spatial clustering of frogs using Network K-function

Figure 21: Spatial clustering of toads using Network K-function

Figure 22: Spatial clustering of birds using Network K-function

Figure 23: Spatial clustering of large mammals using Network K-function

Figure 24: Spatial clustering of small mammals using Network K-function

Figure 25: Spatial clustering of snakes using Network K-function

Figure 26: Spatial clustering of turtles using Network K-function

6.3 Significant relationships of taxon kill with predictor variables

Kill sites by taxon were not always simply related with habitat landscape variables. Turtles were the only taxon to exhibit a simple positive relationship between habitats and kill locations. In this case, there was a positive relationship between kill locations and wetlands.

The traffic volume along the six road segments varied between an average of 1838 and 3644 events per day for the 121 days hourly traffic data were collected. Figure 27 displays the daily traffic volume for the 121 days for all of the traffic counters (see Figure 6 for the locations of the counters). The average traffic volumes were: segment 1: 1838, segment 2: 2080, segment 3: 1958, segment 4: 2334, segment 5: 2941 and segment 6: 3644. Traffic volume was half the amount in the eastern sections of the survey route as in the western sections. The large variation in volume was not expected when designing the study. There are a variety of potential reasons for this difference. Spatial patterns of residential land use seemed to be similar throughout the study route. One potential explanation is that traffic from Highway 401 might be using the first section of the study area to get to the Hill Island Bridge en route to the United States. There are also a lot of marinas west of Hill Island, and people from the west might be travelling on Highway 401 until they can exit onto the parkway to have quicker access to those marinas.

Thousand Islands Parkway Traffic Counters: Daily Composite Charts
 April 11, 2008 to October 10, 2008: 121 days

Figure 27: Daily traffic volumes for six road segments on the study route from traffic counters capturing hourly data for a duration of 121 days

One hundred and ninety five culverts were located along the parkway. For some culverts it was impossible to find both the ends because they were buried in rock or other debris. Some of the qualities gathered about each culvert were included in the subsequent landscape analysis.

The specific significant variables and the directions of the relationships for the landscape analysis of all taxa are presented in Table 6. Appendix 2 lists all the relationships evaluated from the 10 sets of non-overlapping sites, including those that failed to show significance. All correlations between the independent variables were analyzed and the two highest correlations were: forest area and elevation (+0.64); water area and wetland area (-0.54) (Table 7). Neither correlation was above the arbitrary cutoff for reducing multicollinearity used by Clevenger et al. (2003) of 0.7.

Table 6: Taxon-specific results of wildlife road kill relationships with predictor variables (average of 10 random runs for 600 sites per taxon)

Kill	Builtup Area	# of Buildings	# of Culverts	Elevation	Forest Area	Traffic Volume	Undifferentiated Area	Water Area	Water Edge	Wetland Area	# of Wet Culverts
Frogs						(-)			(+)		
Toads						(-)		(-)			
Birds					(-)	(+)		(-)			
Large Mammals											
Small Mammals											
Snakes				(-)	(+)				(+)		(+)
Turtles										(+)	

(+): significant positive relationship at $p = 0.1$ level

(-): significant negative relationship at $p = 0.1$ level

Table 7: Predictor variable correlation matrix from one random non overlapping selection of 626 neighborhoods

	Builtup Area	# of Buildings	# of Culverts	Elevation	Forest Area	Traffic Volume	Undifferentiated Area	Water Area	Water Edge	Wetland Area	# of Wet Culverts
Builtup Area	1										
# of Buildings	0.4898	1									
# of Culverts	0.0187	-0.1328	1								
Elevation	-0.2778	-0.1183	-0.1737	1							
Forest Area	-0.3381	-0.1729	-0.0493	0.6403	1						
Traffic Volume	0.0084	0.0993	-0.5533	-0.0628	-0.056	1					
Undifferentiated Area	-0.1517	-0.2492	-0.0538	-0.1119	-0.2511	0.1223	1				
Water Area	-0.1049	0.1758	-0.2583	0.195	0.1634	0.2106	-0.1684	1			
Water Edge	-0.053	-0.0364	0.2351	-0.4234	-0.3642	-0.0404	0.0496	0.0689	1		
Wetland Area	0.0553	-0.1725	0.465	-0.5381	-0.454	-0.3045	0.092	-0.6168	0.4183	1	
# of Wet Culverts	0.1689	0.0294	0.5238	-0.2809	-0.2549	-0.4237	-0.0336	-0.3495	0.2285	0.5407	1

The negative association of frog kill with traffic volume could represent the lag effect of population decrease due to traffic volume increase. Higher water edge is associated with lower elevation, where water accumulates, which makes sense for areas of high frog kill.

The negative association of toads with traffic volume could be due to the same population removal effect as noted for frogs. Lower water area is associated with higher wetland area, which is a sensible habitat constraint for toads.

Bird kill associations make sense in terms of bird mobility. Birds were killed more often in areas with low forest cover, low water area, and higher traffic volume. Cluster analysis reveals that bird kills were dispersed at scales greater than 7 km, a pattern not seen in other taxa. Their ability to move over relatively large distances likely shields them from long term effects of traffic in specific locations, so they do not experience the local population decimations seen in lower mobility organisms such as frogs.

Small and large mammal kill were not significantly related to any of the landscape variables.

