Evaluating the effects of wildlife exclusion fencing on road mortality for medium-sized and small mammals along Quebec's Route 175

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ABSTRACT

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Katrina Bélanger-Smith

Increasingly, transportation agencies are implementing mitigation measures with the aim of alleviating the negative effects of roads on wildlife. Few studies have examined the responses of medium-sized and small mammals to these mitigation measures. Route 175 between Quebec City and Saguenay was widened from two to four lanes and in conjunction wildlife passages and associated exclusion fencing designated for medium-sized and small mammals were implemented. We surveyed mammal mortality along a 68 km section of Route 175 to address two research questions: (1) Do passages in combination with exclusion fences reduce road mortality? and (2) Are small-meshed fences effective in guiding animals towards the passages or do they displace road mortality to fence-ends? Daily mortality surveys were conducted between June and October 2012 and 2013, detecting 528 road mortalities comprising 18 species or taxonomic groupings. There was no statistically significant reduction in wildlife vehicle collisions (WVCs) with the existing exclusion fencing design. Additionally, WVCs occurred at a higher rate at fence-ends than in unfenced road segments for all medium-sized mammals grouped and for red fox. Habitat variables were found to influence the locations of WVCs, however these effects are highly species-specific. We recommend the implementation of species appropriate exclusion fencing to better guide animals towards wildlife passages. Species morphology, behavior, and daily movement range should be considered in the construction of exclusion fencing.

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Contribution of Authors

As the first author, I was responsible for the conception, design, data analysis and the writing of the manuscript related to this thesis. The manuscript was co-authored by Dr. Jochen Jaeger and Dr. Anthony Clevenger who supervised the work and provided mentorship. Dr. Jaeger advised on experimental design and assisted in the correction of the manuscript. Dr. Clevenger advised on experimental design, provided models for data collection standards and database design and assisted in the correction of the manuscript

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Evaluating the effects of exclusion fencing on road mortality for medium-sized and small mammals along Quebec's Route 175

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Introduction

Roads are an intrinsic aspect of human development. They accompany commercial and residential projects as well as resource extraction ventures. Increasing human populations have led to the creation of new roads as well as the enlargement of previously existing roads into expansive multi-lane highways. Roads are thought to be among the greatest threats to biodiversity, upsetting the ecological balance for flora and fauna alike (Forman et al. 2003). Through continuing research the negative effects of roads on wildlife populations are becoming increasingly clear (Forman 2003). Many studies have shown that roads can be barriers to animal movement, increase wildlife mortality, and reduce both the quantity and quality of available habitat (Fahrig and Rytwinski 2009, Jaeger et al. 2005, Forman et al. 2003, Forman and Alexander 1998). Conversely there are some species that demonstrate neutral or positive reactions to roads, particularly those with high reproductive rates, small range of movement and small territory size such as small mammals (Bissonette and Rosa 2009, Fahrig and Rytwinski 2009). Additionally, scavenging species such as Turkey vultures (*Cathartes aura*) and Black vultures (*Coragyps atratus*) react positively to increased road densities due to increased access to food resources (Fahrig and Rytwinski 2009, Coleman and Fraser 1989). Nevertheless, Fahrig and Rytwinski's empirical review of 79 studies in 2009 found that the negative effects of roads on wildlife greatly outweigh the positive effects (by a factor of 5), and therefore attempts to mitigate these effects are definitely warranted.

The most visible effect on wildlife is direct mortality due to wildlife-vehicle collisions (WVCs), which may have a significant affect on the stability of a population (Forman 2000). In addition, roads may affect wildlife population in ways that are much more difficult to quantify such as through barrier effects, habitat and population fragmentation, and decreased connectivity (Forman et al. 2003, Seiler 2001, Trombulak and Frissell 2000). Without sufficient mitigation, ecological processes and population dynamics can be severely altered, leading to higher mortality, reduced gene flow, increased vulnerability of populations, reduced biodiversity, skewed sex ratios, shifts in community composition, lower reproduction rates, and increased predation (Beckmann et al. 2010). Additionally, it has been demonstrated that the mere presence of roads can modify the behaviour of wildlife through five primary mechanisms (Trombulak and Frissell 2000). The presence of roads may cause individuals to shift their home ranges in order to avoid areas with a high density of roads, individuals may be forced to alter their movement patterns in order to avoid roads, proximity to roads may reduce reproductive success, roads may alter escape or flight response, and may even alter the physiological state of wildlife increasing heart rate, metabolic rate, and energy expenditure (Trombulak and Frissell 2000).

Recognition of the potentially negative effects of roads on wildlife populations has lead to an increase in attempts to mitigate these effects (Carsignol et al. 2005). Most mitigation measures are built with the intention of reducing vehicle collisions with large mammals, which are of great concern for driver safety (Forman et al. 2003). These measures may include any of the following: exclusion fencing, wildlife passageways (overpass or underpass), signage, reduced highway speeds, reflectors, mirrors, increased lighting, ultrasonic whistles, hazing of wildlife, alterations to habitat, and public awareness campaigns (Forman et al. 2003). Most commonly, mitigation measures consist of exclusion fences, barring wildlife from accessing the roadways, as well as passageways to allow fauna to safely cross the road, maintaining connectivity (Glista et al. 2009). Often, transportation agencies claim that exclusion fencing and wildlife passages are the most effective among these mitigation measures. However research has only recently begun to investigate these claims (van der Ree et al. 2007, Forman et al. 2003). While these studies have focused on large mammals (Glista et al. 2009; Clevenger and Waltho 2005; Donaldson 2005; Clevenger et al. 2001a), the potential negative effects of roads may affect medium and small mammals just as dramatically (Fahrig and Rytwinski 2009, Ford and Fahrig 2008, McGregor et al. 2008).

Wildlife crossing structures and exclusion fencing are often built for a specific target species or groups of species (Clevenger 2005, Forman et al. 2003, Beier and Noss 1998). Underpasses are concrete or metal culverts as small as 2 m in width or as large as 100 m wide bridge-like structures running underneath the roadway (Forman et al. 2003). Overpasses can be between 30 and 200 meters wide running across major highways. These may be simple unpaved bridge-like structures, or planted with native grass and woody vegetation providing cover and natural habitat to augment wildlife movement (Forman et al. 2003). Studies evaluating the effectiveness of large mammal passages have mostly been conducted in Europe (Van Wieren and Worm 2001), Australia (Bond and Jones 2008), and North America (Gagnon et al. 2011, Clevenger and Waltho 2005; Donaldson 2005; Clevenger and Waltho 2000). Exclusion fencing for large mammals is implemented to prevent or reduce large mammals access to the roads. They are usually built of wire-mesh fence between 2.0 to 2.4 meters high with one-way gates or ramps, which allow wildlife to leave the roadway but not enter (Forman et al. 2003).

Although most mitigation measures target larger mammals, some mitigation measures have been specifically built for medium-sized and small mammals. These crossing structures range in size from 30 cm to over 1.5 m wide and fencing is variable although other studies included fencing of roughly 100 m on either side of the passage entrance (Villalva et al. 2013, Grilo et al. 2012, Mata et al. 2008). The passages can be small dry tunnels placed so that water never or only rarely drains through, or they can be located over water-filled culverts equipped with a cement or wooden ledge allowing the animals to move across the road (Forman et al. 2003).

Few studies have evaluated the efficacy of mitigation measures for medium and small mammals (van der Ree et al. 2007). Most of these studies evaluated the use and effectiveness of regular drainage culverts as non-designated wildlife passageways (Serronha et al. 2012, Grilo et al. 2008, Ng et al. 2004, Clevenger et al. 2001b). Only a few studies have specifically examined the effects of mitigation measures on the road mortality of medium-sized and small mammals (Niemi et al. 2014, McCollister and Van Manen 2010, McDonald and St.Clair 2004, Clevenger et al. 2003).

Evaluating the effectiveness of mitigation measures is often done by monitoring changes in the rates and locations of wildlife-vehicle collisions as well as evaluating the use of wildlife passageways (Lesbarrères and Fahrig 2012, van der Ree et al. 2007, van der Grift et al. 2006). Many studies have demonstrated the effectiveness of exclusion fencing for large mammals, actively keeping them off of the roads and thereby reducing mortalities. A study by Clevenger et al. (2001a) found that the construction of exclusion fences reduced ungulate vehicle collisions by 80%. Another significant goal of exclusion fencing is to guide animals towards wildlife crossing structures (Clevenger et al. 2001a). It is recommended that exclusion fences be used in conjunction with wildlife crossing structures as the fencing itself can augment the barrier effect of the road (Jaeger and Fahrig 2004).

It has been hypothesized that larger animals with more extensive home ranges, lower reproductive rates, and lower densities may be more vulnerable to roads than other species (Fahrig and Rytwinski 2009). In contrast, it is theorized that small mammals being less mobile are less likely to encounter roads, have naturally higher reproductive rates and higher densities and therefore may be less susceptible to high road mortality (Rytwinski and Fahrig 2011; Fahrig and Rytwinski 2009). Additionally, the creation of grassy roadside verges may in fact lead to higher densities of small mammals due to increased food availability near roads, regardless of the higher risk of road mortality, however this may be species-specific (Bissonette and Rosa 2009). Medium-sized mammals are rarely mentioned in the literature; however, if the above suppositions are correct the effect of road mortality on medium-sized mammals would also depend on their life history, mobility, reproduction rates, and population density.

Regardless of taxonomy or body size, there may be significant ecological effects of road mortality on wildlife populations. While roads may threaten population persistence by reducing suitable habitat and isolating populations, high road mortality can directly threaten a population's ability to persist. Most natural predation is considered to be compensatory, in that predation reduces competition for resources and triggers a density-dependent decline in natural mortality (Bartmann et al. 1992). Road mortality, however, may be additive and non-compensatory and may display a linear relationship with population size, meaning that roads will maintain a constant mortality pressure on a population (Jackson and Fahrig 2011, Seiler 2001). This can have a devastating effect on small populations or rare species. Road mortality is the primary cause of death for badger (*Meles meles*) in the United Kingdom, causing approximately 20% of annual mortality (Clarke et al. 1998), and while this may be critical, the consequence of this mortality pressure on population persistence has not been studied, whereas for the Florida panther (*Puma concolor coryi*)*,* among the most endangered of the world's large mammals, road mortality has been demonstrated as a significant threat to the persistence of the species. WVCs cause approximately six deaths annually, which for a threatened population of roughly 100 individuals is a substantial threat to population viability (Schwab and Zandbergen 2011). Additionally, multiple studies have found that road mortality may have significant negative effects on population persistence for vagile amphibian species (Jackson and Fahrig 2011, Carr and Fahrig 2001, Hels and Buchwald 2001). Furthermore, a study by Ramp and Ben-Ami (2006) found that road mortalities were a significant threat to the long-term viability of common swamp wallaby (*Wallabia bicolor*) populations. Even reportedly common species such as the common wombat (*Vombatus ursinus*) are being threatened as roadkill can significantly diminish local populations as they have become increasingly isolated through habitat fragmentation (Roger et al. 2007). Accordingly, the cumulative effects of road mortality may in fact be a threat to population stability and viability for not only rare and threatened species but for common species alike. Even populations of seemingly common species may decline as a consequence of road mortality pressures on increasingly fragmented and isolated populations (Roger et al. 2007).

Although wildlife mortalities caused by WVCs are the most visible and widely established effect of roads on wildlife, they remain difficult to quantify (Forman and Alexander

1998). Most studies have focused on avian species (Guinard et al. 2012; Boves and Belthoff 2012, Kociolek et al. 2011), amphibians (Glista et al. 2008, Dodd et al. 2004, Carr and Fahrig 2001), large mammals, in particular ungulates (Rolandsen et al. 2011, Clevenger et al. 2001a), carnivores, and mesocarnivores (Ascensao et al. 2014, Colino-Rabanal et al. 2011; Grilo et al. 2009), or a specific threatened and vulnerable species (Jones 2000). Evaluating road mortality is difficult; even in well-planned assessments it is estimated that only a fraction of the wildlife killed by vehicles are actually accounted for (Boves and Belthoff 2012, Guinard et al. 2012, Santos et al. 2011). One study found that within a 24-hour period the persistence of carcasses on the roadway, ranging in body size from frogs to foxes was only 37% (Eberhardt et al. 2013). The underestimation of roadkills may also be due in part to the fact that many individuals may be injured by collisions but will die away from the roadway and therefore remain undetected (Taylor and Goldingay 2004). Scavengers may also remove roadkill from the roadway before a survey occurs, thus greatly reducing the number of detectable mortalities (Teixeira et al. 2013, Boves and Belthoff 2012). A study by Antworth et al. (2005) placed experimental carcasses along a roadway and found that within 36 hours scavengers had removed 60-97% of the carcasses. Our study includes only road mortalities detected during our road mortality survey and does not aim to account for all road mortalities that occur on Route 175. It is clear that any evaluation of wildlife road mortality estimates only a small percentage of the actual mortality pressure populations are facing (Boves and Belthoff 2012, Guinard et al. 2012, Santos et al. 2011, Antworth et al. 2005).

There is a significant lack of research on the effectiveness of crossing structures and exclusions fencing specifically designated for medium-sized and small mammals at reducing road mortality. It is encouraging that transportation agencies are beginning to implement crossing structures for a wide range of species, with goals beyond improvements of road safety, but also to maintain connectivity and permeability across the roadways to sustain important ecological processes. However, it is imperative that these mitigation measures be evaluated in order to understand their performance at mitigating the negative effects of roads. In addition, such research is essential in order to improve the design and implementation of mitigation measures for medium-sized and small mammals.

For this study, road mortality data was collected to examine whether the presence of exclusion fencing, in combination with wildlife passages, were effective at reducing road mortality for medium-sized and small mammals. The expectation would be that where wildlife passageways and exclusion fencing are located, road mortality would be reduced, as the animals would be directed away from the roadway and towards the passageways. Our primary predictions are, firstly that road mortality will be reduced by exclusion fencing and will therefore be lower in the fenced road segments, and secondly that road mortality will be higher at fence-ends than at fenced or unfenced road segments (Gunson et al. 2011, Dodd et al. 2004). Additionally we predict that road segments closer to the forest edge will see higher road mortality than other road segments (Grilo et al. 2010, Ramp et al. 2006, Clevenger et al. 2003).

