AUDITING A MONITORING PROGRAM: CAN CITIZEN SCIENCE DOCUMENT WILDLIFE ACTIVITY ALONG HIGHWAYS?

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Auditing a monitoring program: Can citizen science represent wildlife activity along highways?

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Mitigating wildlife barriers caused by transportation corridors is an effort occurring across North America. Data on wildlife activity is important for effectively locating sites for mitigation measures. *Road Watch in the Pass* (RW) is a pioneering citizen science monitoring program that engages citizens in collecting data concerning wildlife activity along a highway. It was developed to serve as a supplemental source of information on wildlife activity locations along a 2-lane highway in Crowsnest Pass, Alberta, Canada. This region has been highlighted as a critical area for wildlife movement. There are plans to upgrade Highway 3 to four lanes, with resulting increased traffic volume and speed. The information RW collects is intended to assist mitigation efforts.

This study provides an evaluation of RW, assessing the ability of RW to represent visible wildlife activity along Highway 3. A driving survey was created to collect systematic data assumed to accurately document visible wildlife within 100m of the highway. This was used to compare its spatial, temporal, and species composition wildlife observation distributions to the information gathered by RW using various analyses.

Due to its unsystematic nature and lack of sampling effort documentation, RW is limited in its ability to make some statistical conclusions, thus limiting some analyses and conclusions of this study. Despite these problems, the spatial distribution of RW wildlife observations corresponded with the systematic dataset in the spatial analyses. There was statistical agreement between RW and systematic observation locations up to 4km distances, and there was no significant evidence that relative proportions of wildlife observations by 1-km segment were different between the two datasets. The systematic dataset displayed differences in observation rates by time of day and season. RW in its current form cannot provide unbiased temporal information. Both datasets documented high levels of deer observations and very low levels of non-deer observations, indicating that they are effective at documenting deer but not effective at observing non-deer species.

Several modifications are recommended to enhance the scientific rigor of this pioneering citizen-science program and provide guidance for groups aiming to use a similar volunteer highway wildlife monitoring program.

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INTRODUCTION

Background

The negative effects of roads on wildlife have been widely documented (Bennett 1991, Forman and Alexander 1998, Spellerberg 1998, Trombulak and Frissell 2000, Forman et al. 2003, Coffin 2007). Roads, particularly high-speed highways, can lead to the fragmentation of habitats and populations (Trombulak and Frissell 2000) through road avoidance behavior, movement barriers, and wildlife-vehicle collision (WVC) mortality. The probability of successful crossings decreases with increasing traffic volumes, vehicle speeds, and road widths (Servheen et al. 1998, McCown and Eason 2001, Forman et al. 2003, van Langevelde and Jaarsma 2004, Waller et al. 2005, Gagnon et al. 2007). These effects of roadways can threaten the viability of local populations of some species (Proctor et al. 2005), decrease connectivity of metapopulations (Epps et al. 2005, Proctor et al. 2005), and cause considerable safety issues for motorists (L.P. Tardif and Associates 2003).

Incorporating wildlife ecology considerations into design and alignment of roadways can reduce negative roadway impacts (Forman et al. 2003). Yet, most existing roads were built before such ecological understanding was widespread (Forman and Alexander 1998). For these roads, mitigation measures can be used to minimize existing detrimental impacts. Mitigation measures include a range of techniques and tools, including signage, warning lights, animal detection warning systems, decoys, whistles, and reflectors. These measures have mixed success in increasing road permeability (Romin and Bissonette 1996, Forman et al. 2003). Wildlife crossing structures are widely used as mitigation measures, and numerous studies have demonstrated that such structures can reduce roadway impacts on medium to large mammals (Reed et al. 1975, Singer and Doherty 1985, Clevenger and Waltho 2000, Goosem et al. 2001, Cain et al. 2003, Dodd et al. 2004, Clevenger and Waltho 2005). This is particularly true when crossing structures are coupled with wildlife fencing to help funnel wildlife towards crossing areas (Foster and Humphrey 1995, Yanes et al. 1995, Putman 1997, Clevenger et al. 2001, Taylor and Goldingay 2003, Ng et al. 2004, Dodd et al. 2007).

The success of such mitigation measures is strongly influenced by their placement (Foster and Humphrey 1995, Servheen et al. 1998, Clevenger and Waltho 2000, Malo et al. 2004, Ng et al. 2004). Wildlife road crossings and WVCs are usually clustered in space and time (Puglisi et al. 1974, Gibeau 2000, Hubbard et al. 2000, Clevenger et al. 2001, Clevenger et al. 2003, McCoy 2005, Waller and Servheen 2005). Additionally, species have unique spatial movement requirements and behaviors (Beier and Loe 1992, Yanes et al. 1995, Rodriguez et al. 1996, Clevenger and Waltho 2000, Clevenger and Waltho 2005, Mata et al. 2005). Therefore, mitigation planning should use spatial and temporal activity data for target wildlife species along roadways. Highway designers can use such information to place mitigation measures in areas of highest use; these can be included during retrofitting or reconstruction projects.

Driver safety is generally the main concern of transportation departments when considering wildlife, so many decision-makers and studies have used WVC locations to infer characteristics about where various wildlife species cross highways (Romin and

Bissonette 1996, Finder et al. 1999, McCown and Eason 2001, Clevenger et al. 2003). Areas of highest WVC densities are often recommended or used to determine placement of mitigation measures (Singer and Doherty 1985, Romin and Bissonette 1996, Biota Research and Consulting 2003, Malo et al 2004, Ramp et al. 2005, Ramp et al. 2006). However, focusing only on areas where wildlife unsuccessfully cross may lead to an inaccurate understanding of wildlife movement (Neal et al. 2003), as wildlife may cross highways successfully in different places than indicated by mortalities (McCown and Eason 2001, Alexander et al. 2005, McCoy 2005, Lee 2007). Areas of successful crossings and few WVCs under current conditions may become fatality hotspots as road widths, traffic volumes and/or speeds increase. It is therefore important to incorporate other data sources to aid in identifying areas of highest wildlife use along roadways when planning for the placement of mitigation measures.

Transportation departments seldom have data on live animal movement (Clevenger et al. 2002). Methods for determining wildlife activity along roads other than WVC data collection include track surveys (Scheick & Jones 1999), telemetry-monitoring of animal movements (e.g. Foster and Humphrey 1995, Gibeau et al. 2001, McCown and Eason 2001, McCoy 2005, Waller and Servheen 2005), expert-opinion modeling (Clevenger et al. 2002, Ruediger and Lloyd 2003, Lloyd and Casey 2005), and predictive models of wildlife movement (Finder et al. 1999, Clevenger et al. 2002; Malo et al. 2004, Ramp et al. 2005). Yet, the necessary resources may not be available to use such methods and some methods, such as remote cameras, are limited in scope and feasibility for long stretches of highway. This can lead to a lack of knowledge regarding wildlife movement hotspots, reducing the ability to develop effective mitigation measures.

Crowsnest Pass

The Crowsnest Pass of southwestern Alberta, Canada is identified as a key linkage zone within the Rocky Mountains for regional-scale wildlife movement and has been deemed a priority for conservation planning (Chetkiewicz 2002, Carroll et al. 2001, Weaver 2001). It is the lowest pass in the central Rockies. Alberta Highway 3, a 2-lane transportation route including segments with turning lanes that cuts through the Crowsnest Pass, partially fragments grizzly bear populations by acting as a partial barrier to grizzly bear movement (Proctor et al. 2002, Proctor et al. 2005). In the future this highway may constitute an irreversible fracture zone to large carnivore and ungulate movement patterns as traffic volumes and road width increase (Apps 1997, Weaver 2001, Proctor et al. 2002). Wildlife mortality from WVCs on Highway 3 in the Crowsnest Pass is approximately 109 large mammal deaths reported annually, and is recognized as a major human safety concern and wildlife conservation problem (Lee et al. 2006).

The volume of traffic along Highway 3 is increasing. In response, the Province of Alberta proposed an expansion and realignment of the highway through the Municipality of Crowsnest Pass (AIT 2006b). The expansion, from two to four lanes in the next 10-15 years, has the potential to increase direct wildlife mortality and intensify the barrier effect of the highway, as increased road size may reduce successful crossings (Servheen et al. 1998, McCown and Eason 2001, Forman et al. 2003). A proposed $1.5 billion resort development also has the potential to seriously affect wildlife in the Pass with increased traffic and human recreational activity levels that could disrupt wildlife movement and activity, as it is predicted to attract hundreds of thousands of tourists each year. Specific data documenting where wildlife cross Highway 3 within the Crowsnest Pass are lacking. Information on WVCs collected by highway maintenance contractors is one of the only other sources of wildlife movement data in the Crowsnest Pass. These data may not account for the possibility of changes in locations of crossing success and failure with the incoming road improvements.

Road Watch in the Pass

To address the dearth of recorded information concerning where wildlife cross Highway 3, *Road Watch in the Pass* (RW) was developed and implemented by the Miistakis Institute for the Rockies, an applied research institute affiliated with the University of Calgary. Road Watch is a community-based monitoring project that engages local volunteers in reporting observations of medium and large mammals along Highway 3 through the Crowsnest Pass in southwestern Alberta, Canada (Lee et al. 2006). Road Watch was developed, in part, to engage the local community in monitoring, highlight the value of data collected by the community, and foster an atmosphere where citizens engage in a learning process about their natural environment (Lee 2007). The other objective of RW, which is relevant to this study, is to produce a large dataset of locations where wildlife are crossing, adjacent to, or killed on Highway 3. Road Watch intends to provide this data to support decision making for reducing wildlife vehicle collisions and for developing mitigation measures for the proposed expansion of Highway 3. It is not intended to identify specific locations for mitigation, but rather to act similarly to other citizen monitoring programs as a "red flag," helping develop priority areas for finer scale, more systematic follow-up investigation (Savan et al. 2003, Nicholson et al. 2002).

Volunteers of RW are not required to drive the full length of the study area; their data are opportunistic wildlife observations made while driving the highway. Citizens use an interactive web-based mapping tool (www.rockies.ca/roadwatch) to report animal sightings along Highway 3. High-resolution (1m) digital imagery assists participants in positioning the location of their wildlife observation. Once the observation site is located, participants are prompted with an input form to provide information on species observed, age, whether the animal was adjacent to or crossing the road, status (dead, alive, injured), location description, date and hour of sighting, and additional comments. Groups of animals are recorded as a single observation, noting the number of individuals in the group. Users can view their contributions to the project over time and view all observations.

Since its implementation in 2004, over 70 users have entered over 2400 observations, reporting eleven species of ungulates and carnivores along the highway. Most of the large mammals occurring in the region have been reported, including grizzly bear (*Ursus arctos*), black bear (*Ursus americanus*), lynx (*Lynx canadensis*), cougar (*Puma concolor*), coyote (*Canis latrans*), and wolf (*Canis lupus*), as well as elk (*Cervus elaphus*), mountain goat (*Oreamnos americanus*), moose (*Alces alces*), mule deer (*Odocoileus hemionus*), white-tailed deer (*Odocoileus virginianus*), and Rocky Mountain bighorn sheep (*Ovis canadensis*).

Assessing citizen science

The utility of citizen science is sometimes regarded with skepticism within the scientific community (Stokes and Havas 1990, Heiman 1997, Engel and Voshell 2002). Some disadvantages of citizen science include lack of data credibility, standardization, quality assurance, and data completeness (Stokes and Havvas 1990, Engel and Voshell 2002, Gouveia et al. 2004). In order to be integrated meaningfully into decision-making processes, it is essential that these data be viewed as valid and reliable (Heiman 1997, Engel and Voshell 2002). Good experimental design, quality assurance planning, and data quality control assessments are necessary (Heiman 1997, Engel and Voshell 2002, Savan et al. 2003, Boudreau and Yan 2004).