Snake life characteristics support the kill associations identified in Table 6. Snakes killed are in low lying areas, near vegetated areas (forest), and near water areas and wet culverts. Turtles were simply related to wetland habitat.

6.4 Frog relationships of road kill with landscape spatial structure, controlling for traffic volume

Traffic volume was negatively related to frog and toad road kill (Table 6). This suggests lower overall amphibian frog and toad abundance where higher traffic volume occurs. The frog dataset was by far the most robust due to high numbers of observations (Figure 9). After controlling for traffic volume, the relationships of three variables remained the most consistent through all six road segments: number of buildings (-), built up area (-) and number of wet culverts (+). Appendix 3 lists all relationships tested, including those that failed to show significance. The summary of key independent variables for frog kill divided by road segment is presented in Table 8. Multiple linear regression was used to develop a predictive model using frog kill abundance. The average slopes from 10 random runs using multiple linear regression of the 3 variables were used to develop the model: The model is $6.8546 + (-0.0486 * \text{Built up Area}) + (-0.6404 * \text{Buildings}) + (2.17 * \text{Wet culverts})$.

Figure 28 shows an example of model predictions of frog kill in absence of population constraints, east of Gananoque, where mitigation efforts could be made to attempt population re-establishment.

Table 8: Significant predictor variables for frog road kill, by road segment with traffic volume held out for the relationship

Road Segment	Built up Area	# of Buildings	# of Culverts	Elevation	Forest Area	Undifferentiated Area	Water Area	Water Edge	Wetland Area	# of Wet Culverts
1	(-)			(-)			(+)		(+)	
2						(-)	(-)			
3		(-)	(-)							(+)
4	(-)	(+)								(+)
5		(-)						(+)		
6		(-)		(+)						

(+): significant positive relationship at $p = 0.1$ level

(-): significant negative relationship at $p = 0.1$ level

Frog Kill Model

Figure 28: Example of output for the frog kill model prediction in absence of population constraints by traffic volume, just east of Gananogue. The legend represents the estimated total number of frog kill for the survey duration given the effort of this study's survey.

7.0 Discussion

The locations of high road kill zones and their spatial distributions were different for each taxon group analyzed. The interactions between landscape variables and kills were complex in time and space. It is easy to assume wildlife road kill will be linked to habitat but the relationships between kill sites and predictor variables were much more complicated in this study.

The study area has similar characteristics along the entire length but there are some important differences. The western portion of the study area ends at the edge of Gananoque and there are two large marinas and one golf course between Gananoque and the Hill Island Bridge. Although there are houses all along the parkway there is more built-up area at the edge of Gananoque. There is a marinas east of Rockport and this location consistently comes up as a high kill density zones across many taxon. The only gas station is also in the eastern section of study route east of Rockport. There are many large wetlands and forested areas along the entire study area. The speed limit is constant except a 0.5 km section of 60 km/hr and the road has very low curvature or elevation change.

High frog road kill zones were focused in the eastern part of the study area. The densest zones were east of Rockport and east of Mallorytown Landing. The frog kills were significantly clustered at all spatial scales. Frog kills were significantly positively correlated with water edge and negatively related to traffic volume. Given traffic volume was significantly different on the six road

segments along the study route, yet habitat existed there, this relationship could be the presentation of the prolonged exposure of frog populations to high traffic volume. When traffic volume was controlled for in each of the segments the number of buildings and built up areas were negatively associated with frog kills and the number of wet culverts were positively associated with frog kill locations. A method that could help restore reduced populations is to use the predictor variables that remained constant to find potential road kill in absence of population depression. Mitigation of areas of low kill but high kill potential could be one of the best ways to create an increased number of healthy local populations. Any mitigation strategy for frog road kill should look at this method to identify high potential areas as well as the current high road kill areas.

Toad road kill was only located in the eastern section of the study area. The two densest areas were just east of Mallorytown Landing and Jones creek. There was a high area east of Rockport with lower but still notable road kill density. Toad kills were significantly clustered at scales up to 5 km and then again at smaller scales beyond 10 km. When examining the density maps for toad kills the 5 km scale stands out. Similarly to frogs, toad kill locations were negatively associated with traffic volume. Toad kills were also negatively associated with water edge. This could be explained by the fact that where there is more water area, there are fewer habitats like wetland or forest where depending on the species and time of year one would expect to find toads.

There were only 11 salamander kill locations located during the entire study. The density of these locations was centered on Jones creek and one less

dense spot east of Rockport. The spatial clustering and relationship analyses were not completed on this taxon because of the low numbers, but it is interesting that like many of the other taxa, the Jones Creek and east of Rockport show up as important locations.

Bird kill locations were much different than any of the other taxa. The densest areas of bird kill were in the western portion of the study area, west of Landon's Bay. There were also dense areas east of Rockport and east of Mallorytown Landing. The density zones were also quite elongated compared to other taxa. Bird kill points were the only group to show significant spatial clustering to a certain scale and then change to a dispersed distribution. Birds clustered up to the 5 km spatial scale and this is very evident on the density maps. Bird kill locations were negatively associated with water area, forest area and positively associated with traffic volume. Birds were the only taxon group to be positively associated with traffic volume. Local bird population numbers are probably not affected by road kill because they are much wider ranging than other species such as frogs, therefore where there is more traffic volume it is logical there will be more road kills.