Methods

Study Area

Route 175 is one of only a few roads connecting Quebec City to Saguenay and it is by far the most direct and commercially important of these roads. Built in 1948, the Route was a two-lane road running through the rolling terrain of the Laurentian Mountains (Bédard 2012). Large parts of Route 175 are adjacent to the Parc national de la Jacques-Cartier and Route 175 runs through the Réserve Faunique des Laurentides both serving as important habitat for many species of wildlife (Figure 1). This region maintains high densities of moose (*Alces alces*) and black bears (*Ursus americanus*) along with many smaller species, which has contributed to the persistent threat of WVCs (Dussault et al. 2006). In addition, this region experiences extreme rain and snowfall events and as such Route 175 was considered one of the more dangerous roads in the province of Quebec. In response, the Quebec Ministry of Transportation began an expansion project along 174 km of Route 175 transforming it into a 4-lane road with a median or safety divide between the north- and southbound lanes. This road expansion widened the Route from ~30 m to between ~90-150 m and was among the largest road expansion projects in Canada at the time. Construction began in 2006 and was completed in 2013 (Bédard et al. 2012). With the expansion of Route 175, Quebec has for only the second time systematically included wildlife mitigation measures for large, medium-sized and small fauna in initial construction. The first consisted of three wildlife passages constructed between 2005 and 2007 with the extension of the Robert-Bourassa freeway north of Quebec City (Bédard and Trottier 2009). Along Route 175, six large mammal passages and 33 medium- and small-mammal passages with exclusion fencing were constructed along 84 km in the hopes of reducing WVCs and improving connectivity across the increased barrier of the expanded roadway. The medium-sized and small mammal exclusion fencing, commissioned by the Ministry of Transportation, consists of chain link fences running approximately 100 m on either side of each passage entrance, dug into the ground to prevent digging and measuring 90 cm in height with a mesh diameter of 2.5 cm (Bédard et al. 2012).

This study focused on 18 of the 33 wildlife passages for which construction had been completed by the summer of 2012. Data collection for medium-sized and small mammal mortalities focused on the stretch of road surrounding the 18 completed passages.

Mortality Surveys

Road mortality surveys were conducted from June to October in both 2012 and 2013 along a 68.5 km stretch of road between kilometers 75 and 143.5. Fieldwork was divided into 10-day sessions, consisting of 3 days with mortality surveys in the hours before sunset, followed by one day without a survey (to have no less than 24 hours between surveys) and 6 days of early morning surveys. On average, each mortality survey took three hours to complete the loop of 137 km of road (68.5 km southbound and 68.5 km northbound). To reduce the potential bias due to start location, the starting points for the road mortality surveys were randomized between four different locations. Surveys consisted of a vehicle driving at 70 km/hr in the right lane with one driver and one principle observer in the passenger seat. When a roadkilled animal was detected a Global Positioning System (GPS) point was taken to record the geographical coordinates of the mortality. The species or group (medium-sized or small mammal) was recorded as well as sex and age class when possible, although due to the state of the carcasses this was often labeled as unknown. Data collected for each observed road mortality also included information such as weather, temperature, kilometer marker location, and specific location on the road (0=right shoulder, 1=right lane, 2=left lane, 3=left shoulder). For more details please refer to road mortality survey protocol in Appendix A.

Spatial analysis

Geographic coordinates for road mortalities and locations of wildlife passages and exclusion fencing were mapped using ArcGIS 10.2 (ESRI 2014). Google Earth™ aerial images were used to obtain the distance between the road edge and the nearest forest cover, creating a new polygon shapefile using ArcGIS with the distance from the road to nearest forest cover. These distances were field checked at 36 points with a range finder and accuracy between the two methods was within 5 meters. We then divided Route 175 into 50-meter road segments. The number of road mortalities per 50-meter segment was tabulated and attributed to a centroid point at each 50 m road segment. Habitat variables were acquired from GIS layers and the stratification standards guidebook obtained from 4th forest inventory by the Quebec Ministry of Forest, Wildlife and Parks forest inventory (Ministère des Forêts, de la Faune et des Parcs 2013). The distance from each centroid point to various habitat characteristics was calculated in meters, and included distances to nearest water (combining lakes, streams, rivers, and wetlands), to nearest forest cover (forest cover can comprise any type of forest and shrub vegetation), to area of human disturbance, to coniferous forest, to deciduous forest, to mixed forest, and to powerline clearance area. In our study area, powerline clearance areas run alongside most of the length of Route 175 and consist of a deforested strip that is 30-80 m in width. These powerline clearance areas were included in our analysis as they create deforested areas directly adjacent to the road, which may influence wildlife in their access to the road. In addition, each centroid was attributed to a road type; fenced, fence-ends, and unfenced (Figure 2). Fenced areas are defined as road segments fenced by medium-sized and small mammal fencing for their entire length. Fence-ends include a 50 m road segment that overlaps the end-point of the small/medium-sized mammal fences and then continues for three contiguous 50 m road segments without fencing. Unfenced road segments are those with no small/medium-sized mammal fencing (are more than 150 m from the actual fence-ends) although large mammal ungulate fencing may be present. Large mammal fencing had a mesh size of 30 cm x 18 cm and was not considered a barrier to medium and small mammals (Bédard et al. 2012). Along our survey area, a total of 104 road segments were fenced, 325 road segments were considered fence-ends, and 2280 road segments were unfenced. One 100 m segment of exclusion fencing was excluded from our analysis due to major damage along 50 m of its length.

Statistical analysis

Statistical analysis was conducted using generalized linear models (GLMs; McCullough and Nelder 1989) with Poisson distribution, using the R statistical software (R Development Core Team, 2013). For each of the 2709 road segments, mammal mortalities, either all species combined, or by size division (medium-sized or small), or by individual species were counted for each 50 m road segment and served as our response variables, while explanatory variables included road segment categories (F=fenced, E=fence-end and U=unfenced) and distances to various habitat characteristics. Interactions were not considered in our analysis due to limited sample size. We evaluated for potential collinearity issues between explanatory variables with variance inflation factors (VIF; Brauner and Shacham 1998) using the package *car* (Fox and Weisberg, 2011).

We conducted multiple levels of analysis, looking first at all terrestrial mammal mortalities of medium-sized and small mammal combined (*n*=528), followed by medium-sized mammals (*n*=331), medium-sized mammals excluding porcupines (*n*=130), micromammal (*n*=101), and then each medium-sized mammal species separately. Unidentified carcasses (*n*=96) were included only in the analysis of all terrestrial mammal mortalities of medium-sized and small mammal combined, but excluded from analysis by body-size or species. Volant and semi-arboreal mammals such as bat *spp.* (*n*=4) and North American flying squirrel (*Glaucomys sabrinus*) (*n*=2) were excluded from our analysis. Species with less than 15 observations included North American beaver (*Castor canadensis*) (*n*=5), and raccoon (*Procyon lotor*) (*n*=9), and red squirrel (*Tamiasciurus hudsonicus*) (*n*=12). For these species, analysis was conducted with respect to mortality and presence of exclusion fencing using GLM and post-hoc Tukey test but not with regards to habitat variables as the number of observations limited the use of a more complex model. Although included in the analysis based on body size, American black bear (*Ursus americanus*) (*n*=2) and American mink (*Neovison vison*) (*n*=1) were excluded from the the species level analysis due to insufficient number of observations. Micromammals were not separated to the species level due to elevated risk of error in identifying to the species level from micromammal roadkill. Micromammals, although not a taxonomic group unto themselves, may be defined in various ways based upon size or species groups, as a useful sub-grouping (Morand et al. 2006). For our purposes, micromammals are defined as including all shrews, mice, and vole species, weighing less than 65 g. Although they are able to cross the 2.5 cm diameter mesh of the exclusion fencing, we chose to retain these smaller species in the event that fencing still acted as an edge, effectively guiding them in the direction of the passage or conversely towards the fence end. As our predictions were developed in conjunction with data collection we used post-hoc Tukey HSD test using the package *multcomp* (Hothorn et al. 2008) to evaluate the effect of exclusion fencing on road mortality for medium-sized and small mammals. The post-hoc Tukey's HSD was conducted with a 0.05 level of significance to evaluate if the mortalities detected in each category of road (fenced, fence-end, unfenced) were significantly different from one another. Additionally, we included habitat variables in the GLM model to determine what habitat characteristics best explained variations in WVCs. We used Akaike Information Criterion (AIC; Akaike 1973) by means of a stepwise forward and backward regression for model selection with the packages *MASS* (Venables and Ripley 2002) and *AICcmodavg* (Mazerolle 2013). Final models were selected based on Delta AIC (values less than 2 indicate that there is substantial support for the model), Akaike weights (indicating the probability that the model is best among all tested models), and evidence ratios (which express how much more likely the best model is when compared to other models) (Table 1) (Mazerolle 2006). Residual deviance was used for goodness-of-fit chi-squared tests to assess the overall fit of the model (IDRE 2014). Each model was confirmed to fit the assumptions of a Poisson distribution. For all models the ratio of variance to the mean was approximately 1, furthermore we applied standard diagnostics with Cook's distance to check for influential points or outliers and hat-values to verify for leverage (Guisan et al. 2002).

Results

A total of 545 road mortalities were detected over the two seasons of road mortality surveys. Sample size for individual medium-sized species are listed in descending order: North American porcupine (*Erethizon dorsatum*) (*n*=201), striped skunk (*Mephitis mephitis*) (*n*=31), red fox (*Vulpes vulpes*) (*n*=30), snowshoe hare (*Lepus americanus*) (*n*=26), groundhog (*Marmota monax*) (*n*=16), red squirrel (*Tamiasciurus hudsonicus*) (*n*=12), and raccoon (*Procyon lotor*) (*n*=9). Due to GPS or human error 17 observations were removed from the study and a total of 528 road mortalities were utilized in our analysis (Figure 3). With all mammal mortalities mapped along Route 175, no clear pattern of mortality appears (Figure 4). Micromammal mortalities were considerably higher in 2012 (*n*=91) than in 2013 (*n*=10), which is in accordance with the cyclical nature of vole species in the North American boreal forest (Cheveau et al. 2004). Voles display a regular pattern of cyclical abundance in Quebec's boreal forest, with low populations occurring approximately every 4 years (Cheveau et al. 2004). This corresponds to the substantial decrease in micromammal mortalities detected in 2013.

Mitigation Measures

In the analysis of all medium-sized and small mammals combined there was no statistically significant reduction of mammal mortality in the road segments with exclusion fencing when compared to fenced road segments (GLM, df=2706, z=-1.62, p=0.11, 95% CI [-1.02,-1.21]) or unfenced road segments (GLM, df=2706, z=-1.90, p=0.06, 95% CI [-0.50, 0.02]) (Figure 5). However, mortality surveys detected no mortalities in the fenced sections for groundhog, red squirrel, or snowshoe hare, and while this difference was not statistically significant, it is an interesting pattern to note for the continuation of this research.

A generalized linear model found that road mortality was significantly higher at fence-ends than in unfenced road segments for medium-sized mammals (GLM, df=2703, z=-2.68, p=0.01, 95% CI [-0.07, -0.1]) and red fox (GLM, df=2705, z=-2.24, p=0.02, 95% CI [-1.7, -0.1]). Both medium-sized mammals (Figure 6) and red fox (Figure 7) were detected more often at a road segment at the end of the exclusion fencing than in the unfenced road segments. When compared to fence-ends, medium mammal mortality decreases by a factor of 0.68 in unfenced road segments and red fox mortality decreases by a factor of 0.37 in unfenced road segments. Because porcupines represent a majority of the medium-sized mortalities, we also analyzed medium-sized mortalities while excluding porcupines (*n*=130). For medium-sized mammals excluding porcupines there was no statistically significant difference in mortality between fence ends road segments and fenced road segments (GLM, df=2706, z=-0.95, p=0.34, 95% CI [-2.05, 0.5]) or unfenced road segments (GLM, df=2706, z=-0.31, p=0.8, 95% CI [-0.6, 0.5]) (Figure 8). There was no statistically significant clustering of road mortalities at fence-ends for all medium-sized and small mammals combined, nor for beaver (Figure 9), groundhog (Figure 10), micromammals (Figure 11), porcupine (Figure 12), raccoon (Figure 13), red squirrel (Figure 14), snowshoe hare (Figure 15), and striped skunk (Figure 16).

Habitat Characteristics

We also included habitat variables to determine their effect on mortality (Table 2). Mortality was higher when road segments were close to coniferous forests when all medium-sized and small mammals were combined for analysis (GLM, df=2703, z=-3.05, p=0.002, 95% CI [-0.001, -0.0.0003]), for medium-sized mammals alone (GLM, df=2703, z=-2.15, p=0.03, 95% CI [-0.001, -0.0001]), and for porcupine (GLM, df=2704, z=-1.96, p=0.05, 95% CI [-0.003, -0.0002]).

We found a positive correlation between road mortalities and distance to powerline clearance areas. Mortality was lower near powerline clearance areas for all medium-sized and small mammals combined (GLM, df=2703, z=2.46, p=0.01, 95% CI [0.00004, 0.0004]), for medium-sized mammals alone (GLM, df=2703, z=2.55, p=0.01, 95% CI [0.00006, 0.0006]), and for porcupine (GLM, df=2704, z=3.16, p=0.001, 95% CI [0.0002, 0.0009]).

When all medium-sized and small mammal mortalities were analyzed together, there was a positive correlation between road mortality and distance to areas of human disturbance (GLM, df=2703, z=1.92, p=0.05, 95% CI [-0.000002, 0.0001]). That is, fewer road mortalities occurred close to areas of human disturbance. However, this is likely a reflection of the very few areas of human disturbance in our study area. In contrast, when analyzed at species level, we found a negative correlation between groundhog road mortalities and distance from areas of human disturbance (GLM, df=2704, z=-2.38, p=0.02, 95% CI [-0.002, -0.0002]).

There were fewer micromammal road mortalities on road segments near water (GLM, df=2706, z=3.25, p=0.001, 95% CI [0.0002, 0.001]). While sample size was too low to analyze, unsurprisingly beaver road mortality was associated with the presence of water, as each of the 5 mortalities occurred near a lake or river.

Groundhogs had higher mortality on road segments near mixed forests (GLM, df=2704, z=-1.94, p=0.05, 95% CI [-0.006, -0.0003]), while porcupine mortality was lower near mixed forests (GLM, df=2704, z=2.39, p=0.02, 95% CI [0.0001, 0.001]). Porcupine also had lower mortality near deciduous forests (GLM, df=2704, z=2.26, p=0.02, 95% CI [0.000007, 0.0001]), while snowshoe hare mortality was higher near deciduous forests (GLM, df=2706, z=-2.21, p=0.03, 95% CI [-0.0004, -0.00004]). Snowshoe hare were also more likely to be killed at road segments near the forest edge, regardless of forest type (GLM, df=2706, z=-1.91, p=0.05, 95% CI [-0.05, -0.001]), while striped skunk were more likely to be killed when the forest edge was farther away from the road segment (GLM, df=2707, z=2.03, p=0.04, 95% CI [-0.0005, 0.03]).

Discussion

Mitigation Measures

The objectives of our study were to determine firstly if wildlife passages in combination with exclusion fencing reduce WVCs, and secondly whether exclusion fencing simply displaced road mortalities towards fence-ends. Our results indicate that the currant design of exclusion fencing not significantly reduced road mortality in the fenced road segments for medium-sized or small mammals. Conversely the findings of a study by Taylor and Goldingay (2003) concluded that exclusion fencing and underpasses were successful at reducing road mortalities for a range of species from amphibians to medium-sized and small mammals in New South Wales. They observed high use of the passages, while only detecting 3 mammal mortalities over 20 weeks of roadkill surveys (Taylor and Goldingay 2003). The 2.5 km section of road in their study was fenced along its entire length at 180 cm height with a ‘floppy top’ to repel climbing (Taylor and Goldingay 2003). In our study, we suspect that the lack of reduction in mortality is due in part to mesh size being too large, low fence height, and lack of a top barrier or overhang for climbing species.