Audits of some citizen science programs have been performed, with most studies comparing the accuracy of volunteer-collected and expert-collected data (Bromenshank and Preston 1986, Au et al. 2000, Fore et al. 2001, Engel and Voshell 2002, Genet and Sargent 2003, Newman et al. 2003, Boudreau and Yan 2004, Galloway et al. 2006). The results of such assessments have been mixed. Some studies report a higher degree of variability in certain parts of the volunteer data than professional data (Nicholson et al. 2002, Foster-Smith and Evans 2003, Galloway et al. 2006). In other studies, volunteer results are deemed reliable since they are consistent and comparable with expert-collected monitoring data (Bromenshank and Preston 1986, Darwall and Dulvy 1996, Becker et al. 1998, Au et al. 2000, Fore et al. 2001, Engel and Voshell 2002, Nicholson et al. 2002, Newman et al. 2003). Once assessments are performed and programs critiqued, volunteer protocols that produce more accurate data can be developed (Bromenshank and Preston 1986, Engel and Voshell 2002, Savan et al. 2003).

Citizens can be particularly useful for monitoring wildlife along roadways. They drive specific areas regularly and may be concerned about the human safety and animal welfare impacts associated with WVCs. They can provide a large sample size of wildlife observations at a low cost when that data may otherwise not be collected. Despite their potential usefulness, few highway-related projects incorporate citizens in their research (Biota Research and Consulting 2003, Ruediger and Lloyd 2003, Lloyd and Casey 2005, Moskotwitz et al. 2007). Methods for citizen highway wildlife monitoring have therefore not been previously developed or audited.

As Road Watch is a pioneer in using citizens for wildlife crossing data collection, it requires an audit to examine its ability to accurately represent visible wildlife activity along Highway 3. Potential data quality concerns identified for RW include spatial error in locating observations on the mapping tool, misidentification of species, discontinuous reporting activities, and the unsystematic nature of data collection (Lee 2007). RW program staff took steps to reduce error associated with marking observations accurately on the mapping tool by using 1-m air photo and highlighting 62 locally recognized landmarks. To reduce species misidentification, a wildlife tutorial page on the project website was added and carnivore observations are emailed directly to a local government wildlife biologist for verification (Lee 2007).

The remaining data quality concerns are that data are based on opportunistic observations by volunteers driving along the highway for other purposes and are therefore not systematically collected, making the program susceptible to discontinuous reporting activities. Currently, there is no documentation of the spatial or temporal coverage of participation activity; it is unknown how often specific stretches of the highway or certain times of day are driven. Further, there is no documentation of when, where, and how often participants drive but do not see an animal, which essential to determine where and when animals are not occurring. Additionally, though in the last 3 years there have been 65 users with 70% having entered observations more than once, most of the records are from a few individuals. These dedicated individuals may influence the quality of data and their driving patterns may bias RW data. Another problem is that citizens may be more likely to report unique or rare species rather than every animal seen, as they are more memorable or perceived as more important to report without understanding the bias this selective sampling can create (Galloway et al. 2006).

Without a way of documenting this information, the RW data may be open to spatial, temporal, and species-based biases that cannot be statistically quantified and considered when interpreting these data. These existing problems and possible biases in the current RW data collection method need to be addressed to improve the reliability and accuracy of the RW program.

Objectives

I made the assumption that RW aims to be recognized and used as a legitimate data source, which should have rigorous data collection methods. My main objective was to assess the ability of RW to represent visible wildlife activity along Highway 3.

My specific objectives were to:

- develop a rigorous driving survey sampling method for collecting data systematically,
- assess RW methodology in its capability of providing analyzable data,
- assess accuracy of spatial, temporal, and species distributions of RW wildlife observations by comparing the RW dataset to the systematic dataset either quantitatively if possible or qualitatively if not possible,
- recommend modifications to enhance the scientific rigor of RW,
- and provide guidance for groups aiming to use a similar volunteer highway wildlife monitoring program.

To assess whether RW is accurately representing wildlife along Highway 3, I asked:

Spatial

- Are wildlife observations from the systematic dataset spatially distributed in a non-random, clustered pattern and at what distance scales? Are wildlife observations from the RW dataset spatially distributed in a non-random, clustered pattern and at what distance scales?
- Are observations from the 2 datasets spatially correlated to each other and does that change over different distances?

- Do the 2 datasets document similar proportions of wildlife at the same discrete sections of the highway?

Temporal

- Do wildlife activity levels vary by time (time section, hour, season) in the systematic dataset?
- Do observation levels vary by time for the RW dataset similarly to the wildlife activity levels of the systematic datasets?

Species

- Do wildlife activity levels of different species vary by time in the systematic dataset?
- Do both methods detect multiple species and are the species seen at similar frequencies between the programs?

STUDY AREA

The study area included the Crowsnest Pass area in southwestern Alberta, from the border with British Columbia east to the town of Lundbreck (Figure 1).

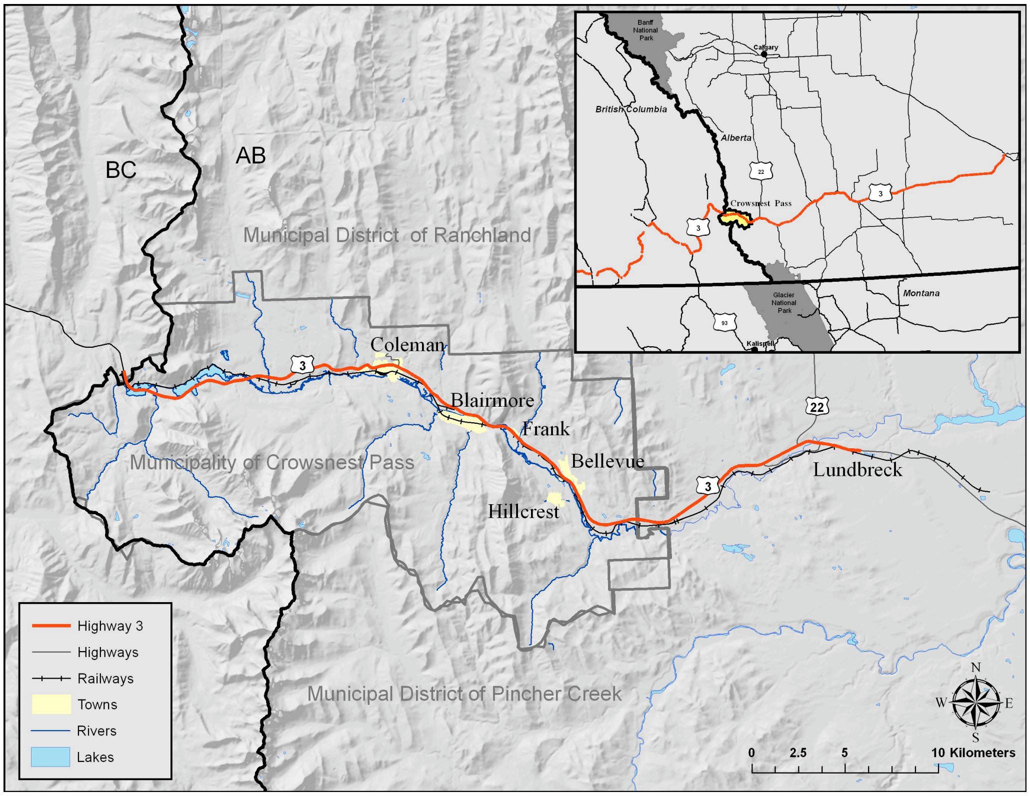


Figure 1. Study area: Highway 3 from the Alberta-British Columbia border to Lundbreck, Alberta

The area consists of the communities of Blairmore, Bellevue, Frank, Hillcrest, and Coleman, which collectively make up the Municipality of Crowsnest Pass, with a total population of 5,750 in 2006. Data were collected along a 46-km stretch of Alberta Highway 3, currently a 2-lane transportation route including segments with turning lanes. The traffic volume is approximately 2,500 to 10,500 vehicles per day with most traffic occurring in July and August and peak daily traffic occurring at 5pm (AIT 2006a). It serves as a trucking route, a commuter route between Calgary, AB and Fernie, BC, and a local commuter road between the 6 communities within the area. The signed vehicle speed limits range from 50-km to 100-km per hour. There is little fencing and few cement medians or cement guard rails along the highway, and there are few culverts or bridges that could serve as wildlife crossing structures.

The highway generally parallels the Crowsnest River Valley and the railroad. Land types next to the highway include lakes, creeks and the Crowsnest River, marshes, cliffs, hills, mixed forest, an enormous rock slide (Frank Slide), and open prairies and agricultural fields. Human developments and impacts occur at varying intensities along the Highway 3 transportation corridor. Land use on public and private lands in the region include town residences, large ranches, forestry, a former lumber mill, a sour gas plant, and recreation such as camping, hiking, recreational vehicle use, and hunting and fishing. The eastern half of the transect is typified by grassland and aspen parkland within private ownership, while the western section is characterized by mountains, forested hillsides, and town sites surrounded by public lands.

Elevation in the region ranges from 1110-m at the valley bottom to 2800-m at the mountain peaks (Lee et al. 2006). There is a rapid transition from grasslands to alpine in this region, resulting in a rich biological diversity of flora and fauna occurring in natural subregions such as montane, subalpine foothills, aspen parkland, and foothills fescue grasslands. Warm Chinook winds also influence this diversity, partly due to areas intermittently blown snow-free. A full range of large carnivores and ungulates occur in the region, including grizzly bear, black bear, bobcat (*Lynx rufus*), lynx, cougar, coyote, wolf, wolverine (*Gulo gulo*), elk, mountain goat, moose, mule deer, white-tailed deer, and Rocky Mountain bighorn sheep.

METHODS

Data Collection

Driving Transects

I collected observations of visible wildlife activity by driving the 46-km stretch of Highway 3 four times a day between 28 May and 14 August 2006, with an average of 20 drives per week. I performed a drive every other hour within a 7-hour cycle, and this cycle shifted 1 hour each day so that every hour within the 24-hour period was sampled equally. From 15 August 2006 through 31 May 2007, a technician drove once a day averaging 5 drives weekly, randomly sampling hourly, with each hour sampled once per month equally over the study period to allow seasonal analysis. Appendix A displays the time distribution of transects driven.

I recorded date, unique drive number, direction of drive (east or west), weather, and visibility data at the beginning of every drive. Each drive lasted approximately 45 minutes and commenced at the top of the hour. When I observed an animal, I did not stop the vehicle, in order to reduce disturbance to the animal and for driver safety concerns. I performed drives as close to 60km/hr as possible. Species recorded included large and medium-sized mammals (mule and white-tailed deer, elk, moose, bighorn sheep, black bear, grizzly bear, mountain lion, wolf, coyote, and other). I noted UTM location on the highway, distance from highway (0-10m, 10-30m, 30-50m, 50-100m), status (adjacent, crossing), species, behavior, sex and age class, and time observed using a global positioning system (GPS) unit (Garmin eTrex Legend) and a digital voice recorder. I recorded groups of animals as a single observation, and the number of individuals in each group was recorded. I did not use road-killed animals in this study to avoid the confounding effect of agency road-kill removal.

Road Watch data included UTM location, species, date and time by hour, status (adjacent, crossing), user id, and additional participant comments. I stratified the RW dataset to include only complete records. I removed records with content errors, such as missing dates, or inconsistencies between the species identification field and species described in the notes. I classified mule deer and white-tailed deer as deer in both datasets to eliminate any problems with misidentification of species, since obtaining dependable deer observation data from a moving vehicle can be difficult (Carbaugh et al. 1975). I assumed animals occurring in distances beyond 10m from the highway, the distance of the vehicle's headlights, were unable to be recorded during hours of darkness.

I created a base map within ArcGIS 9.2 with a high resolution (1m) digital aerial photograph mosaic as a background and RW observation data and the systematic observation data as separate spatial layers. I snapped locations to the highway using Hawth's Analysis Tools (Beyer 2006).