Small and large mammal kill locations were not significantly clumped but exhibited complete spatial randomness. The mammal kill locations also did not have any significant landscape relationships. It makes sense that if there were not any significant spatial clustering it would be more difficult to identify landscape relationships. Small mammal kill density analysis showed a very elongated density pattern along the study area. The large mammal road kills had

high density zones east of Landon's Bay, west of Rockport and near Mallorytown Landing.

Snake road kill exhibited very distinct spatial clustering. Snake clustering typically occurred in similar areas to the frog kill. A partial explanation of this could be the predator- prey relationships between the groups. The densest zones for snake kill were east of Rockport and east of Mallorytown Landing but there were many dense areas along the study route. Snake kill zones were clustering significantly at all spatial scales. The snake kill locations were negatively associated with elevation and positively associated with forest area, water area and the number of wet culverts. It makes sense that snakes that were crossing the road from the river side used lower elevation points to start their journey. It is also rational to think that when possible snakes would use the wet culverts because they were at low elevation points and probably connected to the river.

The simplest landscape relationship to all taxon was the kill locations of turtles to the wetland area predictor variable. Turtle kills also showed a very distinct clumping density pattern. The kills points were significantly clumping up to the 5 km spatial scale. The densest zones for turtle kill were both in the western portion of the study area just east of Landon's Bay, although there were numerous distinctive clumping zones across the entire study area.

The current total kill estimate for this study equates to 5.1 kills per km per day which seems reasonable given Glista et al 2007 calculated an average of 7.1

kills per km per day after an intense effort of 496 surveys in a more southern latitude of Indiana, USA.

If mitigation of road kill occurs, it needs to take place not only in the current areas of high kill but in areas where populations may have already been decimated due to the effects of traffic volume. This could then help restore reduced populations which would help the overall health of the species by providing more local populations.

7.1 Error

As in most studies, this work was subject to various types of potential error that influence the validity of the results. Efforts were made to limit these errors during study design, data collection, analysis and interpretation.

Data were only collected for one season and 2008 was a late spring with a lot of precipitation. The yearly climatic conditions could have influenced the results; for example by providing more amphibian habitat along the road in the ditches and increased usage of culverts.

Many decisions were made when initially designing the study that could lead to some degree of error. The study falls within certain constraints, including time, effort and budget. Given that the study was conducted during a single year, we cannot be certain that this shows typical animal road kill patterns. Moreover, the survey route was travelled in 24 hour intervals, which may limit the ability to measure species with less than 24 hour persistence.

Due to feasibility constraints, the survey route was always travelled east to west starting early in the morning and finishing early afternoon. There is potential that this affected the number of kills sighted for a variety of reasons, including the fact that the surveyor was always on the right side of the road and that the lowest traffic volume segment was always surveyed in the early morning.

Species identification was a source of potential error. Identification proved challenging depending on the level of decay of the individual animal, the size of the animal, and the surveyor's expertise. The road surface was similar throughout the study area, but the western sections of the road did present more of a problem with identification because of a darker road surface. In order to minimize inaccuracy in identification, photos were taken of individuals that were difficult to identify, and then shared with other wildlife experts.

There is a certain amount of spatial uncertainty when locating a road kill's geographic coordinates. The GPS data were collected using differentially correction technology to minimize spatial distortion, and the resulting resolution (± 5 m), is judged suitable for the subsequent analysis, especially given the resolution of the land cover data (below). The handheld mobile GIS software helped minimize data transcription errors (ESRI ArcPad, version 7.1).

The landscape variables were mostly derived from SOLRIS data which has a 30m spatial accuracy and is susceptible to classification errors (Smyth, 2008), both due to the resolution of the original data and standard classification issues.

The Ontario Base Mapping (OBM) data showed far fewer culverts than were actually on the ground. OBM data are based on air photos and mapped 1:10k scale. The OBM transport point layer has 75 points representing culverts for the study area, therefore the culvert survey represents a significant addition to the overall database. For some culverts it was difficult to find both the south and north ends. The culvert data were located with sub 10 m accuracy; however, it is possible that we might have missed a culvert located within the study area.

Traffic variability also introduces some uncertainty. Volumes were collected hourly for 121 days. Although this gives a robust sample to derive the daily average traffic volume for analysis, there is some degree of inaccuracy in the vehicle count from counter error. Traffic speed limits were constant but traffic speed varied depending on driver behavior. The traffic data provides a rich dataset that could be explored in much greater depth than just the total volume differences by road segment that were used in this analysis.

Assessment of the taxa clustering, as generated by kernel density analysis, is subject to visual interpretation. Different interpretations can lead to different results on where someone believes the clustering to be occurring. However, subsequent network K-function analysis allowed testing for statistical significant clustering.

In developing the relationships between kill locations and independent variables, a site with a 25 m radius was used. The 25 m sites were analyzed using a 500 m neighborhood for the other landscape variables. The influence of the 500 m neighborhood would vary for each taxon. The importance of the 500m

landscape around each kill site will be different for different species. Some species might live their whole lives within 500 m of the kill point where others might travel the length of North America.

This study models potential high frog kill zones without the influence of traffic volume to find areas along the study route that might have historically had higher frog road kill but the higher traffic volume has decimated the populations. There is potential that other possible environmental factors that could be limiting frog kill other than higher traffic volume. Other factors could include chemicals from the various marinas or golf courses that are more prevalent in that section of the study route.