Although not a significant result, there were no road mortalities detected in fenced areas for groundhog, snowshoe hare, and red squirrel. This may suggest that fencing for some species is an effective barrier, although sample size was too low to detect the effects of fencing on mortality for these species. The fencing built along Route 175 may be justified biologically for species that are non-climbing and non-arboreal such as the snowshoe hare, which may be successfully excluded from the roadway. However groundhogs and red squirrel are able climbers and so it is not clear if the lack of groundhog and red squirrel mortalities in the fenced segments is reflecting an effect of fencing or simply a lack of sufficient data. For most of the mammals detected in our road mortality surveys, the exclusion fencing was not effective at reducing road mortality.

We would recommend three primary alterations to the current fence construction to improve their effectiveness. Firstly, the installation of fencing with sufficiently small mesh size to exclude the smallest of the species at which the mitigation is aimed (Jackson and Griffin 2000). Secondly, increasing the height of the fence with the inclusion of a solid top barrier or wire overhang to prevent climbing (Gleeson and Gleeson 2012, Klar et al. 2009, Gloyne and Clevenger 2001). Thirdly, extending the fence length to a distance that covers the average daily movement of the species of interest would likely exclude more individuals from the roadway, a suggestion also proposed in a study by Villalva et al. (2013). These amendments would likely improve the effect of exclusion fencing for medium-sized and small mammals. In addition, Clevenger et al. (2001a) suggested designing V-shaped fence-ends thereby directing wildlife away from the road and back towards the forest and also locating wildlife passages at the fence-ends. The caveat to this is that the exclusion fencing is only effective if it is properly maintained; poor construction, improper treatment of fences by ATV- and snowmobile-users amongst others, and changes in landscape composition due to washouts or erosion may cause gaps and holes in the fences. It has been observed that maintenance of exclusion fencing is often neglected not long after construction is completed, while in reality the fences are only effective if they are continually maintained (Clevenger and Huijesr 2011, Cramer and Bissonette 2006, Cavallaro 2005, Iuell et al. 2003).

A recommendation for future research would be to make the suggested improvements to six wildlife passages, while leaving six with the current exclusion fencing, and removing the fencing entirely from the final six passages. Accordingly, the effects of exclusion fencing on wildlife road mortality could be more thoroughly investigated. Furthermore there should be continued long-term monitoring of road mortality and wildlife passage usage. Previous studies have shown that species will habituate to wildlife passages and that usage often increases over time (Gagnon et al. 2011, Clevenger and Waltho 2003). Habituation to wildlife passages could in turn reduce overall road mortality if wildlife increasingly use the underground wildlife passages rather than more riskier crossing the road at grade.

Secondly, our results indicate that exclusion fencing creates a clustering of road mortalities at the ends of the fencing for medium-sized mammals and for red fox. Clustering is also apparent for porcupine (Figure 12) and snowshoe hare (Figure 15), however additional data collection and increased sample-size are needed to explore this relationship further. For raccoons, further research is recommended as we had insufficient data for statistical analysis, however our data may suggest higher mortality near wildlife passages, with no reduction in mortality due to the presence of exclusion fencing (Figure 13). Raccoons may be attracted to the wildlife passages because of the presence of drainage creeks, using them to forage and fish (Ng et al. 2004). Our results are similar to those by McCollister and Van Manen (2010) who found that road mortality in the fenced road segments was actually higher than in the unfenced road segments; they did not examine the effect of fence-ends however, so what is considered "fenced" in the McCollister and Van Manen (2010) study, our study would consider as partly fence-end. Unlike our study, they also determined that road mortality decreased only in road segments located at or directly adjacent to wildlife passages. Their study suggested that wildlife underpasses may only be effective at reducing WVCs in their immediate vicinity, but lose effectiveness within a couple of hundred meters regardless of exclusion fencing being present (McCollister and Van Manen 2010). The authors hypothesize that as distance from the underpass increases; there was also an increased likelihood that the animal would follow the fence away from the underpass, climb over the fence at some distance and then get hit in a fenced segment of the road. Previous studies have found that ungulates and mammals with large home ranges may be more likely to get hit at the ends of exclusion fencing, although it has been found that fences were effective in reducing ungulate mortality (Clevenger et al. 2001a). Other studies have found that species with smaller home ranges and who are adept at climbing and digging will have an increased probability of getting hit in a fenced segment of the road (Villalva et al. 2013, McCollister and Van Manen 2010). Accordingly, a study by Villalva et al. (2013) found virtually no difference in the number of road mortalities detected in a 100 m radius around their 31 focal culverts in the 20 months before (*n*=20) and after (*n*=19) the installation of exclusion fencing.

Habitat Characteristics

In addition, we aimed to characterize the locations of road mortalities to examine what habitat variables may explain road mortality. We predicted that road segments close to forest cover would exhibit increased road mortality. Proximity to vegetative cover has previously been shown to increase WVCs (Clevenger et al. 2003, Grilo et al. 2012). For most groupings and species, distance to the forest edge did not factor into the most parsimonious model and was not a significant parameter explaining road mortality. In fact, our prediction was correct for snowshoe hare only. Their mortality increased when the forest edge and road were adjacent. Avoidance of open areas is an established behaviour for snowshoe hare, among other prey species, and this may explain why there is lower road mortality when the distance between the road and forest edge is high (Pietz et al. 1983). Conversely road mortality of striped skunk was in fact higher when the road was far from the forest edge. Striped skunks have few natural predators and they display less avoidance of open habitat than prey species such as snowshoe hare (Larivière and Messier 2000). In addition, striped skunks feed mainly on insects and micromammals, and the grassy road edge can provide good habitat for both insects and small mammals and so road edges may be abundant with both (Rytwinski and Fahrig 2011, Bellamy et al. 2000, Larivière and Messier 2000, Munguira and Thomas 1992).

In our study area, WVCs were higher near coniferous forests for all medium-sized and small mammals combined and for medium-sized mammals alone. This may reflect increased population densities and habitat selection for coniferous forest. Our results also show an increase in porcupine road mortality near coniferous forests, while lower road mortality was observed near deciduous and mixed forests. Porcupines have been shown to select against coniferous forests and rather prefer mixed and aspen-dominated deciduous forests in the southern-boreal region of eastern Canada (Morin et al. 2005). Habitat with dominant coniferous forests may increase porcupine mobility forcing them to search for preferred deciduous forest and shrub patches, thereby increasing their likelihood of encountering roads. In contrast, snowshoe hare road mortality was higher near deciduous forests, which may be indicative of their preference for deciduous hardwood forest and dense deciduous foliage (Ferron and Ouellet 1992).

For all medium-sized and small mammals combined there were fewer WVCs near areas of human disturbance, which is in accordance with previous findings (Gunson et al. 2011). In contrast, we found that groundhog mortality was higher near areas of human disturbance. This is likely a product of their preference for cleared areas such as along road edges and agricultural areas (Armitage 2003). The distribution of groundhogs has in fact followed areas of deforestation and agriculture and in doing so overtime they have expanded their range (Hellgren and Polnaszek 2011, Armitage 2003).

Contrary to past studies, our study found no significant correlation between WVCs and proximity to water. Riverside habitat has been shown to have a concentration of WVCs for the European otter (*Lutra lutra*) (Guter et al. 2005), raccoon dogs (*Nyctereutes procyonoides viverrinus*) (Saeki and MacDonald 2004), as well as multiple small and medium terrestrial species (Niemi et al. 2014). This association between riversides with WVCs may not be generalized; the link may be more species- or site-specific than previously thought, as proximity to water is not correlated with increased WVCs in our study area nor with the species in our study.

The effects of habitat variables on road mortality may be linked to population density effects that we were not able to account for in our analysis, as there are no population estimates for medium-sized or small mammals in our study area. Yet factors such as species-specific habitat preferences and behavioural adaptations may be important in order to deepen our understanding of WVC locations (Gunson et al. 2011). Previous studies have shown the importance of species-specific habitat selection in the relationship with WVCs; common wombats (*Vombatus ursinus*) are more likely to be killed near blackberry bushes (Roger and Ramp 2009), European-Polecat (*Mustela putorius*) vehicle collisions are associated with the presence of rabbit burrows (Barrientos and Bolonio 2009), and stone marten (*Martes foina*) road mortality is linked with the percentage of proximal cork-woodland forest (Grilo et al. 2009). Our study was aimed at a broad range of species and so while our results may indicate some broad-scale habitat preferences, future analysis may benefit from more species-specific analysis. Perhaps future inclusion of fine-scale elements, while difficult to measure over such a large study area, such as the presence of preferred vegetation, could reveal a greater understanding of WVC locations as it did between the wombat and blackberry bush (Roger and Ramp 2009).

For future studies evaluating the effectiveness of mitigation measures, it is important to note that there may be critical variables that would improve the model. For example, some estimate of population density may have helped improve the variance explained by our model. For this study, this data was not available for the wide range of species we monitored in our study area. Perhaps in future studies a key species could be selected based on the broadest range of available knowledge including population density, daily movement range, and habitat selection on multiple scales. In addition, past studies have suggested that home range size will partially determine road mortality, as species with smaller home ranges will encounter fewer roads and therefore have lower mortality (Rytwinski and Fahrig 2011; Fahrig and Rytwinski 2009). A study by McCollister and Van Manen (2010) found that population density and mobility increased WVCs for both raccoons (*P. lotor*) and Virginia opossums (*Didelphis virginiana*). Conversely, a study of vertebrate roadkill in Mexico found rodents (*Peromyscus spp.*) were the most commonly detected road mortalities (Gonzalez-Gallina et al. 2013). To explore this idea, we plotted our detected road mortalities against species home range size and found that the highest mortalities were observed in species with smaller average home range size, porcupine, and micromammals (Figure 17). This effect could be accounted for if these species also had higher population densities, or because of behavioural attributes (for example speed of movement or defensive stratagem may contribute to porcupine mortality) (Fahrig and Rytwinski 2009). Future studies may wish to include home range size, population density, and behaviour as part of deeper analysis into the effectiveness of exclusion fencing.

Unexpectedly, some species with confirmed presence in our study area were not detected during the mortality surveys. These species include the American marten (*Martes americana*), ermine (*Mustela erminea*), and long-tailed weasel (*Mustela frenata*). These species have been detected in trackbox grids near the wildlife passages as well as inside the wildlife passages themselves, were they have been detected by infrared Reconyx™ HC600 Hyperfire cameras (Appendix B). Previous studies have found that WVCs are a significant source of mortality for the stone marten (Grilo et al. 2012). It is interesting to note that the effects of roads on species may be highly species-specific and also vary considerably with geographic area. Therefore care should be taken when generalizing the results of one study to other locations and/or related species.

Finally, while our sample size was sufficiently large that significant parameters resulted from our analysis, the explained deviance of our models was in fact quite low (Table 2). Therefore, while our variables may have some effect on road mortality, they in actuality explain only a small amount of the variation in road mortality. As such, we report the results of our models with the caveat that the variables we measured are part of a complex ecological system and that these individual parameters are themselves inadequate at explaining a large percentage of the variance in road mortality. We suggest that explained deviance and confidence intervals should be reported in future road mitigation studies, particularly so that they may be properly implicated in future management decisions (Johnson 1999). It is true that the predictive power of most studies in the biological sciences is often quite low as they deal with living organisms under the influence of both biotic and abiotic factors and complex ecological processes (Nakagawa and Cuthill 2007, Møller and Jennions 2002, Johnson 1999). In a meta-analysis of 43 published meta-analyses from ecological and evolutionary journals, Møller and Jennions (2002) found that the average variance explained in published literature is only 2-5%. There are so many competing variables that their effect sizes may in fact be very small or the randomness and noise could be very large (Møller and Jennions 2002). Still although the effect size of a parameter may be minute, over time even small effects like the clustering of road mortality at fence-ends may become biologically significant (Møller and Jennions 2002).

Furthermore, as all of the species detected in this road mortality study are common species, it may be easy to assume that road mortality does not constitute a threat to their population persistence. However, the effects of additive road mortality on populations of seemingly common species can be significant (Roger et al. 2007). Increasingly fragmented habitats only further isolate populations and therefore the pressure of road mortality can greatly reduce or even eradicate isolated populations (Roger et al. 2007). While road mortality may have seemingly limited effects on populations of common species, these effects may accumulate over time and in combination with increased habitat fragmentation the negative implications of road mortality on population viability greatly increase (Roger et al. 2007, Trombulak and Frissell 2000).

Management Implications

There is no denying the significant adverse effects that roads may have on wildlife (Fahrig and Rytwinski 2009). Road mortality specifically may have significant effects on population demography and consequently on population viability (Trombulak and Frissell 2000). The combination of exclusion fencing and wildlife passages has been shown to effectively reduce road mortality and allow connectivity between landscapes for both large mammals (Olsson et al. 2008, Clevenger et al. 2001a, Foster et al. 1995), mesocarnivores (Ascensao et al. 2013, Clevenger et al. 2001), and medium to small mammals (Niemi et al. 2014, Taylor and Goldingay 2003). The results of our study neither fully support nor refute these studies; rather they lend support to studies which have emphasized the need for exclusion fencing which are biologically relevant for the species of interest (Villalva et al. 2013, Grilo et al. 2010, McCollister and Van Manen 2010). To effectively reduce road mortality, exclusion fencing should be implemented with smaller mesh size, greater height, increased length, bottom barriers for digging species, and top barriers for climbing species to exclude the broadest range of species. These characteristics can be adjusted depending upon the species for which the fences are intended. Furthermore, fence maintenance is as important as the initial construction of the exclusion fencing if the intended benefits of reduced road mortality and increased passage-use are to result. As studies into the effectiveness of road mitigation measures often aim at informing management practices and encouraging the implementation of future road mitigation, it is imperative that studies report not only statistical significance but also biological significance including explained deviance and confidence intervals.