Spatial data analysis

Univariate Methods

Wildlife activity along highways tends to cluster, with important implications for determining locations for mitigation techniques. To examine whether and to what degree and distance scales observations were distributed in a non-random, clustered pattern in the RW dataset and the systematic dataset, I calculated a linear version of univariate Ripley's K-statistics for each. Because the locations are collected along a road, both processes were viewed as 1-dimensional spatial processes. Ripley's K-statistic describes the dispersion of data over a range of spatial scales (Ripley 1977, Ripley 1981). The K-statistic (adapted from Clevenger et al. 2003) is computed as:

$$\hat{K}(h)_{obs} = \frac{R}{n^2} \sum_{i=1}^{n} \sum_{\substack{j=1 \\ i \neq j}}^{n} \frac{I(d_{ij})}{w_{ij}}$$

with scale distance h, sample size n, and road length R; d_{ij} is the distance between observation points i and j, and $I(d_{ij})$ is an indicator function that returns 1 if $d_{ij} \leq h$ and zero otherwise; w_{ij} is a weighting factor that corrects for the edge effect. Distances were calculated by first projecting the animal's location to the road and then computing the distance of separation from other locations along the road. To assess whether the distribution of each process was significantly different from random, I ran 200 simulations of the K-statistic based on random distributions of points, of equal number of observations to the appropriate dataset.

I used the Ripley's L-function as a scaled, standardized version of Ripley's K-function, defined as: $L(h) = \sqrt{K(h)/\pi} - h$ (Besag 1977). I displayed results as plots of $L(h)$, calculated as the difference between the observed K-function value and the mean of the K-values for the 500 simulations, by distance (Clevenger et al. 2003). This function has an expectation of zero for any value of *h* when the pattern is random, and tends to be positive when locations are clustered and negative when they are not. I deemed significant clustering as any value of *L(h)* above the 95% percentile, calculated as the upper or lower 95th percentile of the random simulations minus the mean of the random simulations. These functions and corresponding 95% confidence envelopes were scripted and computed using the S-PLUS SpatialStats statistical package (Insightful Corp 2005).

Bivariate Methods

As the systematic driving survey presumably represents accurate wildlife spatial patterns, I compared RW to the systematic data to determine the accuracy of RW spatial observations. To examine whether observations from both methods tend to occur together, looking for overall spatial clustering agreement between the two data collection methods (systematic and RW) at a continuum of spatial scales, I completed a bivariate K analysis using a one-dimensional version of Ripley's $L_{12}(h)$-function (Lotwick and Silverman 1982, Diggle 1983).

Ripley's $L_{12}(h)$-function is a scaled, linearized transformation of $K_{12}(h)$ and is expressed (Bailey and Gatrell 1995) as:

$$\hat{L}_{12}(h) = \sqrt{\frac{\hat{K}_{12}(h)}{\Pi}} - h$$

where $\hat{K}_{12}(h)$ is the standard estimator of the intertype Ripley's K-function $K_{12}(h)$ proposed by Lotwick and Silverman (1982) and modified from Bailey and Gatrell (1995) as:

$$\hat{K}_{12}(h) = \frac{R}{n_1 n_2} \sum_{i=1}^{n_1} \sum_{j=1}^{n_2} \frac{I_h(d_{ij})}{w_{ij}}$$

with scale distance h, n_1 and n_2 as the total number of individuals of each process type (systematic and RW) in road length R, d_{ij} is the distance along the road between the ith type $_1$ event and the jth type $_2$ event, $I_h(d_{ij})$ is an indicator function that returns 1 if $d_{ij} \leq h$, 0 otherwise, and w_{ij} is the edge correction factor. The intertype K_{12} function characterizes the spatial relationship between 2 types of points located in the same study area (Goreaud and Pelissier 2003), resulting in a lower value under repulsion and a higher value under attraction (Bailey and Gatrell 1995). The hypothesis being tested was whether there were significantly more RW observations associated with a given individual systematic observation than would be expected if the RW observations were distributed independently of the systematic locations (Goreaud and Pelissier 2003).

I tested the statistical significance of the departure from independence ($\hat{L}_{12}(h) = 0$) using 200 Monte Carlo simulations, where each simulation consisted of randomly and continuously assigning new coordinates to RW observations, while the coordinates of the systematic observations remained unchanged (Lotwick and Silverman 1982, Diggle 1983, Goreaud and Pelissier 2003). If the value of $\hat{L}_{12}(h)$ was significantly larger than 0 according to Monte Carlo 95% confidence envelopes that were generated by recalculating the $\hat{L}_{12}(h)$ formula for each of the 200 simulations, there was positive spatial association between the two processes at range h, so the two processes were in agreement. Deer species prevalence in both datasets (81% RW, 88% systematic) could overwhelm the patterns of other species; therefore I also computed Ripley's L_{12} excluding deer observations from both datasets. The bivariate Ripley's $L_{12}(h)$ function and corresponding Monte Carlo confidence envelopes were computed in S-PLUS (Insightful Corp 2005).

Segment analysis

Wildlife highway mitigation and other conservation and management often occur at specific locations on a highway. I therefore analyzed relative frequencies of wildlife observations per 1-km segment to assess the spatial agreement at specific segments between the RW and systematic datasets, using a permutation modeling process, described below, to allow significance testing of these spatially correlated data. I analyzed the distribution of all species and species other than deer using statistical software (S-PLUS) to develop a script. To compare relative frequencies of observation per segment over total observations of each process between the RW and systematic processes, the observation locations for the RW data were permuted at random 999 times on a continuum between 0 and 46-km, with the road considered a "circle" or "continuous line" for permutation purposes. This was done to maintain the spatial structure of the two processes before comparison. The 1-km relative frequencies for each permutation RW dataset were computed and resulted in 999 sets of 46 relative frequencies (corresponding to the 46 1-km segments) for each spatial process.

The script computed the differences in relative frequencies between the systematic data and the RW permutation data for each 1-km segment. The 25th and 975th difference values at each 1-km segment were found to construct Monte Carlo permutation 95% confidence envelopes. These envelopes assessed the significance of the difference between the relative frequencies of sightings between the RW and systematic processes.

To examine whether the spatial distribution was influenced by participants, I displayed the spatial observation distributions of the 4 participants who provide the most observations to the RW program. I removed the data of one of the observers from the RW dataset and determined whether changing observer effort influenced spatial agreement of RW and systematic observations using the segment analysis.

Temporal analysis

As wildlife can be variably active at different times of day and different seasons, information about temporal wildlife activity patterns is important for appropriate mitigation measures. To examine whether wildlife activity in the Crowsnest Pass supports the literature in finding varying activity levels through different periods, I qualitatively compared wildlife activity by periods from the systematic dataset. These periods consisted of 1) time section (dawn = from 1 hour before to 1 hour after sunrise, dusk = from 1 hour before to 1 hour after sunset, day = between dawn and dusk, night = between dusk and dawn; monthly times of sunrise and sunset times obtained from NRCC 2007); 2) hour of day; and 3) season (solstice and equinox dates: summer = 21 June 2006 – 22 September 2006; fall = 23 September 2006 – 21 December 2006; winter = 22

December 2006 – 20 March 2007; spring = 21 March 2007 – June 20 2007). I accounted for different sampling effort across periods by dividing the number of observations seen in a period by the number of transects driven during that time to get a rate of the number of animals seen per transect during that time. I then created proportions from the total number of animals seen per transect.

I also looked to see if RW observation levels were equal or if there was variation over the different periods. Proportions were calculated by dividing number of observations during a period of total observations from all periods, as RW cannot be adjusted for sampling effort. I compared these RW and systematic proportions to qualitatively display differences in observation levels.

Species analysis

Since wildlife activity levels may differ by time, there may be species-specific differences in activity patterns (Beier and Loe 1992, Yanes et al. 1995, Rodriguez et al. 1996, Clevenger and Waltho 2000, Clevenger and Waltho 2005, Mata et al. 2005). This has implications for addressing possible species-specific mitigation goals and types of mitigation used. I examined species-specific activity levels during time sections and seasons from the systematic data to see if possible differences could be discerned qualitatively.

As citizens could report unique or rare species more so than every animal seen regardless of species, there may be species reporting bias. To examine this, I compared species composition between RW and systematic data using a chi-square test of homogeneity to test for homogeneity between counts of RW to systematic observations among species

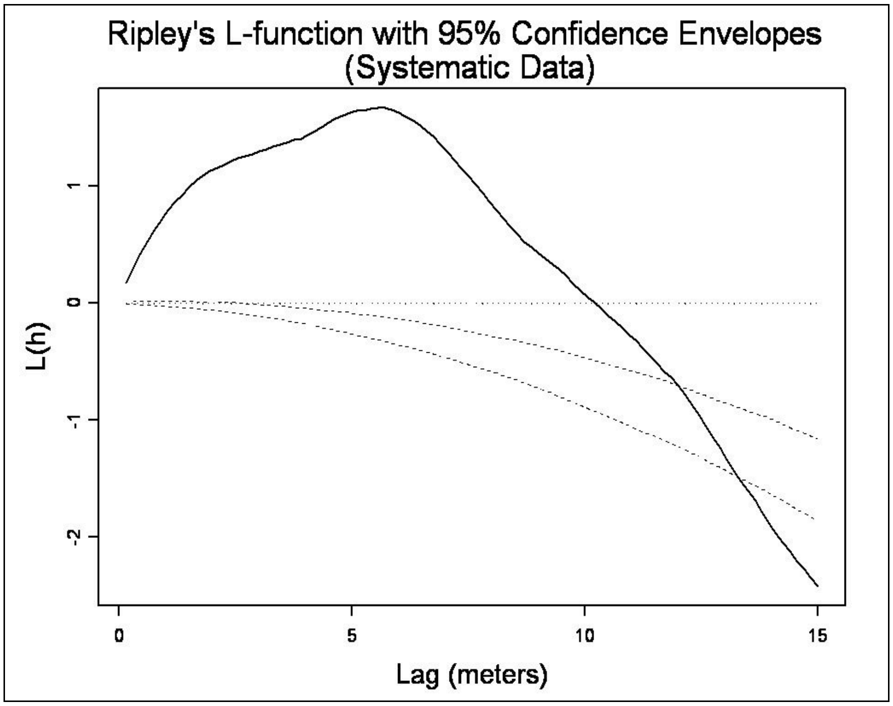
RESULTS

From May 29, 2006 to May 31, 2007, 432 systematic transects were driven (19,900 km total). Of those, 260 transects encompassed 573 wildlife sightings observed within 100m of the highway. During the same period, there were 1136 live wildlife observations reported by 27 RW participants, of which 640 observations were within 100m of the highway. Of the total RW wildlife observations, 4 participants contributed 80% of the data, with each of the 4 individuals contributing roughly the same number of observations. Most observations were of animals adjacent to the highway; only 4% systematic observations and 14% RW observations were of animals crossing the highway.

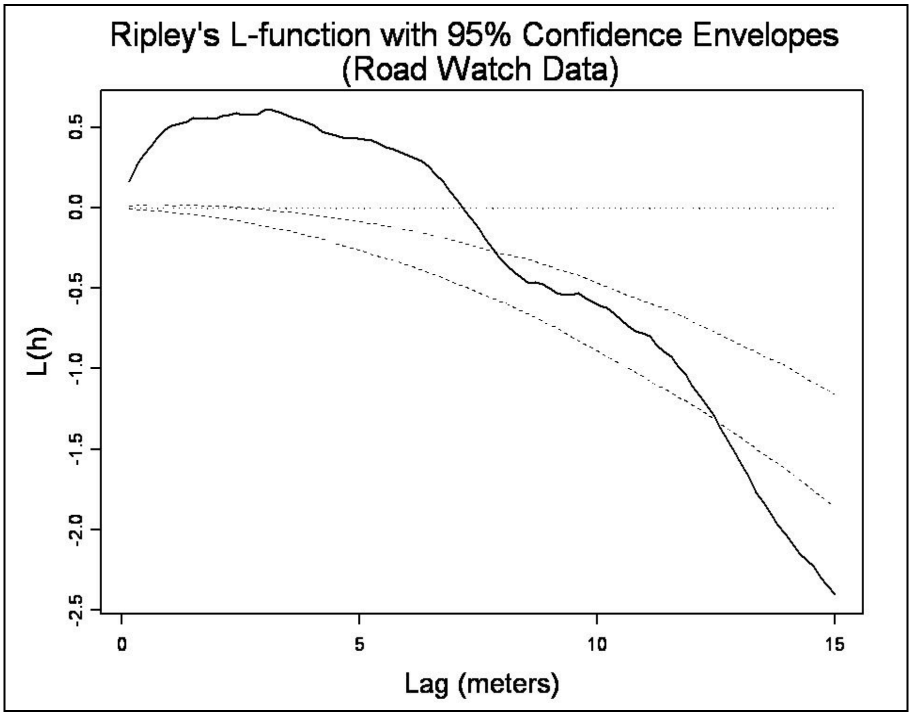
Spatial analysis

Univariate Analysis

The locations of wildlife observations from both the systematic driving survey and the RW process were not randomly distributed along the highway (Figs. 2a, 2b); the univariate Ripley's K analysis indicated that the spatial distribution of wildlife activity observed in both the datasets were heterogeneous and significantly more clustered than would be expected under randomness (significant where it falls out of 95% confidence envelopes).