8.0 Conclusions

Wildlife road kill is an important issue that has wide ranging spatial and temporal effects. This study demonstrated the extent of road kill by estimating the total number of kills, identifying the locations of species killed, and identifying relationships between predictor variables and road kills along the Thousand Islands Parkway. Given different species have different life history characteristics, road kill can be a very significant issue for local populations (Row et al., 2007; Gibbs et al., 2002).

Taxon specific high kill zones were identified and some taxon showed significant clustering at various spatial scales. For example, frogs showed clustering at all spatial scales where birds clustered only up to 5 km. The

relationships between kill sites and the independent variables were complex and kill sites were not simply related to habitat variables. The two mammals groups showed no significant clustering and no significant relationships to landscape variables.

This study demonstrated the importance of traffic volume on amphibians by finding lower frog kill where higher traffic volume occurred. If mitigation of road kill occurs, it needs to take place not only in the current areas of high kill but in areas where populations may have already been decimated by traffic. The issue is specifically important in this study area because the Canadian government mandates that St. Lawrence Islands National Park (SLINP), a component of the Canadian national park system, maintains and protects ecological integrity.

This study has highlighted the issue of road kill in the study area but also presents a methodology for locating areas of low road kill but high road kill potential. If mitigation was to happen looking at both current and potential high road kill is important because having an increased number of healthy local populations might be the best way to help the overall health of the species.

9.0 References

- "A2A Conservation Association's Story." The Algonquin to Adirondack Conservation Authority. 2005. 26 Feb. 2008 <<http://www.a2alink.org/>>.
- Aresco, Matthew J. "The Effect of Sex-Specific Terrestrial Movements and Roads on the Sex Ratio of Freshwater Turtles." Biological Conservation 123 (2005): 37-44.
- Ashley, E P., and J T. Robinson. "Road-Mortality of Amphibians and Other Wildlife in the Long Point Causeway." Canadian Field-Naturalist. 110 (1996): 403-412.
- Bailey T.C. and Gatrell A.C. Interactive Spatial Data Analysis. Longman Scientific and Technical, Essex, UK. 1995.
- Beyer, Hawthorne. Hawths Analysis Tools. Vers. 3.27. Computer software. Spatial Ecology: Hawth's Analysis Tools for ArcGIS. 1 Oct. 2008 <<http://www.spatial ecology.com/htools/overview.php>>.
- Bradford, Lori. Road Mortality Effects on the Turtle Population At St. Lawrence Islands National Park. St. Lawrence Islands National Park. Parks Canada, 2003. 1-5.
- Carr, Laurie W., and Lenore Fahrig. "Effect of Road Traffic on Two Amphibian Species of Differing Vagility." Conservation Biology 15 (2001): 1071-1078.
- Clevenger, A. P., Chruszcz, B. and Gunson, K. E. Spatial patterns and factors influencing small vertebrate fauna road kill aggregations. Biological Conservation (2003) 109(1): 15:26.
- Fahrig, Lenore. "Introduction to landscape ecology." Landscape Ecology. Carleton University, Ottawa. Fall 2007.
- Fahrig, L., J. H. Pedlar, S. E. Pope, P. D. Taylor and J. F. Wegner. Effect of road traffic on amphibian density. Biological Conservation (1995) 74:117 – 182.

- Fahrig, Lenore. "Non-Optimal Animal Movement in Human-Altered Landscapes." Functional Ecology (2007): 1365-2435.
- Fahrig, Lenore. When is a Landscape Perspective Important? Wiens and Moss ed. Cambridge: Cambridge UP, 2005. 3-9.
- Fahrig, L, J H. Pedlar, S E. Pope, P D. Taylor, and J F. Wegner. "Effect of Road Traffic on Amphibian Density." Biological Conservation 73 (2005): 177-182.
- Farmer, Robert G. "Factors Associated with Vertebrate Roadkill in Southern Ontario Parks." Diss. Univeristy of Guelph, 2007.
- Findlay, C S., and Josee Bourdages. "Response Time of Wetland Biodiversity to Road Construction on Adjacent Lands." Conservation Biology 14 (2000): 86-94.
- Forman, Richard T., Daniel Sperling, John A. Bissonette, Anthony P. Clevenger, Carol D. Cutshall, Virginia H. Dale, Lenore Fahrig, Robert France, Charles R. Goldman, Julia A. Jones, Frederick J. Swanson, Thomas Turrentine, Thomas C. Winter, and Kevin Heanue. Road Ecology Science and Solutions. Washington: Island P, 2003. 3-481.
- Forman, R T. "Estimate of the Area Affected Ecologically by the Road System in the United States." Conservation Biology 14 (2000): 31-35.
- Freund, Rudolf J., Ramon C. Littell, and Lee Creighton. Regression Using JMP(R). New York: SAS P, 2003.
- Gibbs, James P., and W G. Shriver. "Estimating the Effects of Road Mortality on Turtle Populations." Conservation Biology 16 (2002): 1647-1652.
- Glista, David, DeVault travis, and DeWoody Andrew. "Vertebrate Road Mortality Predominantly Impacts Amphibians." Herpetological Conservation Biology 3 (2007): 77-87.