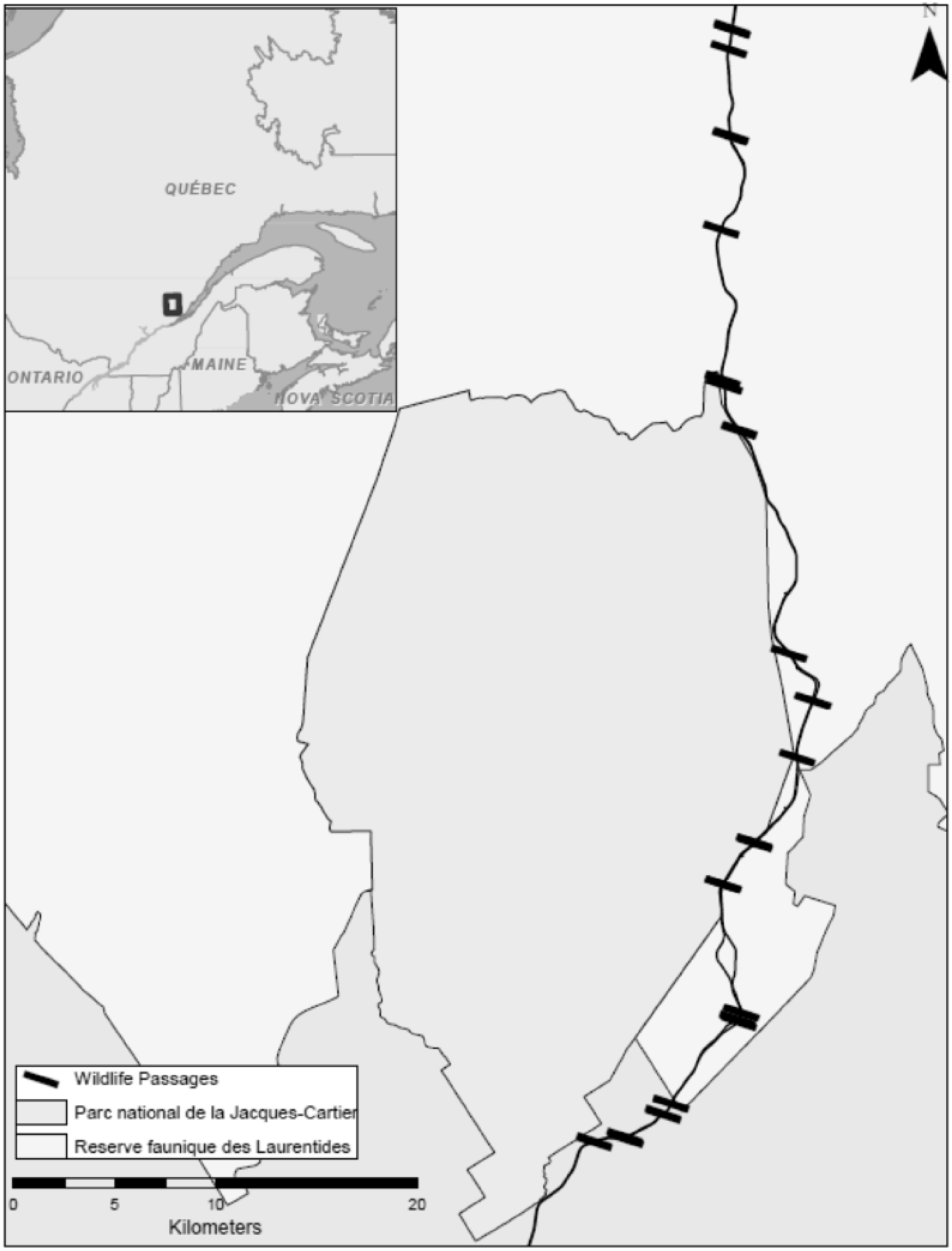

Figure 1: Study area, shown with Route 175 running through the Reserve faunique des Laurentides (RFL), paler gray indicates the RFL. The small darker gray section indicates the Parc national de la Jacques Cartier. Black bars indicate the 18 wildlife passages, with associated exclusion fencing running roughly 100m on either side of the passage entrance (200 m total) for medium-sized and small mammals that were monitored for this study.

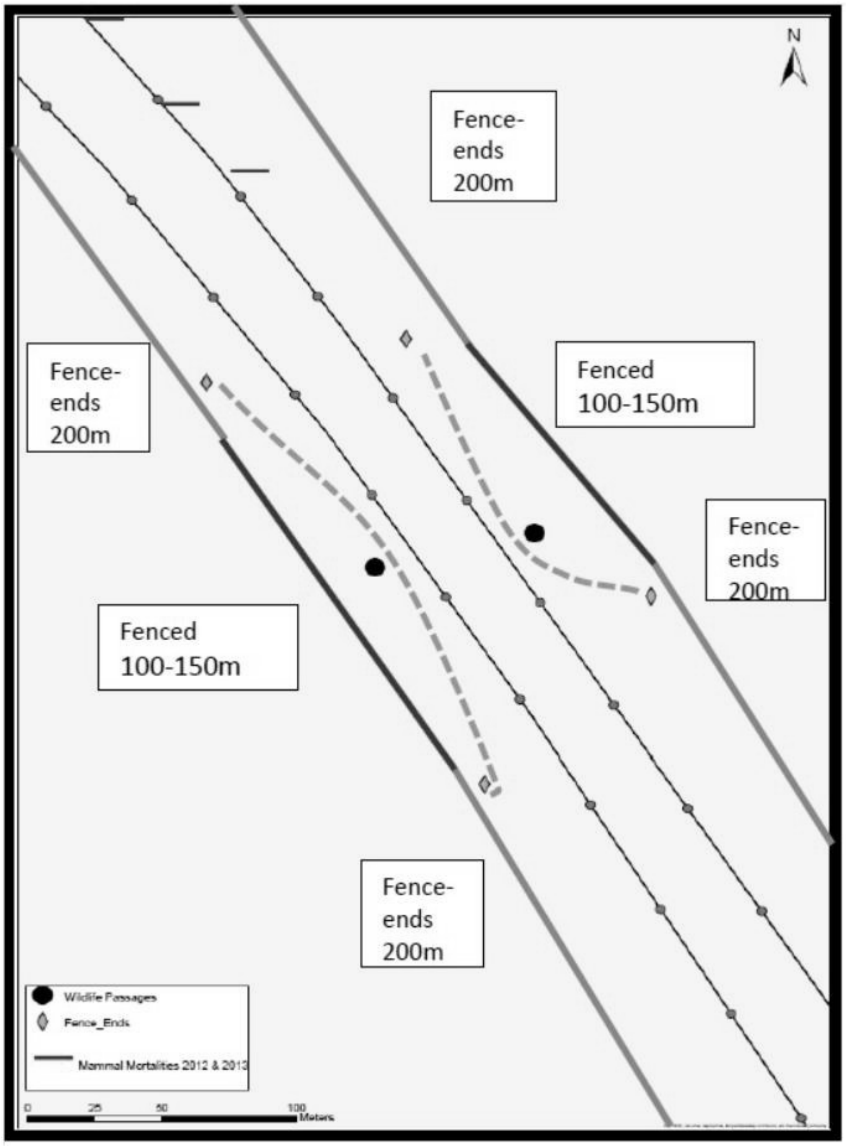

Figure 2: Fenced road segments are defined as 50 m road segments fenced by medium-sized and small mammal fencing for their entire length, the fences are approximately 100-150 m in total length. Fence-ends include the first 50 m road segments overlapping the end-point of the small/medium-sized mammal fences and then continue for 3 contiguous 50 m road segments, for a total of 200 m. Unfenced road segments are those with no small/medium-sized mammal fencing, although large mammal ungulate fencing may be present. Our study area has a total of 104 fenced road segments, 325 fence-end road segments and 2280 unfenced road segments.

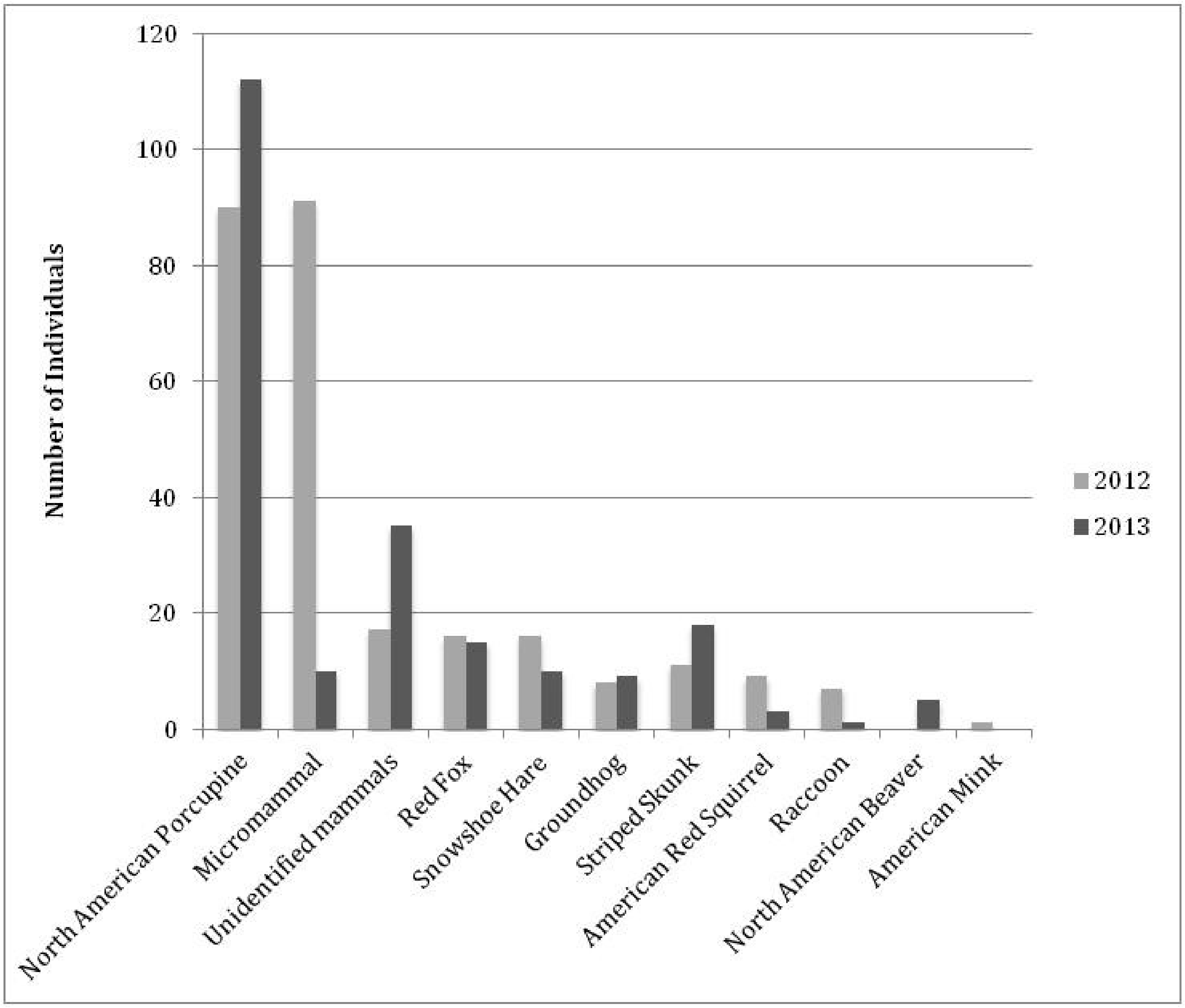

Figure 3: Number of terrestrial mammal species and groups detected as roadkill during surveys on the Route 175 study area for June through October 2012 and 2013.

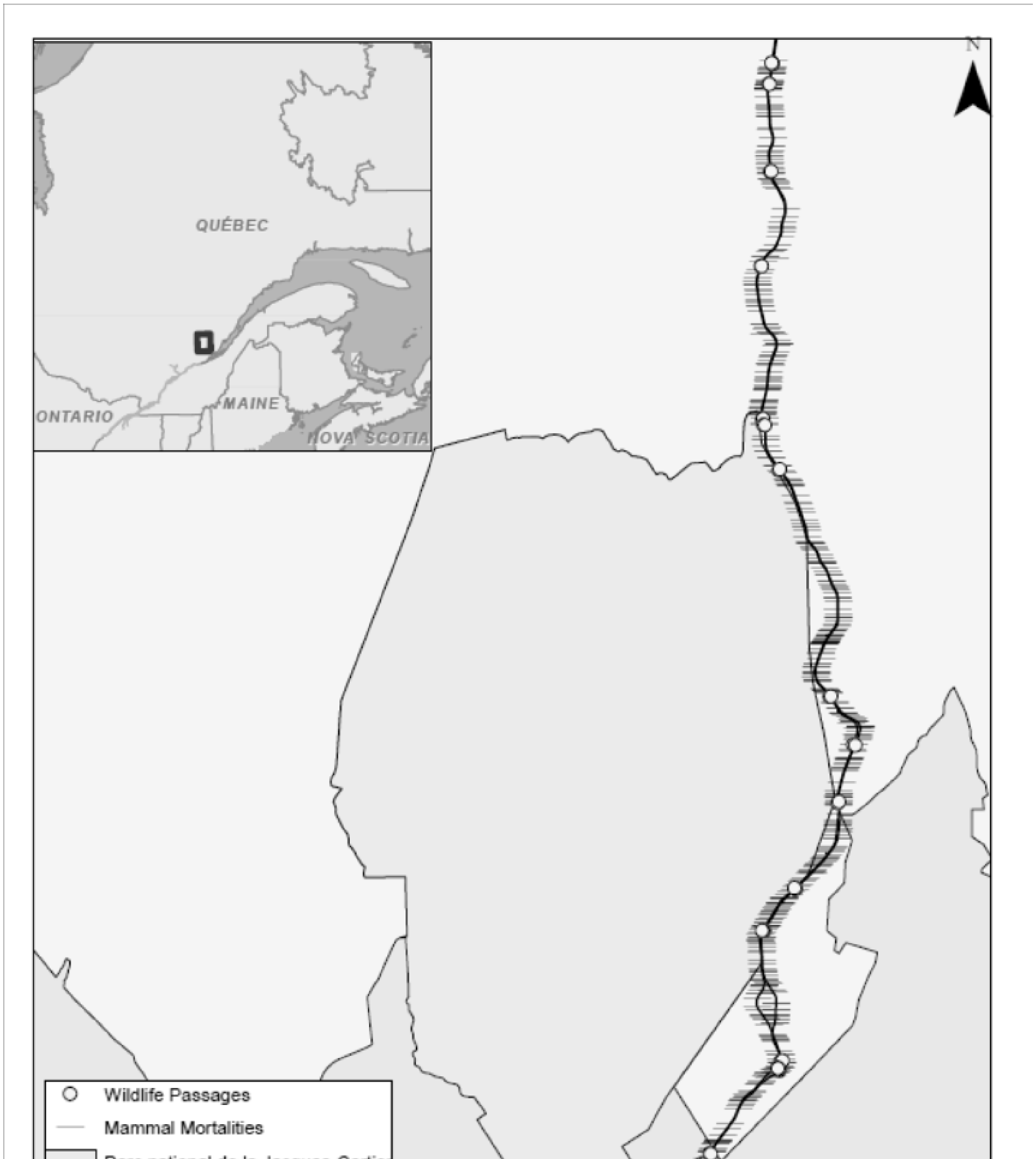

Figure 4: Map of all medium-sized and small mammal road mortalities (n=528) detected as roadkill during surveys conducted June through October in 2012 and 2013.