(a)

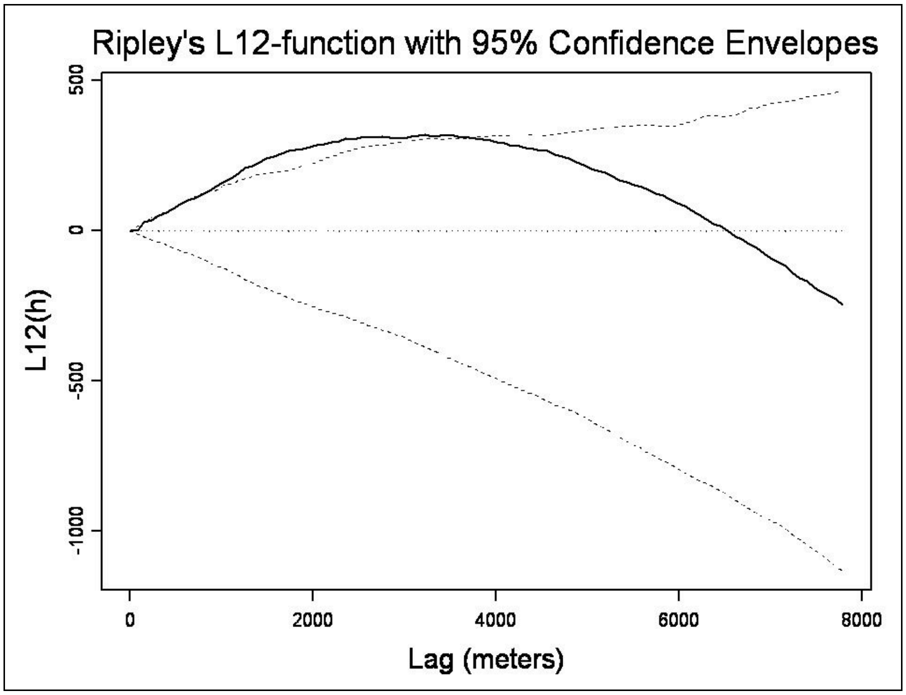


(b)

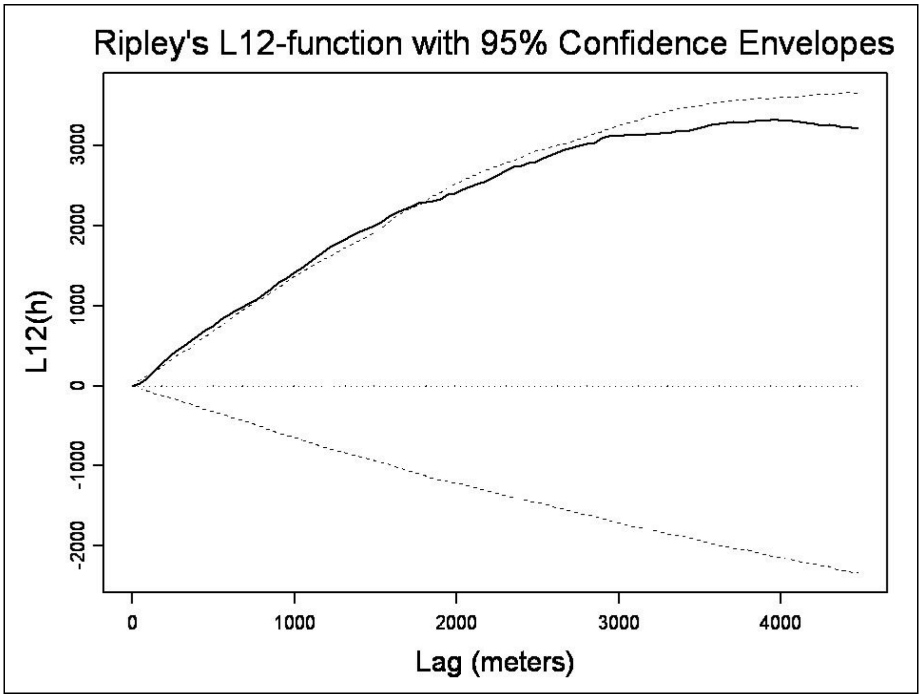
Figure 2a and b. Plot of univariate $\hat{L}(h)$ as a function of linear scale distance *h* in kilometers, from the systematic dataset (a) and from the RW dataset (b). Solid line = $\hat{L}(h)$ function. Short-dashed line = 95% confidence envelope of $\hat{L}(h)$ from 500 randomizations, above which the distribution is significantly clustered at scale *h*.

Bivariate Analysis

In the Ripley's L_{12} analysis, RW and systematic observations were significantly spatially correlated positively when deer were both included and excluded in analysis. The number of RW observations of all species within a distance scale interval within about 4000m from a systematic observation was significantly larger (significant where it falls out of 95% confidence envelopes) than would be expected if the RW observations were distributed independently (Fig. 3a). For species other than deer, the number of RW observations of all species within a scale up to about 2000m from a systematic observation was significantly larger (significant where it falls out of 95% confidence envelopes) than would be expected if the RW observations were distributed independently (Fig. 3b).



(a)



(b)

Figures 3a and b. Plot of bivariate $\hat{L}_{12}(h)$ as a function of linear scale lag distance h in meters, including deer (a) and excluding deer (b). L(h) is the average number of 'extra' neighbors within a distance t of any given individual in the distribution. The 'extra' neighbors are those which were not expected if the individuals of the 2 processes were arranged independently along the transect. Solid line = $\hat{L}_{12}$ (h) function. Short-dashed line = 95% confidence envelope of L(h) from 200 randomizations. The scale of association is the value of the lag h where it extends above (or below) the confidence envelope.

Both datasets contained segments with different clustering levels of wildlife activity. The wildlife observations from the two datasets had similar spatial distributions; the differences in relative frequencies of RW and systematic observations by kilometer were not significant (largest difference $p = 0.12$) (Fig. 4). Similarly, the spatial distributions of relative frequencies from each 1-km segment of observations of species other than deer were statistically similar between the RW and systematic datasets (largest difference $p = 0.17$) (Fig. 5). Appendix B provides a mapped image of the area with the highest non-deer levels.

The spatial distribution of the observations reported by the four main RW participants indicated individual spatial biases (Fig. 6). The relative frequencies of RW and systematic data by segment after removing the data from one of the observers (Observer 3) displayed that the RW relative frequencies were considerably smaller between the 37th and 45th km (Fig. 7). These apparent differences were not significantly different (largest difference $p = 0.06$).

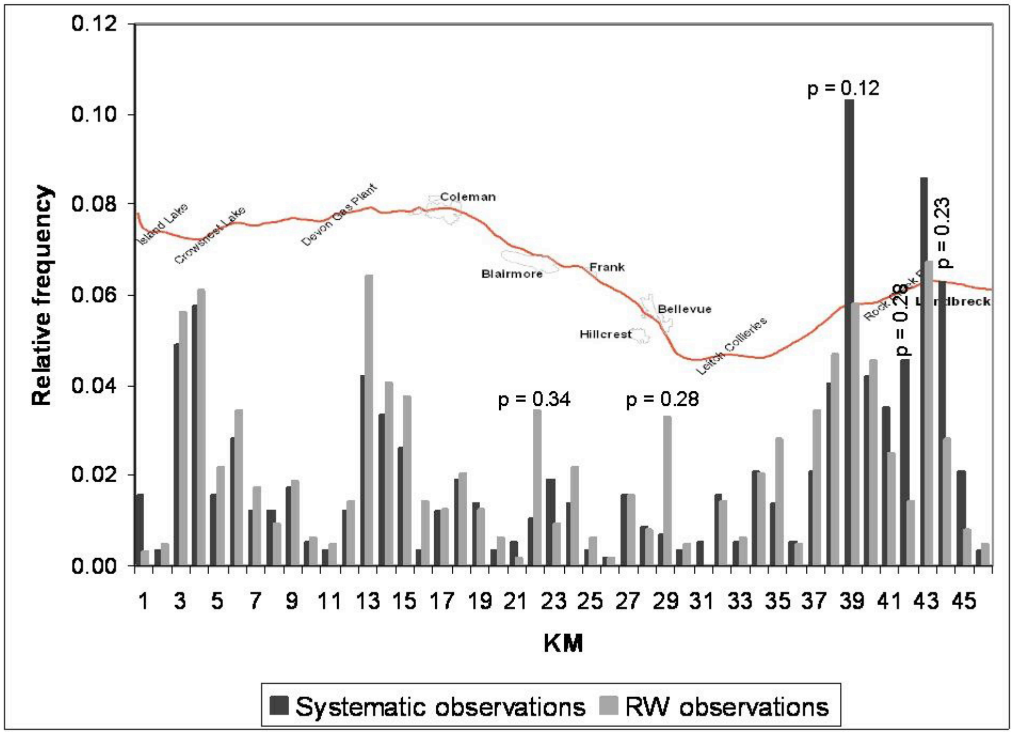


Figure 4. Relative frequencies by kilometer of all species from RW and systematic observations on Highway 3, Crowsnest Pass, Alberta, Canada, in 2006-2007

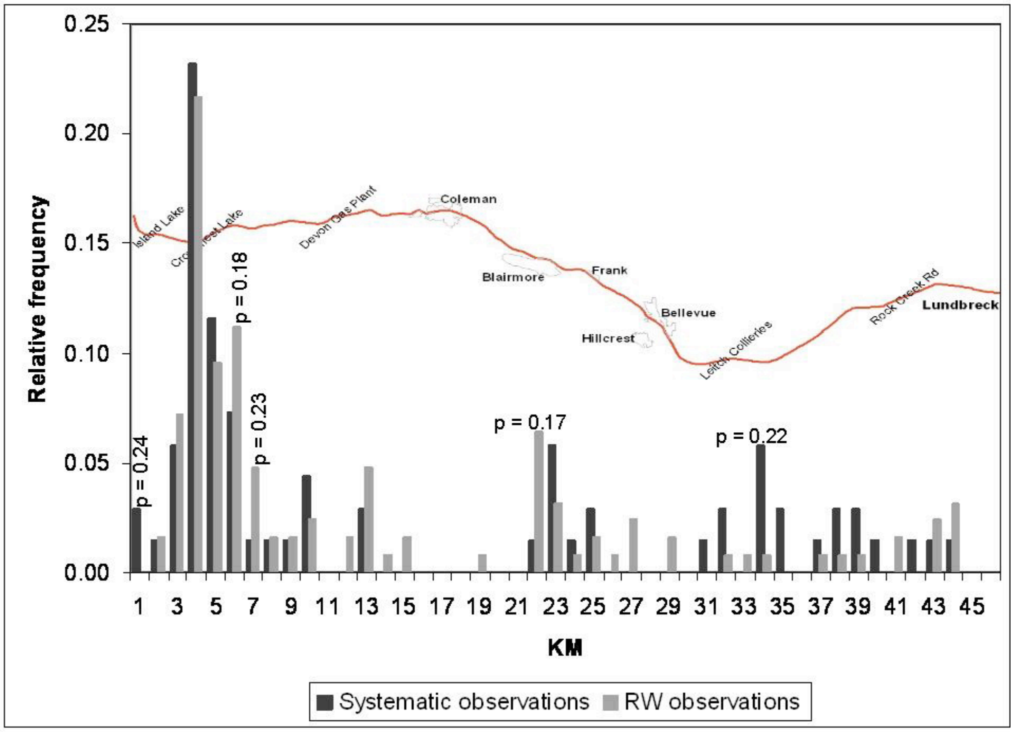


Figure 5. Relative frequencies by kilometer of species other than deer from RW and systematic observations on Highway 3, Crowsnest Pass, Alberta, Canada, in 2006-2007