- Guthery, Fred S., and Ralph L. Bingham. "A Primer on Interpreting Regression Models." The Journal of Wildlife Management 71 (2006): 684-92.
- Gutzwiller, Kevin J., ed. Applying Landscape Ecology in Biological Conservation. New York: Springer, 2002. 3-518.
- Holland, Jeffrey, Daniel Bert, and Lenore Fahrig. "Determining the Spatial Scale of Species' Response to Habitat." BioScience 54 (2004): 227-33.
- Hooge, P. N. Animal Movement Analysis Extension for ArcView. Vers. 2.0. Computer software. Alaska Science Centre-Biological Science Office. 19 Sept. 2002. 15 Oct. 2008 <<http://www.absc.usgs.gov/glba/gistools/>>.
- Jenness, Jeff. Jenness Random Selection. Vers. 1.0. Computer software. Jenness Enterprises. 27 Sept. 2008. 1 Oct. 2008 <<http://www.jennessent.com>>.
- Langen, Tom A., Angela Machniak, Erin K. Crowe, Charles Mangan, Daniel F. Marker, Neal Liddle, and Brian Roden. "Methodologies for Surveying Herpetofauna Mortality on Rural Highways." The Journal of Wildlife Management 71 (2007): 1361-1368.
- Lee, Jay, and David W. Wong. Statistical Analysis with ArcView GIS. New York: John Wiley and Sons, Inc, 2001. 1-192.
- Mazerolle, M J. "Amphibian Road Mortality in Response to Nightly Variations in Traffic Intensity." Herpetologica 60 (2004): 51-59.
- McNally, Ralph. "Multiple Regression and Inference in Ecology and Conservation Biology: Further Comments on Identifying Important Predictor Variables." Biodiversity and Conservation 11 (2002): 1397-1401.
- Mitchell, Andy. The ESRI Guide to GIS Analysis: Volume 2; Spatial Measurements and Statistics. Vol. 2. Redlands: ESRI P, 2005. 2-238.

Okabe, Atsuyuki. Spatial Analysis on a Network (SANET). Vers. 3. Computer software. SANET: Spatial Analysis on a Network (Version 3). 2008. 1 Oct. 2008 <<http://ua.t.u-tokyo.ac.jp/okabelab/atsu/sanet/index.html>>.

Okabe, Atsuyuki, Kei-Ichi Okunuki, and Shino Shiode. "SANET: a Toolbox for Spatial Analysis on a Network." Geographical Analysis 38 (2006): 57-66.

Okabe, A, and I Yamada. "The K-Function Method on a Network and Its Computational Implementation." Geographical Analysis 33 (2001): 271-290.

Ramp, D, J Caldwell, K A. Edwards, D Warton, and D B. Croft. "Modeling of Wildlife Fatality Hotspots Along the Snowy Mountain Highway in New South Wales, Australia." Biological Conservation 126 (2005): 474-490.

Ripley, B D. "The Second-Order Analysis of Stationary Point Processes." Journal of Applied Probability 13 (1976): 255-266.

Row, Jeffrey, Gabriel Blouin-Demers, and Patrick Weatherhead. "Demographic effects of road mortality in black ratsnakes (*Elaphe obsoleta*)." Biological Conservation 137 (2007): 117-24.

Smyth, Ian. SOLRIS: Southern Ontario Land Resource Information System. Peterborough, ON: MNR, 2008.

Spooner, Peter G., Ian D. Lunt, Atsuyuki Okabe, and Shino Shiode. "Spatial analysis of roadside Acacia populations on a road network using the network K-function." Landscape Ecology 19 (2004): 491-99.

Trafx Manual 2008 Edition. Canmore: Trafx Research, 2008.

"Understanding GPS Technology." Beagle Software. 9 Mar. 2007. 10 Aug. 2008 <<http://www.beaglesoft.com/gpstechonology.htm>>.

Wiens, John A., Michael R. Moss, Monica G. Turner, and David J. Mladenoff.

Foundation Papers in Landscape Ecology. New York: Columbia UP, 2007.

5-582.

10.0 Appendices

Appendix 1: Road kill summary from the survey including: scientific name, common name, NatureServe Unique

code, Provincial status, COSEWIC status and, number of recorded kills

Scientific Name	Common Name	NatureServe Unique Code	Provincial Status	COSEWIC Status	Number of Recorded Kills
<i>Agelaius phoeniceus</i>	Red-Winged Blackbird	ABPBXB0010	S5B, SNA		1
<i>Ambystoma laterale</i>	Blue-Spotted Salamander	AAAAA01060	S4		2
<i>Ambystoma maculatum</i>	Spotted Salamander	AAAAA01090	S4		3
<i>Anas platyrhynchos</i>	Mallard	ABNJB10060	S5B, SNA		3
<i>Bombycilla cedrorum</i>	Cedar Waxwing	ABPBN01020	S5B, SNA		3
<i>Branta canadensis</i>	Canada Goose	ABNJB05030	S5B, SNA		1
<i>Bucephala albeola</i>	Bufflehead	ABNJB18030	S3B, SNA		1
<i>Bufo americanus</i>	American Toad	AAABB01020	S5		50
<i>Carduelis tristis</i>	American Goldfinch	ABPBY06110	S5B, SNA		3
<i>Castor canadensis</i>	American Beaver	AMAFE01010	S5		2
<i>Chelydra serpentina</i>	Snapping Turtle	ARAAB01010	S5		39
<i>Chrysemys picta marginata</i>	Midland Painted Turtle	ARAAD01013	S5		70
<i>Colaptes auratus</i>	Northern Flicker	ABNYF10020	S5B, SNA		1
<i>Condylura cristata</i>	Star-Nosed Mole	AMABB05010	S5		1
<i>Corvus brachyrhynchos</i>	American Crow	ABPAV10010	S5B, SNA		10
<i>Cyanocitta cristata</i>	Blue Jay	ABPAV02020	S5		2
<i>Danaus plexippus</i>	Monarch	IILEPP2010	S4	Special Concern	23
<i>Dendroica petechia</i>	Yellow Warbler	ABPBX03010	S5B, SNA		12