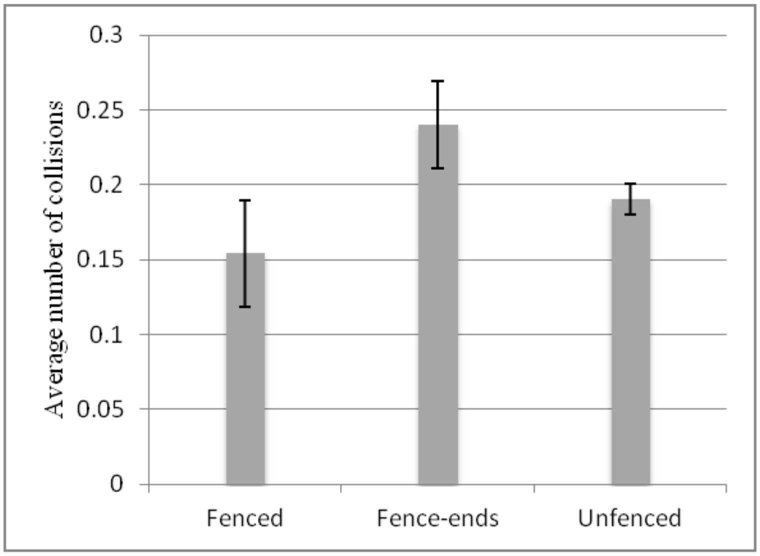

Figure 5: Average number of collisions (with standard error bars) observed in 50 m sections for all medium-sized and small mammals combined (*n*=528). Post-hoc Tukey's HSD detected no significant difference in mortality between road segment types at 0.05 level of significance for all medium-sized and small mammals combined.

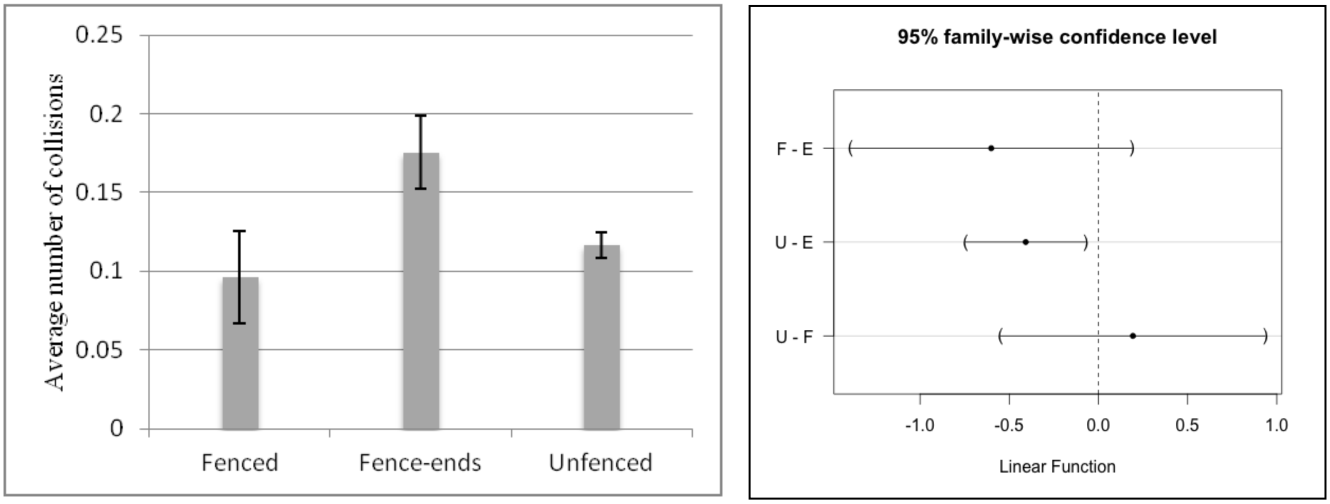

Figure 6: Average number of collisions (with standard error bars) observed in 50 m sections for all medium-sized mammals (*n*=331). Plot of post-hoc Tukey's HSD indicated significantly more mortalities of medium-sized mammal detected at fence-ends than on road sections without mitigation (p=0.01). F=fenced road segments, E=fence-ends road segments, and U=unfenced road segments.

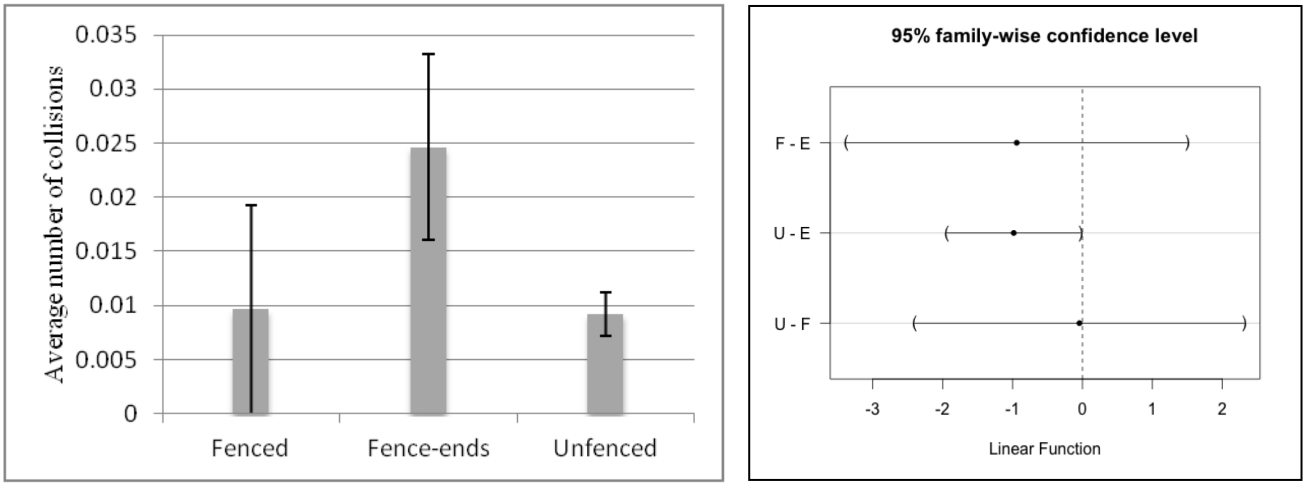

Figure 7: Average number of collisions (with standard error bars) observed in 50 m sections for red fox (*n*=30). Post-hoc Tukey's HSD detected significantly more mortalities of red foxes at fence-ends than on unfenced road segments (p=0.05). F=fenced road segments, E=fence-ends road segments, and U=unfenced road segments.

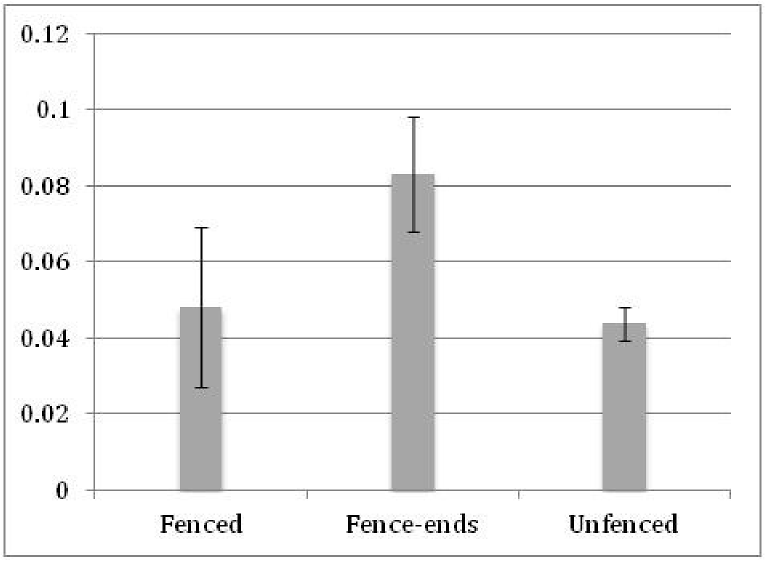

Figure 8: Average number of collisions (with standard error bars) observed in 50 m sections for all medium-sized mammals excluding porcupines (*n*=130). Post-hoc Tukey's HSD detected no significant difference in mortality between road segment types at 0.05 level of significance for all medium-sized excluding porcupines.

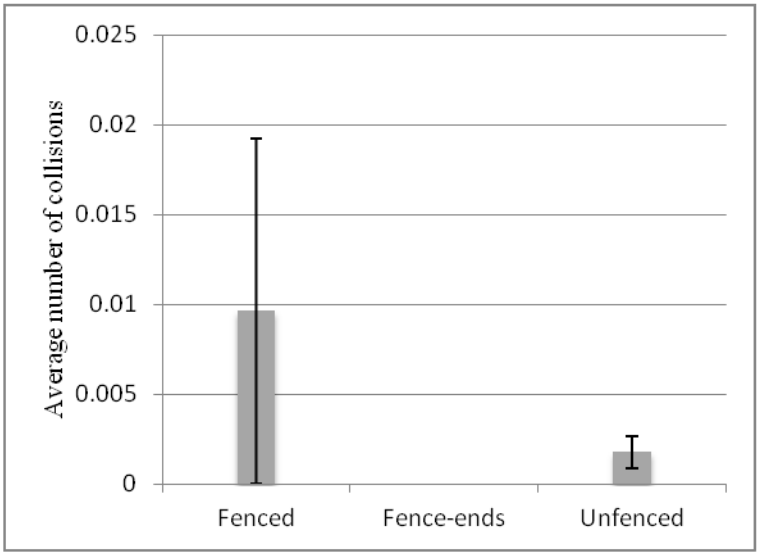

Figure 9: Average number of collisions (with standard error bars) observed in 50 m sections for beaver (*n*=5). Post-hoc Tukey's HSD detected no significant difference in mortality between road types at 0.05 level of significance for beavers; however, sample size (*n*=5) was too low for further analysis.

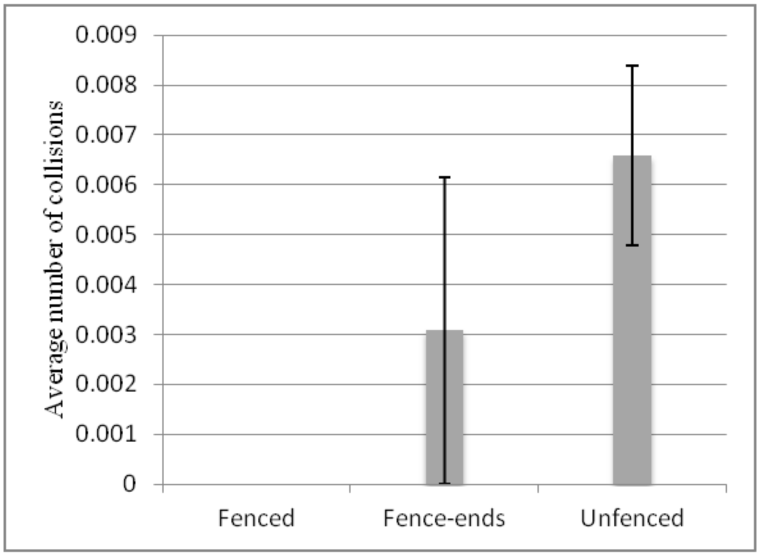

Figure 10 Average number of collisions (with standard error bars) observed in 50 m sections for groundhogs (*n*=16). Post-hoc Tukey's HSD detected no significant difference in mortality between road types at 0.05 level of significance for groundhogs.

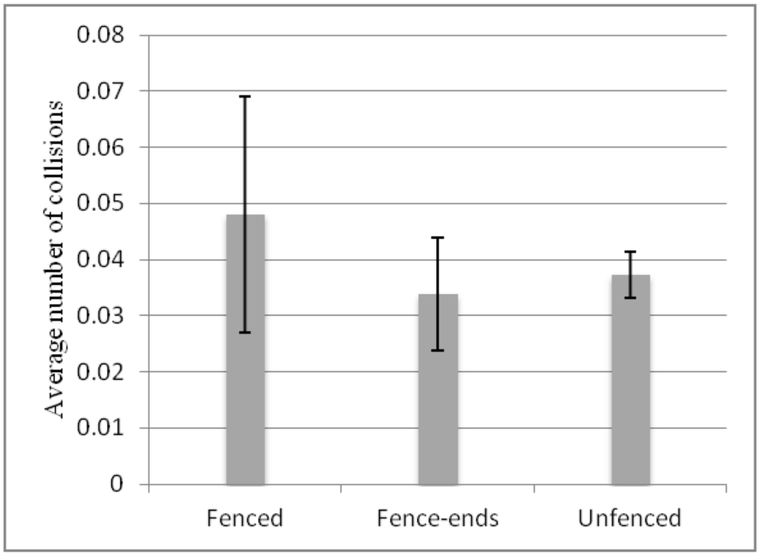

Figure 11: Average number of collisions (with standard error bars) observed in 50 m sections for micromammals (*n*=101). Post-hoc Tukey's HSD detected no significant difference in mortality between road types at 0.05 level of significance for micromammals.

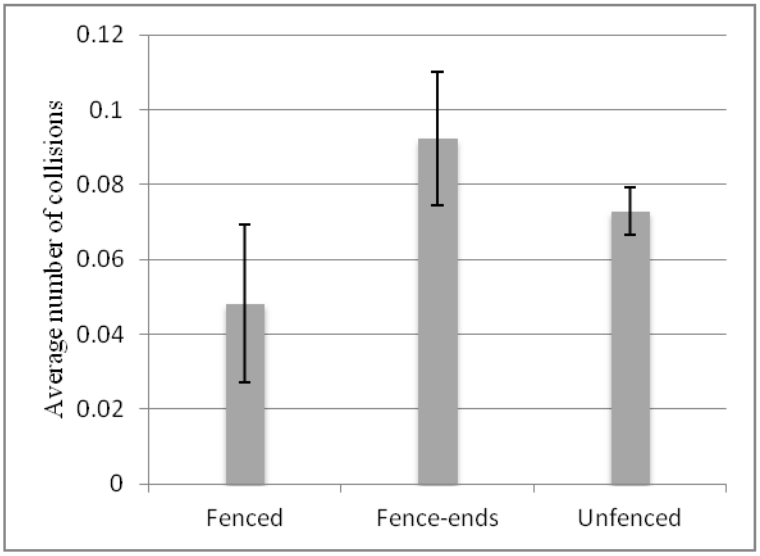

Figure 12: Average number of collisions (with standard error bars) observed in 50 m sections for porcupines (*n*=201). Post-hoc Tukey's HSD detected no significant difference in mortality between road types at 0.05 level of significance for porcupines.

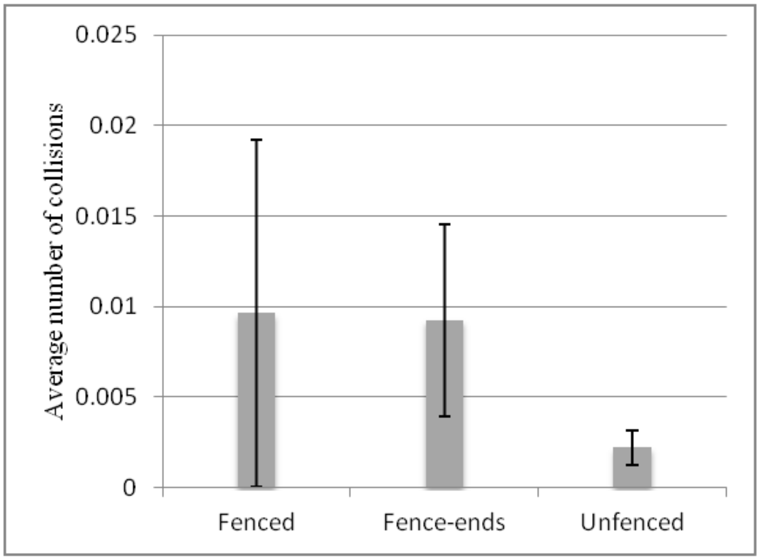

Figure 13: Average number of collisions (with standard error bars) observed in 50 m sections for raccoons (*n*=9). Post-hoc Tukey's HSD detected no significant difference in mortality between road types at 0.05 level of significance for raccoons.