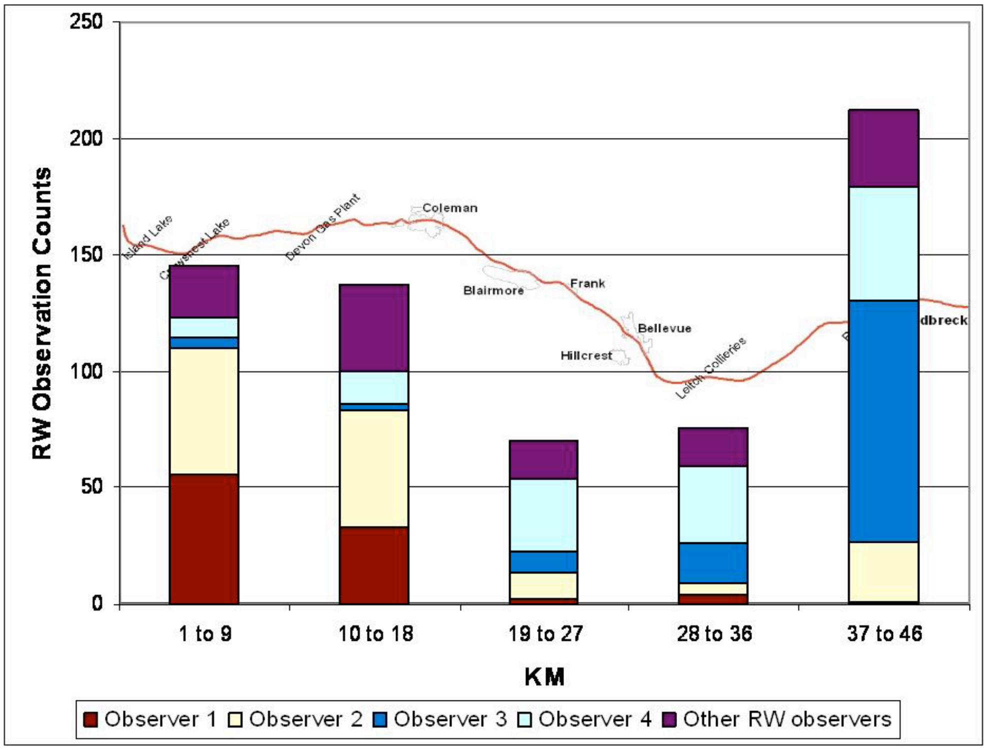


Figure 6. Number of observations of all species by 9-kilometer sections from four main RW participants on Highway 3, Crowsnest Pass, Alberta, Canada, in 2006-2007

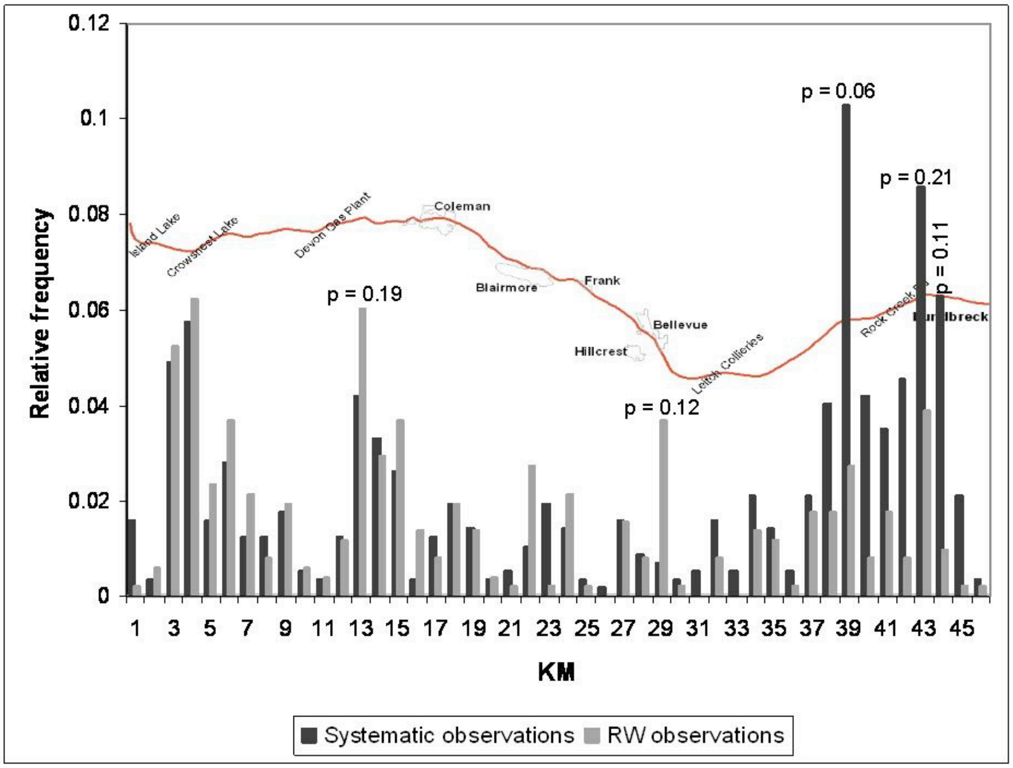


Figure 7. Relative frequencies by kilometer of all species from RW and systematic observations, excluding data from RW Observer 3, on Highway 3, Crowsnest Pass, Alberta, Canada, in 2006-2007

Temporal analysis

Distributions of proportions of wildlife observations by time periods indicated differences in wildlife activity levels within and between the RW and systematic datasets. This was seen by time sections (that account for changing light hours) (Fig. 8), hours (Fig. 9), and seasons (Fig. 10). Average traffic volume patterns did not appear to influence RW and systematic hourly times of wildlife observations (Fig. 9) (Alberta Transportation and Infrastructure 2006).

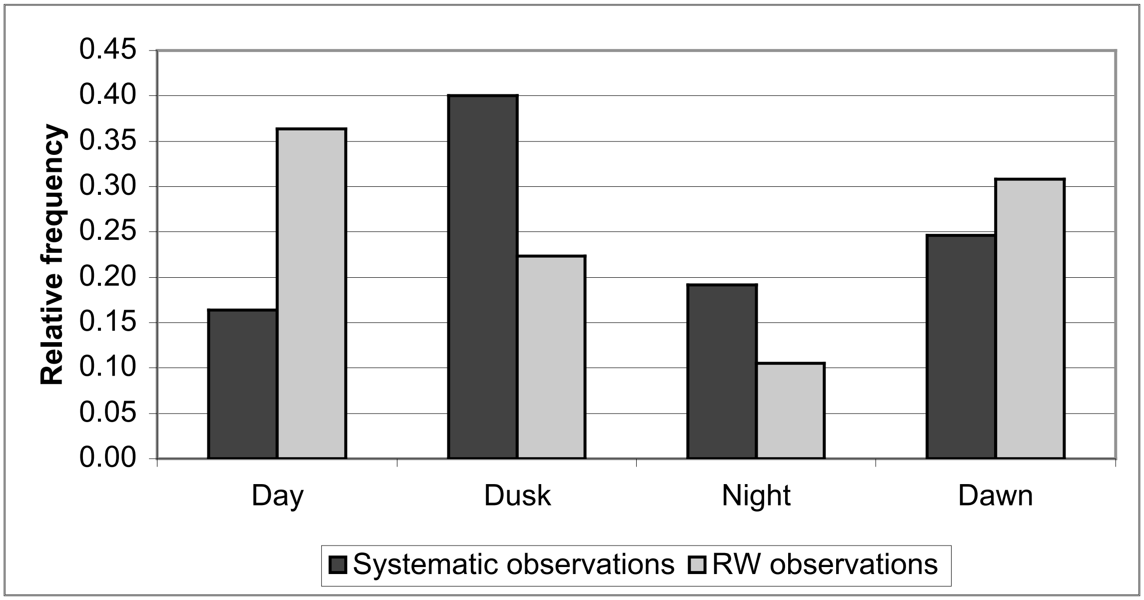


Figure 8. Relative frequencies by time section of all species from RW and systematic observations on Highway 3, Crowsnest Pass, Alberta, Canada, in 2006-2007. Dawn = from 1 hour before to 1 hour after sunrise, dusk = from 1 hour before to 1 hour after sunset, day = between dawn and dusk, night = between dusk and dawn.

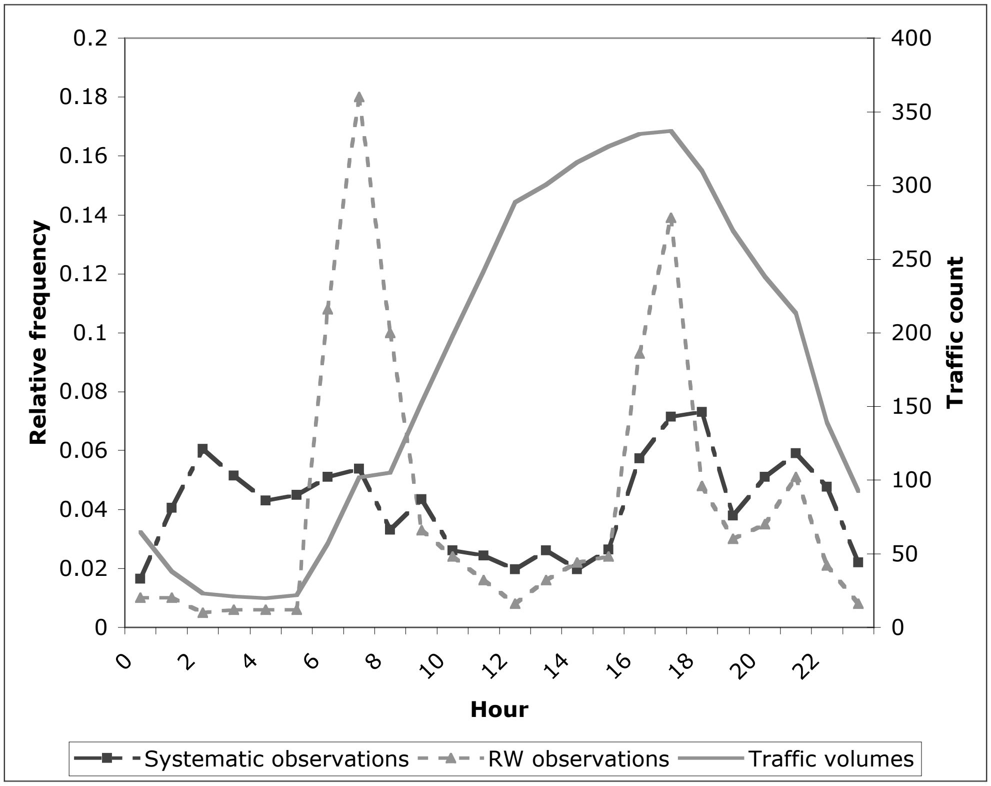


Figure 9. Relative frequencies by hour of all species from RW and systematic observations and traffic volume on Highway 3, Crowsnest Pass, Alberta, Canada, in 2006-2007

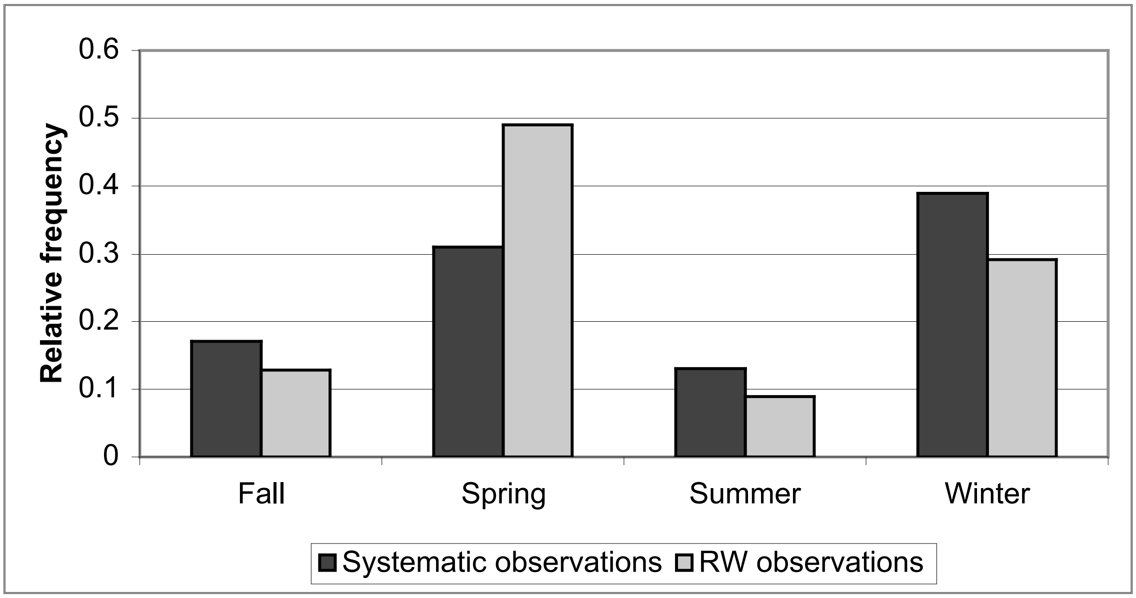


Figure 10. Relative frequencies by season of all species from RW and systematic observations on Highway 3, Crowsnest Pass, Alberta, Canada, in 2006-2007. Seasons based on solstice and equinox dates: Summer = 21 June 2006 – 22 September 2006; fall = 23 September 2006 – 21 December 2006; winter = 22 December 2006 – 20 March 2007; spring = 21 March 2007 – June 20 2007.