<i>Diadophis punctatus</i>	Ringneck Snake	ARADB10010	S4		1
<i>Dumetella carolinensis</i>	Gray Catbird	ABPBK01010	S5B, SNA		3
<i>Erethizon dorsatum</i>	Common Porcupine	AMAFJ01010	S5		2
<i>Esox lucius</i>	Northern Pike	AFCHD01020	S5		1
<i>Geothlypis trichas</i>	Common Yellowthroat	ABPBX12010	S5B, SNA		1
<i>Graptemys geographica</i>	Northern Map Turtle	ARAAD05040	S3	Special Concern	8
<i>Hirundo rustica</i>	Barn Swallow	ABPAU09030	S5B, SNA	Candidate High Priority	1
<i>Hyla versicolor</i>	Gray Treefrog	AAABC02130	S5		1
<i>Ictalurus punctatus</i>	Channel Catfish	AFCKA01100	S4		1
<i>Icterus galbula</i>	Baltimore Oriole	ABPBXB9190	S5B, SNA		4
<i>Lampropeltis triangulum</i>	Milksnake	ARADB19050	S3	Special Concern	11
<i>Larus argentatus</i>	Herring Gull	ABNNM03120	S5B, SNA		1
<i>Larus delawarensis</i>	Ring-Billed Gull	ABNNM03100	S5B, SNA		5
<i>Melospiza georgiana</i>	Swamp Sparrow	ABPBXA3030	S5B, SNA		2
<i>Mephitis mephitis</i>	Striped Skunk	AMAJF06010	S5		7
<i>Mustela frenata</i>	Long-tailed Weasel	AMAJF02030	S4		2
<i>Neovison vison</i>	Mink	AMAJF02050	S5		8
<i>Nerodia sipedon sipedon</i>	Northern Watersnake	ARADB22063	S5	Not at Risk	86
<i>Notophthalmus viridescens</i>	Eastern Newt	AAAF01030	S5		6
<i>Parascalops breweri</i>	Hairy-Tailed Mole	AMABB03010	S4		3
<i>Peromyscus maniculatus</i>	Deer Mouse	AMAFF03040	S5		7
<i>Pheucticus ludovicianus</i>	Rose-Breasted Grosbeak	ABPBX61030	S5B, SNA		2
<i>Phoxinus eos</i>	Northern Redbelly Dace	AFCJB31020	S5		1
<i>Poecile atricapillus</i>	Black-capped Chickadee	ABPAW01010	S5		5
<i>Procyon lotor</i>	Common Raccoon	AMAJE02010	S5		15
<i>Pseudacris crucifer</i>	Spring Peeper	AAABC05090	S5		8

<i>Quiscalus quiscula</i>	Common Grackle	ABPBXB6070	S5B, SNA		1
<i>Rana catesbeiana</i>	Bullfrog	AAABH01070	S4		179
<i>Rana clamitans</i>	Green Frog	AAABH01090	S5		18
<i>Rana pipiens</i> pop. 3	Northern Leopard Frog - Eastern population	COSEWIC578	SNR	Not at Risk	85
<i>Sciurus carolinensis</i>	Eastern Gray Squirrel	AMAFB07010	S5		46
<i>Seiurus noveboracensis</i>	Northern Waterthrush	ABPBX10020	S5B, SNA		1
<i>Sorex cinereus</i>	Masked Shrew	AMABA01010	S5		1
<i>Sturnotherus odoratus</i>	Stinkpot	ARAAE02040	S3	Threatened	2
<i>Storeria dekayi</i>	DeKay's Brownsnake	ARADB34010	S5	Not at Risk	35
<i>Sturnus vulgaris</i>	European Starling	ABPBT01010	SNA		2
<i>Sylvilagus floridanus</i>	Eastern Cottontail	AMAE01040	S5		1
<i>Tamias striatus</i>	Eastern Chipmunk	AMAFB02230	S5		25
<i>Tamiasciurus hudsonicus</i>	Red Squirrel	AMAFB08010	S5		9
<i>Thamnophis sirtalis</i>	Common Garter Snake	ARADB36130	S5		2
<i>Turdus migratorius</i>	American Robin	ABPB20170	S5B, SNA		19
<i>Tyrannus tyrannus</i>	Eastern Kingbird	ABPAE52060	S5B, SNA		1
<i>Vulpes vulpes</i>	Red Fox	AMAJA03010	S5		3
<i>Diadophis punctatus edwardsii</i>	Northern Rinkneck Snake	ARADB10014	S4		1
<i>Elaphe obsoleta</i>	Eastern Ratsnake	ARADB13030	S3	Threatened	5

Appendix 2: Taxon kill relationships with predictor variables from the average of 10 roving window analyses. Each analysis was calculated using multiple logistic regression using over 600 non-overlapping sites, across the study region.