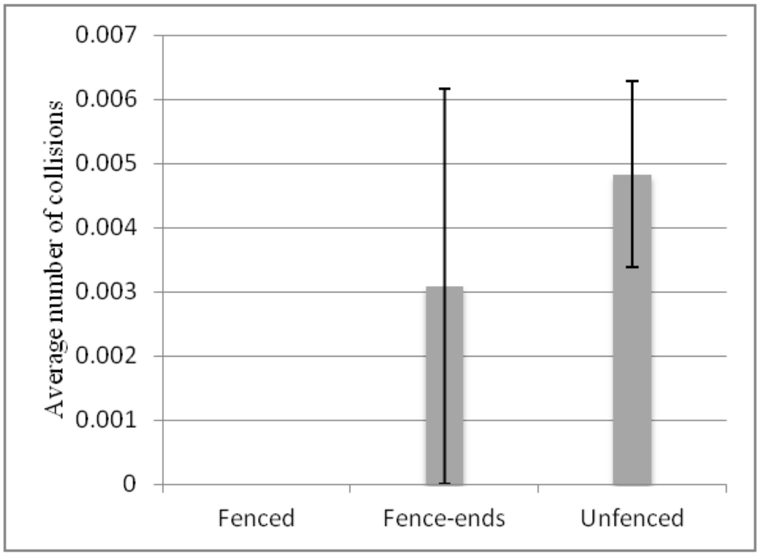

Figure 14: Average number of collisions (with standard error bars) observed in 50 m sections for red squirrel (*n*=12). Post-hoc Tukey's HSD detected no significant difference in mortality between road types at 0.05 level of significance for red squirrel.

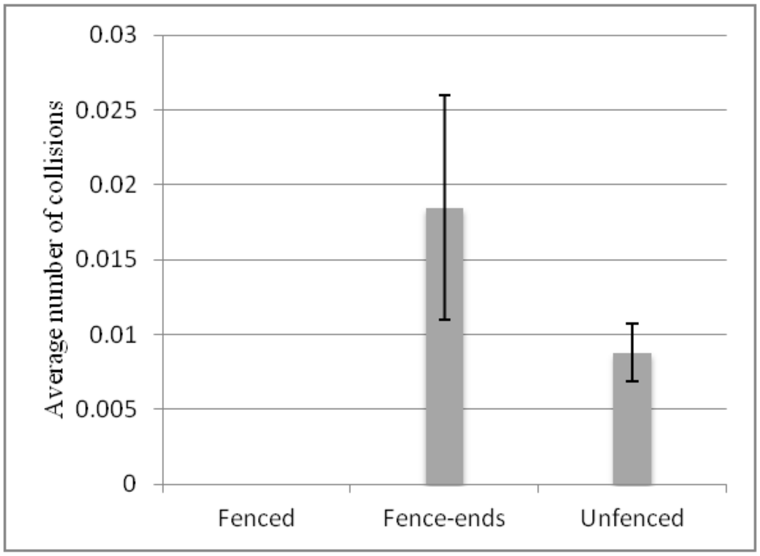

Figure 15: Average number of collisions (with standard error bars) observed in 50 m sections for snowshoe hare (*n*=26). Post-hoc Tukey's HSD detected no significant difference in mortality between road types at 0.05 level of significance for snowshoe hare.

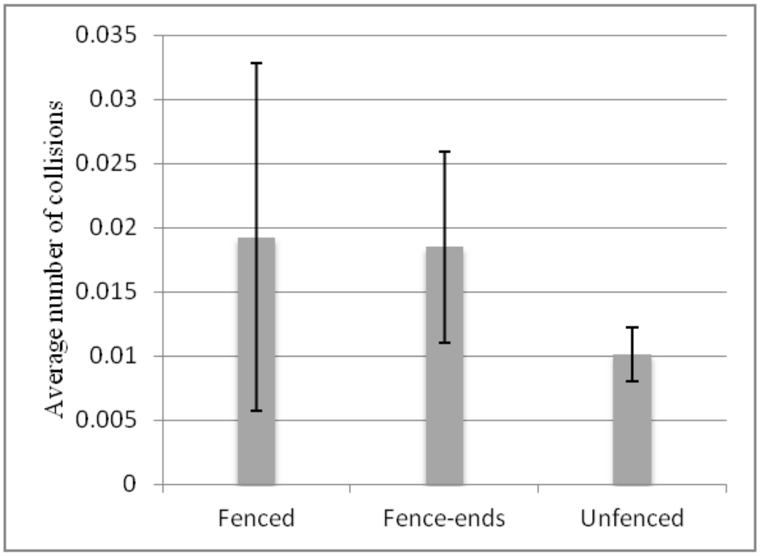

Figure 16: Average number of collisions (with standard error bars) observed in 50 m sections for striped skunk (*n*=31). Post-hoc Tukey's HSD detected no significant difference in mortality between road types at 0.05 level of significance for striped skunk.

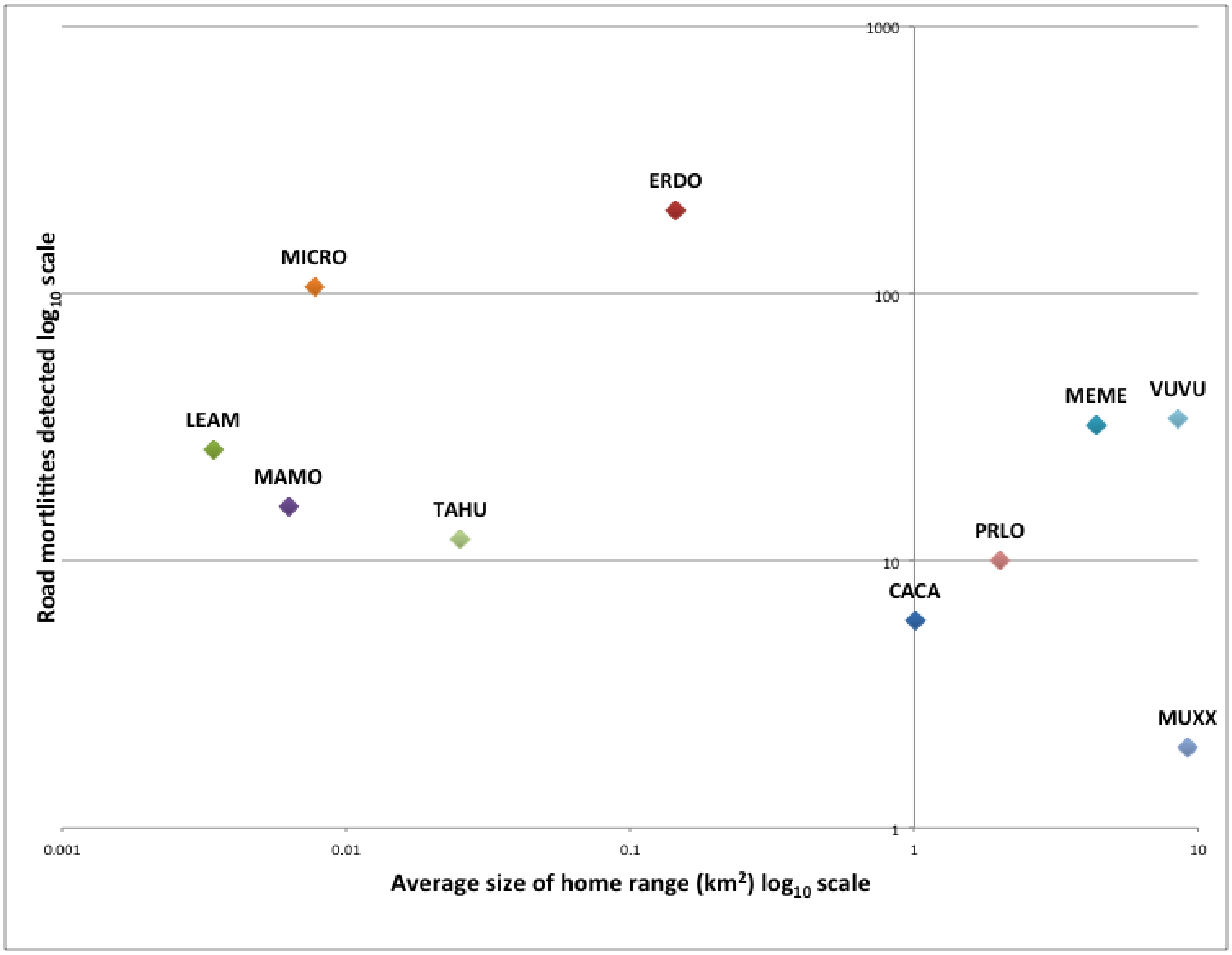

Figure 17: Plot of the total number of road mortalities detected by species plotted against the average home range size in km^2 per species, all values on $\log_{10}$ scale. Species codes in alphabetical order; CACA= North American beaver (*C. canadensis),* ERDO=North American porcupine (*E. dorsatum*), LEAM=snowshoe hare (*L. americanus*), MAMO=groundhog (*M. monax*), MEME=striped skunk (*M. mephitis*), MICRO=micromammals, MUXX= *Mustela* spp., PRLO=raccoon (*P. lotor*), TAHU=red squirrel (*T. hudsonicus*), and VUVU=red fox (*V. vulpes*). Source for species home range sizes was Wund and Myers (2005).

Table 1. AIC stepwise (forward/backward) model selection using R packages *MASS* (Venables and Ripley 2002) and *AICcmodavg* (Mazerolle 2013). Values shown for both the Full models and Final models selected. Model selection based on AICc, Delta AIC, and evidence ratios (Mazerolle 2006). *K* is the number of parameters included the model, including both the number of variables and the intercept. Variables are coded as follows; Type_v3=Type of road segment (fenced, fence end, unfenced), FMR_DIST=Distance to Forest Cover, FWaterDIST =Distance to Water, F_DIST =Distance to Deciduous Forest, M_DIST =Distance to Mixed Forest, R_DIST =Distance to Coniferous Forest, NF_DIST =Distance to Area of Human Disturbance, LTE_DIST =Distance to Powerline Clearance Area.

All medium-sized and small mammals (*n*=528)	***K***	**AIC_c**	**Δ_i**	**w_i**	**Log-likelihood**
Final model: Type_v3 + R_DIST + NF_DIST + LTE_DIST	6	2889.56	0.00	0.8	-1438.76
Full model: Type_v3+FMR_DIST+FWaterDIST+F_DIST+ M_DIST+R_DIST+NF_DIST+LTE_DIST	10	2892.29	2.73	0.2	-1436.10
Evidence ratio between models=3.91					
Medium-sized Mammals (*n*=331)	***K***	**AIC_c**	**Δ_i**	**w_i**	**Log-likelihood**
Final model: Type_v3+M_DIST+R_DIST+LTE_DIST	6	2106.74	0.00	0.96	-1047.36
Full model: Type_v3+FMR_DIST+FWaterDIST+F_DIST+ M_DIST+R_DIST+NF_DIST+LTE_DIST	10	2113.00	6.26	0.04	-1046.46
Evidence ratio between models=22.82					
Medium-sized Mammals (minus porcupine) (*n*=130)	***K***	**AIC_c**	**Δ_i**	**w_i**	**Log-likelihood**
Final model: Type_v3+F_DIST + M_DIST + NF_DIST	6	1055.58	0.00	0.94	-521.78
Full model: Type_v3+FMR_DIST+FWaterDIST+F_DIST+ M_DIST+R_DIST+NF_DIST+LTE_DIST	10	1061.17	5.59	0.06	-520.54
Evidence ratio between models= 16.33					

Small Mammals (*n*=101)	***K***	**AIC_c**	**Δ_i**	**w_i**	**Log-likelihood**
Final model: Type_v3+FWaterDIST + R_DIST	5	863.81	0.00	0.86	-426.89
Full model: Type_v3+FMR_DIST+FWaterDIST+F_DIST+ M_DIST+R_DIST+NF_DIST+LTE_DIST	10	867.51	3.70	0.14	-423.71
Evidence ratio between models= 6.37					
Porcupine (*n*=201)	***K***	**AIC_c**	**Δ_i**	**w_i**	**Log-likelihood**
Final model: Type_v3F_DIST + M_DIST + R_DIST + LTE_DIST	7	1470.24	0.00	0.9	-728.10
Full model: Type_v3+FMR_DIST+FWaterDIST+F_DIST+ M_DIST+R_DIST+NF_DIST+LTE_DIST	10	1474.66	4.42	0.1	-727.29
Evidence ratio between models= 9.1					
Striped Skunk (*n*=31)	***K***	**AIC_c**	**Δ_i**	**w_i**	**Log-likelihood**
Final model: FMR_DIST	4	340.66	0.00	0.98	-166.32
Full model: Type_v3+FMR_DIST+FWaterDIST+F_DIST+ M_DIST+R_DIST+NF_DIST+LTE_DIST	10	348.22	7.56	0.02	-164.07
Evidence ratio between models=43.73					
Red Fox (*n*=30)	***K***	**AIC_c**	**Δ_i**	**w_i**	**Log-likelihood**
Final model: Type_v3	3	331.44	0.00	1	-162.72
Full model: Type_v3+FMR_DIST+FWaterDIST+F_DIST+ M_DIST+R_DIST+NF_DIST+LTE_DIST	10	343.15	11.71	0	-161.54
Evidence ratio between models=349.46					

Table 2: Most parsimonious regression model for each group and/or species based on stepwise AIC model selection using R packages *MASS* (Venables and Ripley 2002) and *AICcmodavg* (Mazerolle 2013). Fence ends are not represented in the model output, however they are accounted for in the model, as the GLM model selects a dummy variable to avoid overfitting the model. For coefficient of determination, the Nagelkerke's pseudo-R^2 was used (Nagelkerke 1991). The direction of the relationship is indicated by the test statistic (Wald *z*).