Species composition

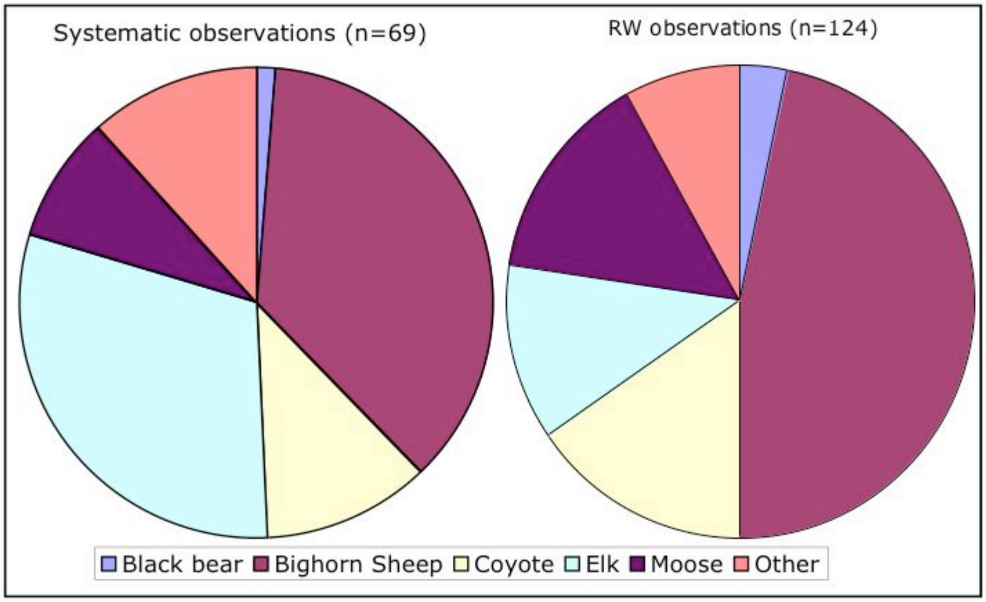
The majority of observations for both datasets were of deer (Tables 1, 2). The species compositions of deer and species other than deer were similar ($\chi^2 = 2.01$, 1 df, $p = 0.156$) between the two datasets. RW and systematic species compositions were significantly different ($\chi^2 = 11.2$, 4 df, $p = 0.025$) when deer were excluded from analysis to avoid swamping (Fig. 11) (note: black bear lumped with other in chi sq analysis). Activity levels of species differed by time section (Fig. 12).

Table 1. Numbers of species individuals, observations, percent of total observations, and rate of observations by number of transects, from systematic data

Species	Number of observations	Percent of total observations	Rate of observation by number of transects (n= 432)
Black bear	1	0.2	0.002
Bighorn sheep	25	4.4	0.058
Coyote	8	1.4	0.019
Deer	504	88.0	1.164
Elk	21	3.7	0.049
Moose	6	1.0	0.014
Other	8	1.4	0.019
Total	573	100	

Table 2. Numbers of species individuals, observations, and percent of total observations from RW data

Species	Number of observations	Percent of total observations
Black bear	4	0.6
Bighorn sheep	58	9.1
Coyote	19	3.0
Deer	516	80.6
Elk	15	2.3
Moose	18	2.8
Other	10	1.6
Total	640	100



Figures 11. Relative frequencies by species other than deer from systematic and RW observations on Highway 3, Crowsnest Pass, Alberta, Canada, in 2006-2007

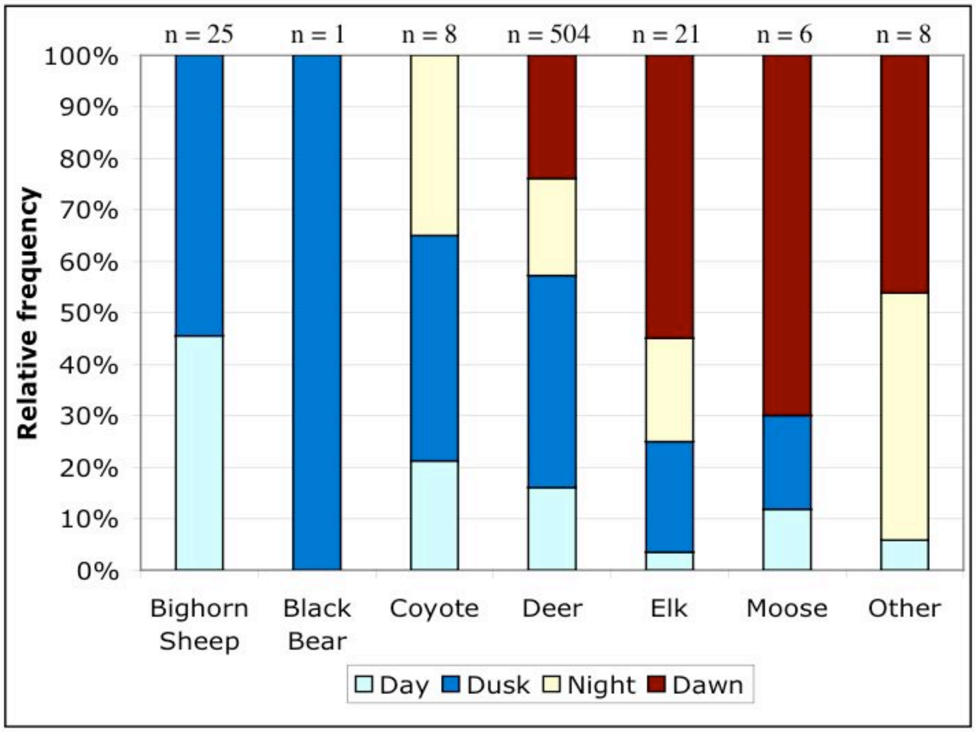


Figure 12. Relative frequencies by species from systematic observations per time section on Highway 3, Crowsnest Pass, Alberta, Canada, in 2006-2007

DISCUSSION

Using volunteers for data collection has gained in popularity as a valuable and relatively inexpensive method to gather needed information. There are many volunteer programs, particularly in ecological monitoring, that collect data used by organizations and government agencies (Stokes et al. 1990, Fore 2001, Engel and Voshell 2002, Nicholson et al. 2002, Boudreau and Yan 2004, Galloway et al. 2006). There are numerous advantages in integrating local citizens into research. Volunteers provide an inexpensive and potentially large labor force (Bromenshank and Preston 1986, Stokes et al. 1990) that can save time and produce long-term datasets while covering a large geographical area (Newman et al. 2003). Volunteers also become better informed and more personally involved in environmental issues (Bromenshank and Preston 1986, Gouveia et al. 2004). These benefits make the use of citizens in data collection valuable.

The intended use of volunteer monitoring data guides the structure of the program, the roles of volunteers, and the training and data collection methods (Savan et al. 2003). Road Watch was not developed to stand alone for fine-scale study or to generate scientifically defensible, detailed siting and design information for mitigation structures on Highway 3. Instead, it is intended act similarly to other citizen monitoring programs as a "red flag" (Savan et al. 2003, Nicholson et al. 2002), by producing a large dataset of locations where wildlife are crossing, adjacent to, or killed on Highway 3 to identify areas of wildlife clustering where further, more detailed research can determine specific mitigation locations. The goals of citizen engagement and fostering an atmosphere where citizens engage in a learning process about their natural environment were not examined within this assessment. The importance of these goals and their implications cannot be diminished. Due to its current unsystematic method of documenting information, however, RW data have limited value on which to base scientifically defensible conclusions of wildlife activity along Highway 3. Yet, the spatial comparisons I performed between systematic data and RW data indicate that RW data do generally represent spatial wildlife patterns. With relatively simple changes to the RW protocol, RW can improve into a rigorous citizen-science highway wildlife monitoring program that can provide analyzable data.

Spatial

The systematic protocol required driving the entire 46-km study area at one time. The RW protocol, taking advantage of citizens' local movements, allows observations from any duration of drive within the study area. Road Watch data reporting does not document the stretches of the highway that were driven nor therefore the frequency that certain segments were driven. This could lead to under- or over-representation of highway sections, without any ability to account for these varying degrees of participant spatial coverage. Therefore, it cannot be concluded that peaks and lows in the distribution of RW wildlife observations were due to different levels of wildlife activity at different locations; rather, they were just as likely due to sampling bias. One RW segment displayed this issue. Kilometer 29 had distinctly, though not significantly, higher observation frequencies than the systematic dataset (Fig. 4). This can likely be attributed to one of the main observers, as it is known that he adds observations if an animal can be seen from his house which is near the highway on that segment. Of the 21

RW observations at that segment, 19 were from that observer.

Without the necessary information, RW is reliant on equal coverage of its participants' driving activities throughout the study area. Between them, the four primary RW participants fortuitously covered the spatial length of the study area (Fig. 6) and submitted roughly equal numbers of observations relatively uniformly across the study area. Yet, the danger of depending upon a few citizens to fully cover the study area in a protocol lacking spatial accountability was highlighted when I removed the data of one main participant. The eastern section of the study area had markedly fewer observations and the 1-km spatial distributions between the two datasets were less similar (Fig. 7).

Knowledge of where wildlife are crossing the highway is essential, since the success of mitigation measures is strongly influenced by their placement (Foster and Humphrey 1995, Servheen et al. 1998, Clevenger and Waltho 2000, Malo et al. 2004, Ng et al. 2004). Areas with the highest frequency of wildlife observations, dependent on focal species, would likely be the areas considered for mitigation. Other elements such as engineering, hydrology, levels of human development and land ownership, and landscape features such as stream crossings and cover on both sides of the highway are also involved in identifying mitigation types and locations. The systematic dataset, with its documentation of sampling effort and rigorous protocol, showed that wildlife are clustering in non-random patterns (Fig. 2a) and can be used to inform where visible wildlife are active at varying levels along the highway (Fig. 4, 5). There were 4 groups of segments that would likely be examined for mitigation based on highest wildlife activity of all species (Fig. 4). The 1-km segments used in this study can help prioritize areas for further research for the exact siting of mitigation measures, or smaller distance scales could be used to examine more specific areas of wildlife clustering along the highway since the Ripley's univariate L function indicated that clustering was observed from 0 to 12 km distance scales (Fig 2a).