Taxon Group					
Amphibian Frog:	Variables	Avg. Slope	Average P-Value	Significance	
	Builtup Area	0.0192	0.5846	no	
	# Buildings	-0.0156	0.5202	no	
	# Culverts	0.1171	0.4454	no	
	Elevation	0.0605	0.2898	no	
	Forest Area	0.0000	0.2150	no	
	Traffic Volume	-0.0017	0.0000	yes	
	Undifferentiated Area	0.02548	0.6462	no	
	Water Area	-0.0313	0.5087	no	
	Water Edge	0.0009	0.0129	yes	
	Wetland Area	-0.0000	0.6879	no	
	# of Wet culverts	0.1239	0.5417	no	
Amphibian Toad	Variables	Average Slope	Average P-Value	Significance	
	Builtup Area	0.0324	0.5424	no	
	# Buildings	-0.1083	0.6522	no	
	# Culverts	-0.0409	0.7128	no	
	Elevation	0.0139	0.7628	no	
	Forest Area	-0.0000	0.7648	no	
	Traffic Volume	-0.0021	0.0047	yes	
	Undifferentiated Area	-0.0207	0.6869	no	

	Water Area	-0.0504	0.4030	no
	Water Edge	0.0001	0.6555	no
	Wetland Area	0.0000	0.6603	no
	# of Wet culverts	-0.1305	0.5447	no
Amphibian Salamander	Not enough data			
Bird	Variables	Average Slope	Average P-Value	Significance
	Builtup Area	-0.0219	0.4320	no
	# Buildings	-0.0600	0.6781	no
	# Culverts	0.1531	0.2375	no
	Elevation	-0.050	0.1905	no
	Forest Area	-0.0000	0.0038	yes
	Traffic Volume	0.0007	0.0007	yes
	Undifferentiated Area	-0.0632	0.2228	no
	Water Area	-0.0754	0.0245	yes
	Water Edge	-0.0001	0.3173	no
	Wetland Area	-0.0000	0.6832	no
	# of Wet culverts	0.1830	0.2411	no
Large Mammal	Variables	Average Slope	Average P-Value	Significance
	Builtup Area	0.0041	0.8794	no
	# Buildings	-0.1255	0.6438	no
	# Culverts	-0.0178	0.7533	no
	Elevation	-0.0735	0.2800	no
	Forest Area	0.0000	0.2632	no

	Traffic Volume	-0.0002	0.6326	no	
	Undifferentiated Area	0.2545	0.2880	no	
	Water Area	0.0644	0.4478	no	
	Water Edge	-0.0000	0.8061	no	
	Wetland Area	0.0000	0.6464	no	
	# of Wet culverts	-0.3180	0.4518	no	
Small Mammal	Variables	Average Slope	Average P-Value	Significance	
	Builtup Area	-0.0027	0.7490	no	
	# Buildings	0.1059	0.5217	no	
	# Culverts	-0.0865	0.4650	no	
	Elevation	-0.0418	0.2250	no	
	Forest Area	-0.0000	0.7050	no	
	Traffic Volume	0.0000	0.7182	no	
	Undifferentiated Area	0.0744	0.1999	no	
	Water Area	0.0241	0.4865	no	
	Water Edge	-0.0001	0.6003	no	
	Wetland Area	0.0000	0.5851	no	
	# of Wet culverts	-0.1018	0.5700	no	
Reptile Snake	Variables	Average Slope	Average P-Value	Significance	
	Builtup Area	-0.0301	0.2583	no	
	# Buildings	-0.0793	0.5384	no	
	# Culverts	0.0959	0.4185	no	
	Elevation	-0.0590	0.0500	yes	

	Forest Area	0.000007	0.0850	yes
	Traffic Volume	-0.000	0.6880	no
	Undifferentiated Area	0.0089	0.6652	no
	Water Area	-0.0424	0.1903	no
	Water Edge	0.0004	0.0347	yes
	Wetland Area	-0.0000	0.4427	no
	# of Wet culverts	0.3252	0.0349	yes
Reptile Turtle	Variables	Average Slope	Average P-Value	Significance
	Builtup Area	-0.0155	0.6190	no
	# Buildings	-0.0729	0.6144	no
	# Culverts	0.1963	0.2552	no
	Elevation	-0.0253	0.5427	no
	Forest Area	0.0000	0.7374	no
	Traffic Volume	0.0004	0.0150	no
	Undifferentiated Area	0.0446	0.5851	no
	Water Area	0.1035	0.0676	no
	Water Edge	0.0002	0.3573	no
	Wetland Area	0.00002	0.1047	yes
	# of Wet culverts	-0.0918	0.5514	no

Appendix 3: Frog kill relationships with predictor variables from each road segment from the average of 10 roving window analyses. Each analysis was calculated using multiple linear regression using non-overlapping sites across each road segment.