Mortality by species or group (response variable) and distance in meters to habitat characteristics (explanatory variables)	Wald *z*	P	CI 2.5%	CI 97.5%	AIC	Pseudo-R^2	Explained Deviance (%)
All species					2889.5	0.02	1.50
Fenced	-1.65	0.099	-1.026	0.060			
Unfenced	-1.82	0.07	-0.460	0.024			
Coniferous forest	-3.05	0.002*	-0.001	-0.0003			
Area of human disturbance	1.92	0.05*	-0.000002	0.0001			
Powerline clearance area	2.46	0.01*	0.00004	0.0004			
Medium-sized mammals					2119.8	0.02	1.56
Fenced	-1.77	0.08	-1.340	0.021			
Unfenced	-2.72	0.007*	-0.671	-0.095			
Mixed forest	1.44	0.15	-0.0001	0.001			
Coniferous forest	-2.15	0.03*	-0.001	-0.0001			
Powerline clearance area	2.55	0.01*	0.00006	0.0006			
Medium-sized mammals (minus Porcupine)					1055.6	0.01	1.30
Fenced	-0.98	0.33	-2.070	0.480			
Unfenced	-0.20	0.84	-0.540	0.500			
Deciduous forest	-1.45	0.15	-0.0001	0.00001			
Mixed forest	-1.70	0.10	-0.002	0.00009			
Area of human disturbance	2.10	0.04*	0.000003	0.0002			
Micromammal					860.17	0.03	2.71
Fenced	0.62	0.53	-0.820	1.346			
Unfenced	0.39	0.70	-0.458	0.811			
Water	3.25	0.001*	0.0003	0.001			
Coniferous forest	-2.23	0.03*	-0.005	-0.0007			

Porcupine					1468.8	0.03	2.33
Fenced	-1.33	0.20	-1.720	0.220			
Unfenced	-1.30	0.20	-0.637	0.151			
Deciduous forest	2.26	0.02*	0.000007	0.0001			
Mixed forest	2.39	0.02*	0.0001	0.001			
Coniferous forest	-1.96	0.05*	-0.003	-0.0002			
Powerline clearance area	3.16	0.002*	0.0002	0.001			
Red fox					331.43	0.02	1.80
Fenced	-0.87	0.40	-3.860	0.800			
Unfenced	-2.40	0.02*	-1.760	-0.120			
Striped skunk					340.65	0.01	1.30
Fenced	0.09	0.93	-1.900	1.540			
Unfenced	-1.60	0.11	-1.600	0.262			
Forest edge	2.03	0.04*	-0.0005	0.03			
*Denotes significant p-value at 5% level							

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Appendix A: Field Procedures for Mortality Surveys

1. Mortality Surveys are conducted between km 75.5 and km 144.5. The starting point for the mortality survey alternates equally between 4 points (Point A= 129N, Point B=129S, Point C=103N, Point D=103S).

2. Work session consists of 10 days. Mortality surveys during these 10 days are as follows. On day 1, 2 and 3 an evening mortality survey is conducted. The survey begins 3 hours before sunset. There is no mortality survey conducted on Day 4 to not have less than 24 hours between mortality surveys. On days 5 through 10 morning mortality surveys are conducted. Morning surveys begin roughly 30 minutes after sunrise to allow for better visibility.

3. Safety

Safety in the field is of utmost concern; at all times when in the field safety is the priority. As such reflective safety vests are worn at all times when in the field. When working near the roads hardhats are worn as well. Proper footwear, closed toed protective footwear, is required at all times when working in the field.

4. Data Collected

Data is recorded in a mortality survey notebook which is set up to contain all required fields of information before heading out into the field. This is important to ensure that data is not forgotten. Standard species codes will be used when recording data. (Table A.1.1)

General Mortality Survey Data:

-Date (written out fully in English or French, example 01-June-2012)
-Starting point (Point A= 129N, Point B=129S, Point C=103N, Point D=103S)
-Start time
-End time
-Weather conditions (sunny, overcast, raining, snowing etc.)
-Temperature (°C)
-Average speed (60-70km/hr will be average, however it should be noted each day in the event that weather or other safety concerns requires slower average speed)

Observation Data:

-Km location
-GPS Label (Label given to point in GPS to be uploaded into GPS at a later date. Format: Species Code-Day-Month-Year)
-UTM
-Species (see codes Table A.1)
-Sex
-Age Class (A=Adult, SA=Sub-adult, J=Juvenile, U=Unknown)
-Location (0=right side, 1=right lane, 2=left lane, 3=left side)

-Direction of Travel (N=North, S=South)
-Status (Alive, Dead)
-Notes: Any additional notes for example regarding the condition of the carcass, other sightings etc.

5. Standards for sex and age classification

Sex I.D.

Dependent upon the condition of the mortality, sex and age will be determined as accurately as possible. The sex of small mammals can usually be determined through examination of genitalia and mammaries. Sex determination and breeding status for males may include palpitation of the testes (scrotal or abdominal) or in some species the presence of a baculum. For females identification may include the condition of the vaginal opening (perforated or not) and condition of mammaries (small or large) and if pregnant or not. Field guides will be consulted for sex determination for particular species as position and size of genitalia may vary between species. With juveniles sex maybe difficult to determine and as such may simply be listed as unknown. Shrews are very difficult to sex, and will likely be listed as unknown, unless they are pregnant or lactating females in which case they are easily identifiable (Hoffmann *et al.* 2012; McLaren 1998; Barnett and Dutton 1995).

Age Class

Determining age in the field will consist of distinguishing between three different age classes; juvenile, subadult, and adult if possible (Hoffmann et al. 2012).

Juvenile- Young animal, smaller than subadult with juvenile pelage. Not sexually mature.

Subadult- Smaller than adult, may or may not have adult pelage. May or may not be sexually mature.

Adult-Full grown, adult pelage and sexually mature.

6. Weather Standards

Mortality surveys will be conducted in rain or snow conditions, however these conditions will be noted and any change in driving speed will also be noted. Should weather conditions be severe and be deemed unsafe for driving along the road edge, the mortality survey for that day will be skipped and this will be recorded in the database.

7. Time of day standards

Morality surveys take approximately 2.5-3 hours. Daytime mortality surveys are conducted within the 3 hours following sunrise. Evening mortality surveys are conducted within the 3 hours before sunset. This time may be shifted by 30 minutes in the case of weather events that could affect visibility early in the morning.

8. Mortalities are to be frozen as soon as possible. Any American marten mortalities are collected and frozen for DNA analysis and possible aging. Ensure that all relevant information is recorded on the plastic bag in permanent marker. Or waterproof specimen labels can be Rite-in-Rain letter size sheets (available from Cansel, Montreal) printed with mortality labels (Fig. A.1). Any micro-mammal we are unable to identify to species will be bagged and labeled with its GPS identifier (ex. UNK1 27Aug). In the notes section of the mortality survey book it will be marked as 'bagged', and this specimen will be placed in the freezer and the Carcass Collection Species ID list. Specimens should be identified by species, age class and sex and placed in individual plastic bags with a detailed waterproof data label which includes date of collection and UTM (see Fig. A.1 for mortality labels).

9. DNA samples may be collected from other specimens and preserved as directed. These samples may be collected from only one additional species (ex. Porcupine if they may in the future be chosen as another focal species) or may be taken from all mammal mortalities.

10. Detection Probability (*due to time and limitations with personnel detection probability was not analyzed in 2012 and 2013, future studies may include this as part of there analysis).

Search Bias

To attempt to evaluate search bias we will conduct mortality surveys where we will have had an assistant placed 20 dummy carcasses along Route 175 as per Boves and Belthoff (2011) or Mazerolle et al. (2007). The placement of the carcass will be chosen randomly along Route 175, to include locations on both the left and right sides of the road, as well as distance from the road (1=over white line, but still on pavement; 2=1-2m off pavement; 4-5m off pavement). These test carcasses will be marked with a sharpie pen on their underbellies with the letter (T) for test and will also have a piece of clear tape wrapped around their right hind leg, there location will be noted and marked with a GPS corrdinate. The assistant will place these test carcasses no more than 2 hours before that days mortality survey.

Removal bias

We conduct mortality surveys 9 out of every 14 days, in addition two independent crews of public security patrol the roads twice daily for road kill which may endanger motorists. For this reason large and medium sized mammals have little chance of being scavenged before being discovered in a mortality survey. Micromammals, however, may be scavenged quickly by crows, turkey vultures and other opportunistic birds. For this reason a test of removal bias for micro-mammals will be conducted 2 times during our study (once per year of study). For this test of removal bias in micro-mammals 20 mouse carcasses (to be purchased at a pet store or laboratory facility, brown or grey varieties only) are to be placed in randomly selected locations along the roadside. The variables included in these selected locations include locations on both the left and right sides of the road, as well as distance from the road (1=over white line, but still on pavement; 2=1-2m off pavement; 4-5m off pavement). Once test carcasses are placed in selected locations they will be marked with the GPS and their location will be noted in detail to enable relocation to this site. Test carcasses will be placed in the morning of day 1 of a field session. These sites will be monitored for the following 9 days during our regular mortality surveys. Presence or absence will be noted after thoroughly searching the test area for signs of the test carcass. If the carcass is still present we will also note any signs of scavenging.

Collection Date: Species: Sex: Age: Km: UTM :	Collection Date: Species: Sex: Age: Km: UTM :
Collection Date: Species: Sex: Age: Km: UTM :	Collection Date: Species: Sex: Age: Km: UTM :

Figure A.1: Mortality Specimen Labels

Table A.1: Species codes used for data collection and data entry.

Species Code	**Latin**	**English**	**French**
ARVI	*Arvicolinae*	Vole and bog lemming species	les espèces de souris campagnol
CACA	*Castor canadensis*	American beaver	le castor d'Amérique
ERDO	*Erethizon dorsatum*	Porcupine	le porc-épic d'Amérique
GLSA	*Glaucomys sabrinus*	Northern flying squirrel	le grand polatouche
LEAM	*Lepus americanus*	Snowshoe hare	le lièvre d'Amérique
LOCA	*Lontra canadensis*	River otter	la loutre de rivière
LYCA	*Lynx canadensis*	Lynx	le lynx du Canada
MAAM	*Martes americana*	American Marten	la martre d'Amérique
MAPE	*Martes pennanti*	Fisher	le pékan
MEME	*Mephitis mephitis*	Striped skunk	la mouffette rayée
MICRO	*Arvi, Pero, Soxx*	Micromammals	Micromammifères
MUER	*Mustela erminea*	Ermine	l'hermine
MUFR	*Mustela frenata*	Long-tailed weasel	la belette à longue queue
MUNI	*Mustela nivalis*	Least weasel	
MUXX	*Musstela spp.*	Weasel spp.	
NEVI	*Neovison vison*	American mink	le vison d'Amérique
ONZI	*Ondatra zibethicus*	Common muskrat	le rat musqué commun
PERO	*Peromyscus (or Mus musculus)*	Mice species	les espèces de souris
PRLO	*Procyon lotor*	Racoon	le raton laveur
SOCI	*Sorex cinereus*	Masked shrew	La musarainge cendrée
SOXX	*Sorex sp.*	Shrew	Les musarainge
TAHU	*Tamiasciurus hudsonicus*	Red squirrel	l'écureuil roux
TAST	*Tamias striatus*	Eastern chipmunk	Tamia rayé
TAXX	*Tamias/ Tamiasciurus*	Red squirrel or Eastern chipmunk	
URAM	*Ursus americanus*	Black bear	L'ours noir
VUVU	*Vulpes vulpes*	Red fox	le renard roux

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Appendix B: General Protocol and Camera / Trackbox Sampling

1. Objectives

This study aims to evaluate the effects of mitigation measures used as part of the expansion of Route 175 to reduce the impact of the road on micro and meso-mammals. We will compare observed frequency of wildlife passage use versus the expected use of wildlife passages. Observed frequency will be detected with infrared cameras (Reconyx™ HC600 Hyperfire H.D. Covert IR). Estimated frequency will be determined by evaluating the relative abundance of micro and meso-mammal populations adjacent to below-grade wildlife passageways. In addition, road mortalities will be monitored along the study area to determine the effectiveness of small mammal fencing in guiding wildlife through the passageways.

2. Areas to survey

Our study area is along Route 175 between km 75.5 and 144.5 inclusively, which is the area of the highway in which wildlife mitigation measures are currently in place. Study areas include the road surface along the entire length of Route 175 between km 75.5 and 144.5 for mortality assessment, below-grade wildlife passages for observed usage, and the habitat adjacent to the passageway entrance for expected usage.

3. Equipment

Equipment List

- Cameras (Reconyx™ HC600 Hyperfire HC600 Hyperfire H.D. Covert IR)
- Track Boxes-black coroplast boxes
- GPS (2 Garmin Etrex)
- 50 m tape
- Range finder
- Brown kraft paper for track boxes
- Stapler, staples and scissors
- Carbon black and mineral oil (~1:4 ratio)
- Data entry notebook
- Vinyl gloves for mortalities and for handling carbon black and bait
- Shovel for mortalities
- Masks for handling carbon black
- Plastic sample bags (large, medium and small ziplock)
- Flagging tape for track box grids (pink)
- Pin flag for mortalities
- Identification key or field guides

4. Safety

Safety in the field is of utmost concern; at all times when in the field safety is the priority. As such reflective safety vests will be worn at all times when in the field. When working near the roads hardhats will be worn as well. Proper footwear, meaning closed toed protective footwear, is required at all times when working in the field.

5. Permits

Permit from the MRNF allowing us to cut branches/small trees 300 m into the forest perpendicular to the wildlife passages.

Permis d'intervention du MTQ- to be provided by Yves Bédard

6. Habitat Data

The habitat directly adjacent to the wildlife passage entrances as well as the forest habitat will be characterized. Methods for this will be modeled after previous works done by Anthony Clevenger (pers. comm.) and other studies (Rogers *et al.* 2008; B.C. Resources Inventory Committee 1998)

For small and medium sized mammal study:

- GIS and aerial images will be used to evaluate habitat. This will enable us to evaluate the habitat on a broader scale as well as determine additional variables such as: elevation, power lines, drainage culverts, water features etc.

-Distance from passageway entrance to forest edge
-Distance to stream (m)
-Distance to waterbody (m)
-Proximity to cover (m)-distance in meters to nearest continuous cover with connectivity to larger areas of cover. Cover defined as (≥TBD)
-Evaluation of percent cover (includes CWD, shrub, rocks etc.)
-Evaluate habitat zones around passageway entrance (100m)
    -Zones (open, shrub, forest)
    -Dominant cover type: P/S=Pine/Spruce; MCD=Mixed conifer-deciduous; OFM=Open/Forest mix; OWA=Open wet area; RIP=Riparian area; Other=describe and note.

7. Passageway Characterization Data

Design

-Passage ID (km)
-Type (TBA, marche, rive amanege)
-Width (S and N entrance)
-Height (S and N entrance)

-Median (Y/N) if so then Width and Height of South-East (SE) and North-West (NW) openings
-Aperture (defined as through-culvert visibility, taken at both entrances, (Open=1; ¾ open=0.75; ½ open=0.5; ¼ open=0.25; closed=0.0)
-Distance to nearest drainage culvert
-Sound (may not take this as Clevenger study found no effect of sound)

Road

-Verge width (m)-width in meters of verge (right-of-way) taken on N and S side of road
-Road width (m)-Total width in meters of road (pavement edge to pavement edge)
-Road clearance (m)-Width in meters of area cleared/altered
-Wildlife fence (0=None; 1=Fence for Large Fauna; 2=Fence for Small Fauna)
-Road Lighting present- Y/N
-Traffic volume –mean traffic volume during sampling period (This will be collected from the MTQ traffic counters and can be looked at by month, week or day)

8. Weather Standards

Mortality surveys will be conducted in rain or snow conditions, however these conditions will be noted and any change in driving speed will also be noted. Should weather conditions be severe and be deemed unsafe for driving along the road edge, the mortality survey for that day will be skipped and this will be recorded in the database.

Track boxes can continue in all weather, however with extremely hot or dry conditions oil may need to be checked and replenished more often. And in very wet weather papers may need to be checked and replaced.