Though the RW program is limited in conclusions that it can draw due to its methodology, it is accurately documenting visible wildlife patterns along Highway 3 in the Crowsnest Pass. The spatial distribution of RW wildlife observations was validated by the systematic dataset in both the overall and 1-km segment spatial analyses; there was statistical agreement between RW and systematic observation locations in the bivariate Ripley's L_{12} analysis up to 4-km distances (Fig. 3a, b), and in the 1-km segment analysis, there was no significant evidence that the relative proportions of wildlife by segment were different between the 2 datasets (Fig. 4, 5). While there were segments with distinct differences of possible concern between the 2 datasets, the same 4 segments with highest wildlife observation frequencies for all species were identified by the RW method as the systematic dataset (Fig. 4). If RW had systematic sampling and documented sampling efforts, it could be concluded that its data were based on actual wildlife patterns. Instead, it can only be hypothesized that perhaps spatial patterns of wildlife activity are apparent after a certain threshold of observations were obtained, or that, fortuitously, the spatial coverage of volunteers was equally spread. It appears that in its current methodology, RW is somehow providing relatively accurate spatial information; it is on the right track. With documented sampling effort the RW program could provide this data in an analyzable form.

Assessing the accuracy of RW based on the systematic data required making assumptions. It was assumed that an animal occurring within 100m of the highway was more likely to cross the highway at that location than any other location. This provides a weakness to the study as animals might not choose to cross in that location, but there were so few actual crossings observed that adjacency needed to act as a surrogate for crossing activity.

It must be noted that both the RW and systematic driving survey methodologies could not detect wildlife occurring near the road that were not visible due to cover, darkness, or other reasons. This means that not all activity along the highway was documented, particularly with the inability to see further than headlights during night drives. Due in part to the possibility of non-visibility, the systematic driving survey methodology can act as a wildlife index but cannot provide an abundance or density estimate and could not be used to identify animal populations levels or infer changes in wildlife populations.

In this study, there were indeed areas where a portion though not the entire 100m distance of the roadside was concealed, preventing visibility of some of the study area. A stipulation to this program is then that the systematic dataset provides data on wildlife visible from the highway. However, I do not believe there were sections of the highway that were unrepresented due to cover to the extent that would reduce the ability of this method to report important movement areas. Using a driving survey to collect data on live wildlife along the highway was feasible for the Crowsnest Pass because the study area was relatively open with little forest cover within 100m of the highway in this region, providing easy wildlife viewing. Systematic observations were therefore assumed to be representative of the visible spatial and temporal distribution of wildlife activity within 100m of Highway 3 in the Crowsnest Pass.

Temporal

Knowledge of temporal wildlife activity patterns are important for mitigation planning, as studies have shown that wildlife activity patterns change over seasons and times of day. Temporal wildlife patterns in the Crowsnest Pass as documented through the systematic dataset also suggests that the times of sampling is important for identifying wildlife activity patterns, reflecting the results of other studies. Observation levels of wildlife varied by hour, time section, and season (Fig. 8, 9, 10). The peaks of systematic observations at dusk and dawn (Fig. 8) align with studies of animal-vehicle collisions and wildlife activity (Puglisi et al. 1974, Zagata and Haugen 1974, Kammermeyer and Marchinton 1977), specifically with some studies having a peak at dusk and less so at dawn (Carbaugh et al. 1975, Allen and McCullough 1977, Haikonen and Summala 2001). Nighttime wildlife activity was likely underreported due to the driving methodology.

Due to its unsystematic nature and its lack of documentation of where observers are driving to and from and the number of times they do so including non-observation drives, the RW dataset is unable to statistically analyze its temporal information in a similar manner. Sampling levels that are unequal at different time periods cannot be accounted for, and detection probabilities (numbers of observations divided by number of transects driven during the time period of interest) cannot be calculated. This prevents the ability to statistically compare detection probabilities between time periods, therefore precluding temporal statistical analyses.

Despite the above problems with RW temporal information, to try to get a better understanding of the RW patterns I performed qualitative comparisons of temporal patterns between the RW and systematic processes. There appear to be temporal differences between the two datasets (Fig. 8, 9, 10). If RW provided a sampling effort, those patterns could be statistically analyzed to assess whether the differences were significant, and RW could document trends of visible wildlife activity over time. Without it, there is no way to know if the RW patterns are due to activities of wildlife or to observer temporal driving patterns. The latter is likely; though the RW observations were not affected by the average hourly traffic volume, the hourly RW distribution had two peaks that are probably due to work related travel time (Fig. 9). It is important to note that despite these temporal differences and lack of documentation of temporal sampling effort, RW accurately documented the spatial distribution of visible wildlife activity along Highway 3. This may be due to the majority of observations from both methods consisting of deer, which appear to be active during times (Fig. 12) when most RW observations (likely due to participant activity) are recorded (Fig. 9, 10).

Species

Deer often occur near roadways, and in this study they represent the highest proportion of animals observed near roads (Table 1, 2). While deer populations are typically of little conservation concern with habitat connectivity and movement patterns (Forman and Alexander 1998), deer are a major human driver safety issue. Mitigation measures intended for reducing WVC rates may focus on areas of high numbers of large wildlife occurring near the road. Both the systematic and RW methods may be biased towards seeing these visible and common species along roadsides; they were effective at observing deer, as each documented an overwhelming majority of them (Tables 1, 2). The systematic driving survey was an effective method at locating areas to place mitigation for maintaining movement and possibly reducing WVCs of species with relatively high occurrence along roadways.

Several of the non-deer species occur in low densities or have extensive home ranges, making them uncommon in the region and particularly unlikely to observe along the highway. Species such as grizzly bears tend to display vehicle avoidance behaviors (Waller and Servheen 2005), choosing to cross highways when they are less likely to encounter highway traffic (Chruszcz et al. 2003, Waller and Servheen 2005). Further, several of these non-deer species may be more active during dark hours, and nighttime visibility only extended the distance of vehicle headlights, making animals further than 10m but within 100m unseen and unreported.

For both RW and the systematic dataset, observations of species other than deer were very low relative to deer observations (Tables 1, 2). Several species of conservation concern that occur within the study area were not observed, such as grizzly bears, wolves, and mountain lions. Population impacts of highways are thought to be more severe for rare or uncommon species (Forman et al. 2003, Forman and Alexander 1998), such as wide-ranging carnivores. Reduction of these impacts is essential to enhance or maintain connectivity of these animals across highways. I observed only two black bears and no other carnivores within this year-long study, despite driving transects during times of the night when bears are more active (Appendix A) (Waller and Servheen 2005). Low observation counts affect analysis, as very low numbers result in low predictability of locations of where these animals occur along Highway 3 (Table 1), causing difficulty in concluding whether and where they are clustering in species-specific spatial patterns. The relative frequencies of species observations were significantly different between the datasets (Fig. 11), but due to the low detection probabilities as well as the lack of RW sampling effort documentation, I cannot be certain as to the cause of these differences, such as whether citizens are biased towards certain species, or temporal or spatial biases translate to differences in species composition. Without extensive studies, it cannot also be determined whether the low numbers are due to small population sizes or due to the nature of the driving survey approach and species behaviors. Regardless of cause, the systematic and RW methods appear to be less effective at observing less visible animals. This makes the use of these driving surveys for identifying activity areas of uncommon species of limited value.

Road Watch reported relatively higher levels of non-deer species observations than that of the systematic dataset (Table 1, 2). While the differences were not significant, it brings up concern that RW participants may be biased in their reporting of certain species. It is possible that participants are more likely to report a unique animal, possibly deciding not to report common animals such as deer. This could impact the understanding of animal composition within the study area, which could potentially influence mitigation decisions.

The driving survey method is effective at documenting varying levels of wildlife activity at different locations and times. However, individual animals cannot be readily distinguished using this methodology, allowing the possibility of numerous observations of the same individual over different times. This has implications if mitigation is intended to enhance connectivity across the landscape, rather than providing for safe movement for one individual. This issue can be species-specific, as movement of one individual from a small population of a wide-ranging carnivore can be far more important than one individual from a large, localized population.

Individual animals observed along the roadway may also be habituated to human disturbances. Habituation of animals to roads can play a complex role in mitigation of wildlife highway impacts. If mitigation placement is based on locations of high levels of wildlife activity, these levels may be based on activity patterns of habituated animals. Habituation can lead to higher levels of human-wildlife conflict, and when this occurs in animals such as bears it may lead to removal of the individual habituated animal from the population. This can thereby reduce any actual connectivity across the roadway and landscape (McCoy 2005). As individuals cannot be distinguished using the driving survey methodology, it was not possible to assess the possible impacts of this issue in this study.

RECOMMENDATIONS

The following recommendations are intended for the RW program, as well as specified recommendations to groups that may want to develop a citizen highway wildlife monitoring program.

RW: Account for temporal and spatial patterns of observers

If the only goal of RW were to provide accurate data at very fine scales for the specific placement of wildlife crossing structures, a rigorous, systematic data collection methodology should be undertaken. Yet as a major goal of RW is to engage citizens, using an opportunistic methodology is still desirable. To overcome its current limitations in its conclusion-making ability, the current RW methodology can be modified to include documentation of spatial and temporal sampling effort. By making these changes, RW can describe spatial and temporal trend*s* in wildlife activity along Highway 3 that are statistically defensible.

In the opportunistic sampling approach, participants drive certain segments of the highway more often than others. Information of the spatial duration of a particular drive on which animals were observed is needed, in terms of distance and point-to-point locations. This is also needed for drives without any wildlife observations, in order to determine regions of animal absence as well as presence. This would reveal levels of participant activity for each segment, which could later be corrected for by dividing the number of observations by the number of drives driven for each segment. The same approach could be taken for times driven, to account for temporal biases.

These descriptions of spatial and temporal coverage by each individual participant could be reported by the individual within the data input form and obtained from specific questions or drop-down lists to provide the specific desired sampling effort information. This would need to be a flexible system, as a participant's activities may continuously vary. A driving pattern survey, performed relatively often, could be an alternative though less controlled and preferred method to obtain this information.

RW: Include systematic program

Even accounting for sampling effort, the modified opportunistic sampling approach is less preferred than a systematic methodology. Participant activity cannot be controlled, leaving the information susceptible to discontinuous data if participant level is uneven. One suggestion to continue to utilize current volunteers at their own capacity and yet to increase the scientific rigor of the program is to use a modified RW opportunistic methodology combined with a systematic protocol to act as a data quality control assessment. The systematic data could be used to continuously assess the accuracy of the opportunistic program. A systematic protocol should include driving the entire 46km each drive, or driving specific segments at different times. To ensure systematic temporal coverage, times and dates to perform a drive should be designated.

Dedicated RW volunteers could be asked to perform systematic drives at specific times at a determined frequency. An example where citizens were designated certain times and locations to gather highway and wildlife-related data is a study in Jackson Hole, Wyoming that used volunteers to determine locations of WVC hotspots on a state highway. Volunteers were assigned specific sections of highway within Teton County to drive at least 5 days a week to record observations of wildlife traffic mortality. These data were combined with local government WVC databases to identify high collision zones. The citizen data substantially augmented the information base of WVC hotspots (Biota Research and Consulting 2003).

The times of systematic temporal coverage will depend on the goals of RW or other groups. An important consideration is that spatial locations of wildlife activity may change over time. Studies have shown wildlife movements to shift spatially by time of day (Montgomery 1963) and season (Chruszcz et al. 2003, Gagnon et al. 2007). This has implications on mitigation decisions, whether to select year-round use areas, species-specific mitigation tools for migration movements, or to use any mitigation tool at all. This also has implications for data collection methods. For instance, it may be desired by RW or other groups to maximize effort for collecting spatial locations of wildlife by selecting only certain times of day or year to systematically sample. Knowledge of whether spatial locations of wildlife activity change over time is necessary to ensure coverage of important seasonal or daily differences of spatial wildlife movement. Due to restrictions on data and computational methods, I was not able to statistically assess these issues for this study. Without these analyses and possibly regardless of their result, it remains important to sample all time sections of daylight and all seasons, to ensure possible temporal changes in wildlife activity are not missed.