Road Segment Analysis	Frogs			
Road Segment 1: 159 sites	Variables	Average Slope	Average P-Value	Significance
	Builtup Area	-0.5997	0.0088	yes
	# Buildings	0.1846	0.8326	no
	# Culverts	0.3008	0.6937	no
	Elevation	-0.5421	0.0176	yes
	Forest Area	0.0000	0.3754	no
	Undifferentiated Area	0.1469	0.7365	no
	Water Area	0.8757	0.0061	yes
	Water Edge	0.0003	0.7825	no
	Wetland Area	0.0001	0.0005	yes
	# of Wet culverts	-0.1131	0.7898	no
Road Segment 2: 48 sites	Variables	Average Slope	Average P-Value	Significance
	Builtup Area	0.1754	0.3783	no
	# Buildings	-2.4337	0.2470	no
	# Culverts	0.2537	0.7304	no
	Elevation	-0.1677	0.5801	no
	Forest Area	0.0000	0.1883	no

	Undifferentiated Area	-0.5429	0.0619	yes
	Water Area	-0.5920	0.0685	yes
	Water Edge	0.0032	0.1846	no
	Wetland Area	0.0000	0.7293	no
	# of Wet culverts	-0.3550	0.7086	no
Road Segment 3: 124 sites	Variables	Average Slope	Average P-Value	Significance
	Builtup Area	0.5207	0.1303	no
	# Buildings	-3.9654	0.0570	yes
	# Culverts	-3.0714	0.0369	yes
	Elevation	-0.4164	0.3561	no
	Forest Area	-0.0000	0.4021	yes
	Undifferentiated Area	-0.2778	0.6718	no
	Water Area	0.6873	0.1574	no
	Water Edge	0.0017	0.4000	no
	Wetland Area	-0.0000	0.7668	no
	# of Wet culverts	5.2111	0.0001	yes
Road Segment 4: 66 sites	Variables	Average Slope	Average P-Value	Significance
	Builtup Area	-0.8574	0.0569	yes
	# Buildings	2.2380	0.0426	yes
	# Culverts	-0.3156	0.6232	no
	Elevation	0.1843	0.5707	no
	Forest Area	0.0000	0.6062	no
	Undifferentiated	0.1737	0.6994	no

	Area			
	Water Area	1.4993	0.3147	no
	Water Edge	-0.0038	0.4954	no
	Wetland Area	0.0003	0.3329	no
	# of Wet culverts	5.0153	0.0485	yes
Road Segment 5: 169 sites	Variables	Average Slope	Average P-Value	Significance
	Builtup Area	0.0143	0.8485	no
	# Buildings	-0.8220	0.4728	no
	# Culverts	-0.2082	0.7957	no
	Elevation	0.6504	0.0424	yes
	Forest Area	-0.0000	0.8213	no
	Undifferentiated Area	2.0763	0.1507	no
	Water Area	-0.1834	0.4586	no
	Water Edge	0.0049	0.0093	yes
	Wetland Area	-0.0000	0.6862	no
	# of Wet culverts	0.9946	0.5485	no
Road Segment 6: 61 sites	Variables	Average Slope	Average P-Value	Significance
	Builtup Area	0.1130	0.2811	no
	# Buildings	-1.6228	0.0068	yes
	# Culverts	0.0571	0.7501	no
	Elevation	0.2992	0.0714	yes
	Forest Area	-0.0000	0.5529	no
	Undifferentiated Area	-0.1256	0.3150	no

	Water Area	0.2953	0.1535	no	
	Water Edge	0.0002	0.7736	no	
	Wetland Area	0.0000	0.4253	no	
	# of Wet culverts	1.4701	0.1371	no	

Appendix 4: Example logistical regression from one random non overlapping run
of 626 sites for frogs for the whole study site

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	59.70101	11	119.402	<.0001
Full	190.81112			
Reduced	250.51213			

RSquare (U) 0.2383
Observations (or Sum Wgts) 626

Converged by Objective

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	-3.6955376	4.0999002	0.81	0.3674
Log Builtup Area 2	0.01020004	0.0342065	0.09	0.7656
Log Buildings 2	-0.0028286	0.1691575	0.00	0.9867
CULVERTS	0.1893728	0.1413404	1.80	0.1803
MEANZ	0.09523376	0.045804	4.32	0.0376
FORES_AR	2.22873e-6	4.0286e-6	0.31	0.5801
AVGTRA_MAX	-0.0015853	0.0002683	34.90	<.0001
Log Undiff Area 2	0.03240588	0.0640937	0.26	0.6131
Log Water Area 2	-0.005002	0.0440734	0.01	0.9096
WEDGE	0.00064407	0.0003126	4.24	0.0394
WETLAN_AR	4.73641e-6	7.5979e-6	0.39	0.5330
WETCUL	0.1403705	0.2599181	0.29	0.5892

For log odds of 1/0

Appendix 5: Example linear regression from one random non overlapping run for
159 sites for frogs for road segment 1

Summary of Fit

RSquare	0.235805
RSquare Adj	0.18417
Root Mean Square Error	8.976608
Mean of Response	10.66038
Observations (or Sum Wgts)	159

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	43.66831	17.28437	2.53	0.0126
Log Builtup Area 2	-0.527985	0.220211	-2.40	0.0177
Log Buildings 2	0.1122604	0.993291	0.11	0.9102
CULVERTS	0.1867289	0.803896	0.23	0.8166
MEANZ	-0.583	0.220941	-2.64	0.0092
FORES_AR	5.6214e-5	4.537e-5	1.24	0.2173
Log Undiff Area 2	0.1364702	0.439551	0.31	0.7566
Log Water Area 2	0.9629895	0.306489	3.14	0.0020
WEDGE	5.1439e-5	0.001873	0.03	0.9781
WETLAN_AR	0.0001361	3.574e-5	3.81	0.0002
WETCUL	0.1005472	1.136076	0.09	0.9296