Cameras may be removed from the large passageways (landscaped stream beds) in November before the snow buries or damages them.

9. Time of day standards

Morality surveys take approximately 2.5-3 hours. Daytime mortality surveys will be conducted within the 3 hours following sunrise. Evening mortality surveys will be conducted within the 3 hours before sunset. This time may be shifted by 30 minutes in the case of weather events that could affect visibility early in the morning.

Track box checking and pulling of track box papers will take place in the same order as the track boxes were installed to allow the track boxes to be available for the maximum amount of sampling time (14 days).

Field Procedures for Camera Sampling (Wildlife Passage Use)

1. Cameras are installed at either end of all below grade wildlife. Cameras are to be installed just within the passageways to protect them from dust and road debris. Ensure that all cameras are synchronized for time and date. Camera angle can be checked by viewing the SD cards in the field camera.

2. Cameras will be checked once every 2 weeks for battery life and SD card replacement. Until such time as track boxes are installed camera checks will be divided into 2 days: one day will consist of checking the 9 passages north of km 122, the second day the 13-16 passages south of km 122 will checked. This will reduce driving time, and other work such as culvert site data collection and habitat assessment at culverts can take place. Once track boxes are installed camera checks will be synchronized with track box checking. Two passages per day will have track box paper pulled and camera SD cards replaced.

3. Camera checks will be conducted with roadside security at the forefront of concern. For this reason passageway will not necessarily be checked at the same time but rather one side (ex. West side of road) first and then the other side (East side) will be checked. This is to minimize the requirement of crossing the highway. However in some instances there is safe parking for the vehicle on only one side of the highway. These locations will be recorded and added to the protocol at a later date. If this is the case then we will park on one side of the highway and safely cross the road to check both sides of the passageway.

4. Batteries will be replaced if they are at or near 40% charge. Batteries should be on a rotation so not all of the batteries are at low charge at the same time. Replacement batteries are to be charged a few days before use, as they can lose charge if they are charged too far in advance.

5. Date from the SD cards will be uploaded into the Reconyx™ HC600 Hyperfire archive every evening and then backed-up into the projects external hard drive.

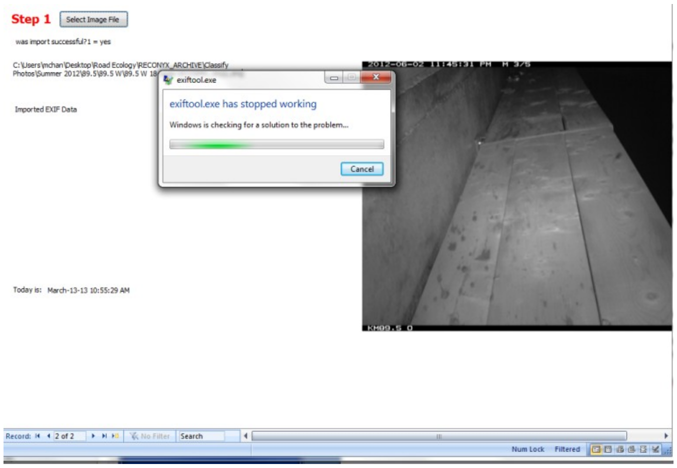
6. Witness images will be selected for each observed use of the passageway and will be imported into the Access database with all relevant data for the crossing or intrusion. Although only witness images are imported into the Access database all images containing wildlife will be saved in the computer, external hard-drive and Concordia server.

PHOTO CLASSIFICATION-ACCESS DATABASE PROCEDURE

1. Open the **WCS_monitoring** file on ACCESS
2. Click the **Database Tools** tab on the top of the window
   Click **Visual Basics**. A window will open but you can close it.
3. You are now ready to start looking at images!
4. Look for your folder of images (RECONYX_ARCHIVE > Classify Photos > Summer or Fall 2012 > Passage name)
5. Pick the date you want to start off with and open a window for the first image of each side (e.g. East and West) in Microsoft Office Picture Manager so that you can look at both sides of the passageway at the same time. This means you should have 2 windows open: one for each side.
6. Once you find a picture of an animal, go through 1/5 to 5/5 for the best image of the individual for identification. If there are more than 5 images of an individual, go through them until you do not see it anymore and check the other side of the passageway to see if the individual passes through or turns back. You can note down any other behaviour.
7. **To import an image**
   Click the Reconyx Data Entry button on the Main Switchboard
8. You will be brought to the Reconyx Data Entry tab. There, you can select an image.
9. When the image is selected you should be on the Basic Attributes page
   (Make sure the image has been imported properly. To know, look at the Imported Information box on the right of the screen. It should be filled out. If not, try and import the image again. Worst case scenario, use the image information on the top and bottom of the image to fill in the Location, Temperature, Date and Time. It only occurred once for me so if it keeps happening, you have a problem with the exiftool file and should seek help from someone familiar with the database.)
10. **Fill in**:
    Direction
    Species
    Age (generally left as adult unless a distinct indicator of age is present)
    Sex (unknown)
    Number of individuals
    Passage (yes, no or unknown. Unknown if the individual has clearly gone straight and has not returned in several minutes but is no present on the other camera)
    Species behaviour (note whether they have turned back or not and other behaviours observed. Anything peculiar can be noted in the text box below the species behaviour box)
11. Once done, go to Save Image with New File Name
12. Press Update File Name. Check if the name looks correct (species_date_number_code) and then press Rename File and Set Form to New Record.
13. Done!

Warning. When importing an image, if you get an **error with exiftool.exe**. The image will still show as imported but you will notice that the data was not carried over with it. Simply **Select Image File** again and it should work.

Also, on very few occasions, the program has crashed during the Save Image with New Name. This will use up one of the ID tags, so when you start up the database again, it will skip a number.



was import successful?1 = yes

C:\Users\mchan\Desktop\Road Ecology\RECONYX_ARCHIVE\Classify Photos\Summer 2012\89.5\89.5 W\89.5 W 18

Imported EXIF Data

exiftool.exe has stopped working

Windows is checking for a solution to the problem...

Today is: March-13-13 10:55:29 AM

For Scoring:

When an individual has clearly crossed the passage, Save Image With New Name. Copy the name and find the image of the individual leaving the other end of the passage in the other folder (e.i. if you are in the west, go to the east folder) and then paste the file name followed by a "b": (species_date_number_code**b**)

If you see an individual run across the image and shows no sign of turning back but at the other end, there is no sign of passage, note the direction it was headed and put passage as UNKNOWN

DO NOT worry if you cannot ID an individual. Try and if it is too blurry, classify it as UNKNOWN and in the comments mention what possible species you think it could be.

A handout of example pictures with identification is available to you, as are field guides and a great website to use is the Smithsonian North American Mammals, which provides physical characteristics, and photos as well as life history traits (http://www.mnh.si.edu/mna)

Track / Camera Station Protocol

Track boxes are to be placed at each passage on both the East and West sides following the format found in Figure B.1. Track and camera stations are an establishes method of non-invasive multi-species inventorying and their use and construction was modeled after previous studies used to monitor a variety of species (Jenks et al. 2011; Rovero et al. 2010; Ray and Zielinski 2008; Wiewel et al. 2007; Gompper et al. 2006; Glennon et al. 2002; Carbone et al. 2001) as well as some studies directed specifically towards fishers (*M. pennanti*) and martens (*M. americana*) (Thayer et al. 2008; Green 2007; Mowat et al. 2000; Forseman and Pearson 1998).

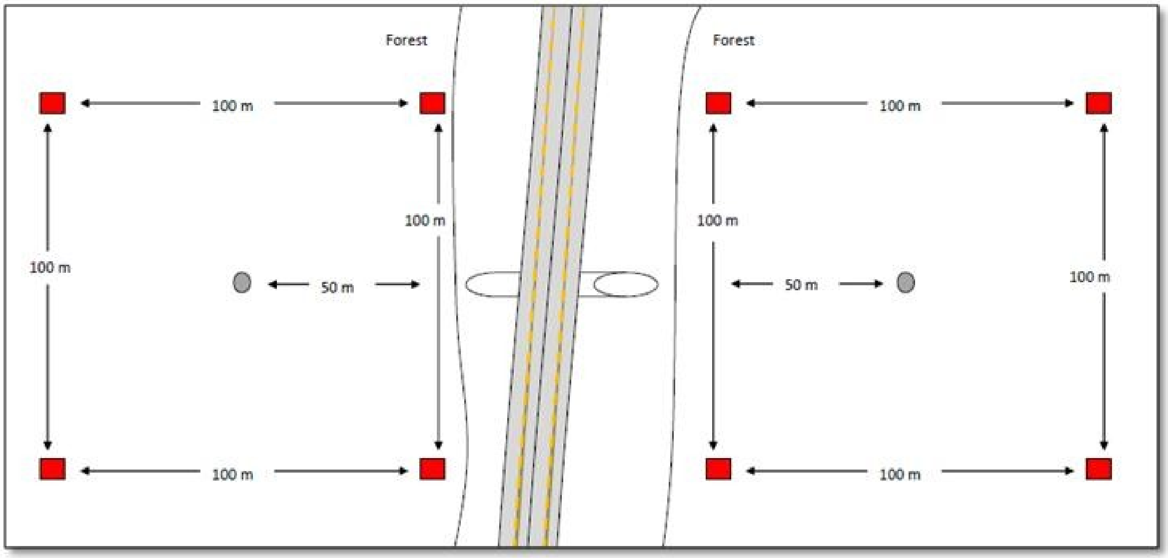


Figure B.1. Four trackboxes are placed at the East and West entrance of each wildlife passage beginning at the forest edge.

Method for Track Box Grid Formation

From the below-grade wildlife passageway we walked to the nearest forest edge, this edge point was flagged and marked with a GPS coordinate. From this point, we took a back-bearing using the road as a reference so that our bearing was perpendicular to the road. From this we obtained our original azimuth by which we are able to remain perpendicular to the passageway entrance and the road. To get to the first track station, point A, we subtracted 90° from our azimuth and obtained the new bearing; we then projected a waypoint in the GPS which was 50 m away at this new bearing for point A. Inversely, to get the last track station, point D, we added 90° to our azimuth to get the bearing for point D and projected a waypoint 50 m away at this bearing. Point A and point D are therefore 100 m apart and placed approximately 5 m from the edge, into the forest. If the point fell in an open area we took our original azimuth and follow this to the forest and entered 5 m into the forest. Projected waypoints were moved on the GPS to relocate the point if field characteristics made this necessary. Track boxes are placed within 5-10m of point because of the difficulty finding a suitable opening for the track box, exact placement of the track boxes was chosen based on topography as well as animal sign. Points B and C were projected from points A and D respectively at 100 m and with the degree of our original azimuth. Each point was roughly 100 m from each other. Exceptions occurred in the event of a major landscape characteristics which was inevitable. For example, if points B or C fell into a powerline these points were pushed back into the forest and so they may be further than 100 m from the other points.

Track Box and Camera Station Session Protocol

The initial 'set' day of the track boxes is when, for the first time, ink and track paper are added to the boxes as well as fresh lure (8 oz. of seal oil and 10 drops of anise oil). When track paper is placed into the track box the set date and station ID number will be inscribed on the back of the paper using a permanent marker. Check days will be 15 days later. As an example if the box is 'set' on the first Monday of a 10 day session it will be checked on the first Monday of the next session. On check days the track boxes will be visited, track paper will be pulled and conserved for analysis and to serve as a permanent record. When track paper is pulled the pull date will be inscribed on the back of the paper and the station ID number will be verified for accuracy. The track paper will be replaced and new oil and lure will be added if needed. Track box paper will be carried out of the field with the upmost of care, using either artist tubes or a chloroplast case. Once these papers have been returned to the cabin, they will be examined and tracks will be measured (both anterior and posterior) these measurements as well as the species ID will be recorded in the Track Box database. Any comment regarding uncertainty of the identification or idiosyncrasies will be added to the comment section of the database.

Carnivore/Marten cameras are to be installed 50 m from the forest edge closest to the passageway entrance. These cameras are set up facing a baited and lured tree. This tree has a thin diagonal cut into the trees bark, under which 1-2 Tbs. of Gusto and Vaseline have been placed. In addition on day one of season opening of track boxes a piece of beaver meat was buried at the base of the tree. The meat was buried at this time because the heat and insects at this time would have putrefied the bait too quickly had it been tied to the tree. Once temperatures have cooled the bait can be tied to the bait tree with wire. SD cards will be changed and batteries checked on the same day as the track boxes are checked. Like the passageway's batteries should be changed if they are at less than 15% SD cards should be uploaded to the database that same day.

Track Box Construction

Materials required:

- Black coroplast 122cm x 244cm (4ft x 8ft) sheets cut into 122cm x 122cm (4ft x 4ft)
- Polystrene 020 cut into 49.8cm x 122cm
- Brown kraft paper
- Blackline Chalk
- Mineral oil
- Essential oil-Anis
- Seal oil
- Anis and Seal oil was replaced with mix of castorium and mineral oil in 2013 (provided to us by Eric Alain) in order to decrease bear damage to the boxes
- Plastic cups (for lure)
- Red tape
- Wooden stakes (2012)-In 2013 we did not purchase these, used branches and stakes found in the field
- Measuring tape
- Exacto knife
- Square ruler
- Axe
- Compass
- Paint brush
- Gloves (vinyl)
- Bottles for ink
- Compass
- GPS

1. Coroplast is first cut into 122cm x 122cm sheets.
2. Coroplast is then scored into the following dimensions; 60cm, 50cm, 12cm. Score lines are made parallel to the 'grain' of the coroplast to retain strength.
3. Two sheets are then folded together into a box, one 12cm flap is folded under and the other 12cm flap folded over and then the box is taped together to ensure stability.
4. Once constructed the box can be folded flat and transported this way. In addition, boxes can be overwintered in the field by collapsing them and leaving them at their grid station.
5. Two additional flaps of (40.6cm x 122cm) length are scored into 35,9 cm x 50.2cm x 35.9 cm lengths and are placed at each end of the box to provide additional protection from the rain. Approximately 10cm of the extensions are overlapped and 30.6 cm extends over the boxes floor.
6. The boxes are placed at their grid station on flat ground or they are wedged against a tree, boulder or downed log. Additional wooden stakes are used to solidify them, and then metal wire is used to tie together the stakes (or one stake and one tree) to ensure that the box is stable and this reduces wobbling.
7. The boxes location is based on the grid formation, however the precise location is chosen within 5 m of the grid point. The location is chosen based on the presence of flat ground, trees and animal signs (for example, hare paths etc.).

8. Plastic cups are taped to the top of the inside of the boxes and 1-2TBLS of lure (Seal oil and anis oil) are added to the cup. The mixture recommended is 10 drops of anise oil for 1 pint or 16 oz of fish or seal oil.
9. The polystyrene sheet is placed inside the box, shiny side facing up, and the brown kraft paper (46cm x 50cm) is taped to the middle of the polystyrene sheet.
10. Ink (blackline chalk and mineral oil) is then painted onto the polystyrene track plate on either side of the kraft paper. The dimensions of the inked surface are 38 cm x 50cm on either side of the paper.

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