Though an important percentage of wildlife was observed at night for the systematic dataset (Fig. 8) and wildlife of conservation interest can be more active at that time (Waller and Servheen 2005), the utility of driving at night is questionable. Night drive viewing distances are limited to the span of headlights and the driving method appears to be biased against observing uncommon species, so the driving survey method may be limited in a cost-benefit perspective for observing animals 100m along the road at night using only this method. The bias would be reduced if observations were only recorded of wildlife activity within 0 to 10m (the distance headlights can extend) of the highway from all times of day.

If RW or another group was not able to collect systematic data at a capacity allowing full temporal coverage sampling or aimed to gather data on overall wildlife activity without emphases on specific species, changes in spatial activity over time, or providing trends of wildlife activity over times, those times when the highest levels of animals are seen could provide the best cost-benefit sampling times. However, for other groups, those times of highest wildlife activity should be determined for the specific study area.

A statistician can be consulted to avoid biases and analysis problems, to determine the minimum number and hourly spread of drives that are needed for statistical power for the systematic method, and to determine a statistical comparison of the opportunistic to the systematic dataset.

Other groups: Ensure driving survey method is relevant to study area, then select approach that is relevant to purpose of program

Topography and vegetation patterns may differ elsewhere, which could impact wildlife visibility and usefulness of this driving survey methodology. If the study area provides open viewing, select whether an opportunistic or systematic approach is relevant. The goals of the program will influence the approach to data collection.

- Opportunistic sampling: If the goal is engagement of many citizens at whatever capacity they are able, a less formalized and structured yet rigorous approach can be used. The modified RW method suggested above that necessarily includes documentation of spatial and temporal sampling effort is recommended. Since this approach is opportunistic, it may be difficult to ensure full spatial and temporal coverage of the study area.
- Systematic sampling: If the main objective is to produce a scientific dataset and develop citizens into scientists using a formalized protocol, a systematic approach similar to that performed in this study is recommended. A systematic methodology is essential in a new study area to understand the unique spatial, temporal, and species

trends of that region, since the patterns and results found in this study may not apply there.

- Combination: A combination of both approaches would both yield representative defensible data and involve citizens. Specific details of this combination would have to be worked out by the study area.

RW: Expand number of dedicated volunteers for adequate spatial and temporal coverage

Though recruitment, long term engagement, and consistent involvement of volunteers can be difficult (Bromenshenk and Preston 1986) particularly in a small community, it is important to expand the reporting base and to keep citizens engaged and active in reporting for RW. A large, consistent dataset is important for both a systematic protocol and a modified opportunistic methodology. With the latter methodology, more volunteers than are currently actively engaged in RW would help to expand spatial and temporal coverage, avoiding the problem of data fragmentation and domination by and susceptibility of the dataset to the activity patterns of a few participants. Further involvement of schools and students is one recommendation.

Other groups: Ensure adequate spatial and temporal coverage

To ensure the entire study area is sampled, documentation of spatial and temporal effort is required, as well as an adequate number of volunteers for full spatial and temporal coverage.

RW and other groups: Decide on species approach

The systematic driving survey method was effective at determining areas to place mitigation for maintaining movement and possibly reducing WVCs of species with relatively high occurrence along roadways. A driving survey is therefore a useful tool at gathering this important information. If rare or less visible species are target species of RW or another program, a different research method that is not associated with vehicles and that accounts for the temporal activity patterns of the species may be necessary. Sand trackbeds or snowtracking, remote cameras, radio collars, scat detection dogs (Long et al. 2007) or habitat modeling are some approaches that could help detect movement patterns near roadways of less common species. Yet, while the driving survey method did not provide sufficient data within this study area to make defensible conclusions about non-deer species, species in other study areas may behave differently.

Other groups: Perform a validation study

Any volunteer program should go through validation studies (Engel and Voshell 2002). This can be incorporated into a budget at the outset. Continuous validation may be most useful, particularly in the beginning stages of a program.

RW and others: Provide a clear protocol to volunteers

One study states that "regardless of how effective a volunteer biological monitoring protocol proves to be in a validation study, there must be an adequate quality assurance/quality control plan to guarantee that the protocol is consistently adhered to by all participating volunteer groups" (Engel and Voshell 2002). At minimum, a document providing a very specific description of the improved RW protocol should be provided on the RW website as well as sent to participants.

CONCLUSIONS

Road Watch in the Pass is a cost-effective tool that has potential for providing information on wildlife activity locations in the Pass to provide insight into where highway mitigation or conservation efforts should most effectively take place. Beyond data collection, it is also valuable in engaging citizens in local wildlife issues (Lee 2007). When examined over a yearlong comparative study, the RW citizen science method was able to represent spatial locations of live wildlife activity along Highway 3. The likely mitigation segments suggested from the systematic dataset were the same from RW. Yet unrecorded and uneven spatial and temporal coverage restricts the ability to examine trends in wildlife activity, thus limiting the program's usefulness for guiding mitigation locations. To improve these limitations, modifications should be made to the program, including accounting for temporal and spatial patterns of observers and incorporating a systematic approach to act as a data quality assessment. The driving survey method used by both datasets effectively documents visible and common species, so it is particularly useful for providing information for mitigation focused on human safety, but less so for addressing uncommon species.

LITERATURE CITED

Alberta Infrastructure and Transportation [AIT]. 2006a. Automated Traffic Recorder Monthly Volume Report. <http://www.infratrans.gov.ab.ca/INFTRA_Content/docType181/production/hnp003.htm>. Accessed May 2007.

Alberta Infrastructure and Transportation [AIT]. 2006b. Highway 1 and 3 Functional Study. <http://www.infratrans.gov.ab.ca/INFTRA_Content/docType182/Production/hwy3funcplan.htm>. Accessed 16 October 2007.

Alexander, S. M., N. M. Waters, and P. C. Paquet. 2005. Traffic Volume and Highway Permeability for a Mammalian Community in the Canadian Rocky Mountains. Canadian Geographer 49:321-331.

Allen, R. E. and D. R. McCullough. 1976. Deer-Car Accidents in Southern Michigan. Journal of Wildlife Management 40:317-325.

Apps, C. D. 1997. Identification of grizzly bear linkage zones along the Highway 3 corridor of southeast British Columbia and southwest Alberta. World Wildlife Fund Canada, Toronto, Ontario, Canada, and British Columbia Ministry of Environment, Lands and Parks, Victoria, British Columbia, Canada.

Au, J., P. Bagchi, B. Chen, R. Martinez, S. A. Dudley, and G. J. Sorger. 2000. Methodology for public monitoring of total coliforms, *Escherichia coli* and toxicity in waterways by Canadian high school students. Journal of Environmental Management 58:213 – 230.

Bailey, T. C., and A. C. Gatrell. 1995. Interactive Spatial Data Analysis. Pearson Education Limited, England.

Beier, P., and S. Loe. 1992. A checklist for evaluating impacts to wildlife movement corridors. Wildlife Society Bulletin 20:434-440.

Bennett, A. F. 1991. Roads, roadsides and wildlife conservation: a review. Pages 99-117 *in*: D. A. Saunders, and R. J. Hobbs, R.J., editors. Nature Conservation 2: The Role of Corridors. Surrey Beatty & Sons PTY Limited, Chipping Norton, Australia.

Besag, J. 1977. Contributions to the discussion of Dr. Ripley's paper. Journal of the Royal Statistical Society B 39:193-195.

Beyer, H. 2004. Hawth's Tools. Published Script. www.spatialecology.com.

Biota Research and Consulting. 2003. Final Report: Jackson Hole Roadway and Wildlife crossing study, Teton County, Wyoming. Jackson Hole Wildlife Foundation, Jackson Hole.

Boudreau S. A., and N. D. Yan. 2004. Auditing the accuracy of a volunteer-based surveillance program for an aquatic invader Bythotrephes. Environmental Monitoring and Assessment 91:17–26.

Bromenshenk, J., and E. Preston. 1986. Public participation in environmental monitoring: a means of attaining network capability. Environmental Monitoring and Assessment 6:35– 47.

Cain, A.T., V. R. Tuovila, D. G. Hewitt, and M. E. Tewes. 2003. Effects of a highway and mitigation projects on bobcats in Southern Texas. Biological Conservation 114:189–197

Carbaugh, B., Vaughan, J. P., Bellis, E. D., and H. B. Graves, H. B., 1975. Distribution and activity of white-tailed deer along an interstate highway. Journal of Wildlife Management 39:570-581.

Carroll, C., R. F. Noss, and P. C. Paquet. 2001. Carnivores as focal species for conservation planning in the Rocky Mountain region. Ecological Applications 11:961-980.

Chetkiewicz, C. 2002. Carnivores and corridors in the Crowsnest Pass. Alberta Sustainable Resource Development, Fish and Wildlife Division. Alberta Species at Risk Report Number 50, Edmonton, Alberta, Canada.

Chruszcz, B., A.P. Clevenger, K. Gunson, and M.L. Gibeau. 2003. Relationship among grizzly bears, highways and habitat in the Banff-Bow Valley, Alberta, Canada. Canadian Journal of Zoology 81:1378-1391.

Clevenger, A. P., B. Chruszcz, and K. E. Gunson. 2001. Highway mitigation fencing reduces wildlife–vehicle collisions. Wildlife Society Bulletin 29:646–653.

Clevenger, A. P., J. Wierzchowski, B. Chruszcz, and K. Gunson. 2002. GIS-generated, expert-based models for identifying wildlife habitat linkages and planning mitigation passages. Conservation Biology 16:503-514.

Clevenger, A. P., B. Chruszcz, and K. E. Gunson. 2003. Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. Biological Conservation 109:15–26.

Clevenger, A. P., and N. Waltho. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. Conservation Biology 14:47–56.

Clevenger, A. P., and N. Waltho. 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. Biological Conservation 121:453-464.

Clevenger, A., J. Wierzchowski, B. Chruszcz, and K. Gunson. 2002. GIS-generated, expert-based models for identifying wildlife habitat linkages and planning mitigation passages. Conservation Biology 16:503-514.

Coffin, A. W. 2007. From roadkill to road ecology: A review of the ecological effects of roads. Journal of Transport Geography 15:396-406.

Darwall, W. R. T., and N. K. Dulvy. 1996. An evaluation of the suitability of non-specialist volunteer researchers for coral reef fish surveys. Mafia Island, Tanzania: A case study. Biological Conservation 78: 223–231.

Diggle, P. J. 1983. Statistical analysis of spatial point patterns. Academic Press, New York.

Dodd Jr., C. K., W. J. Barichivich, and L. L. Smith. 2004. Effectiveness of a barrier wall and culverts in reducing wildlife mortality on a heavily traveled highway in Florida. Biological Conservation 118:619–631.

Dodd, N. L, J. W. Gagnon, S. Boe, and R. E. Schweinsburg. 2007. Assessment of elk highway permeability by using Global Positioning System Telemetry. Journal of Wildlife Management 71: 1107-1117.

Engel, S. R., and J. R. Voshell. Jr. 2002. Volunteer biological monitoring: can it accurately assess the ecological condition of streams? American Entomologist 48:164–177.

Epps, C. W., P. J. Palsboll, J. D. Wehausen, G. K. Roderick, R. R. Ramey, II, and D. R. McCullough. 2005. Highways block gene flow and cause rapid decline in genetic diversity of desert bighorn sheep. Ecology Letters 8:1029–1038.

ET Spatial Techniques. 2006. ET GeoTools for ArcGIS. Published script. www.ian-ko.com.

Finder, R. A., J. L. Roseberry, and A. Woolf. 1999. Site and landscape conditions at white- tailed deer vehicle collision locations in Illinois. Landscape and Urban Planning 44:77-85.

Fore, L. S., K. Paulsen, and K. O'Laughlin. 2001. Assessing the performance of volunteers in monitoring streams. Freshwater Biology 46:109 – 123.

Forman, R. T., and L. E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29:207-231

Forman R. T., D. Sperling, A. P. Clevenger, J. A. Bissonette, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. Road ecology: Science and solutions. Island Press, Washington, D.C.

Foster, M.L., and S. R. Humphrey. 1995. Use of highway underpasses by Florida panthers and other wildlife. Wildlife Society Bulletin 23:95-100.

Foster-Smith, J., and S. M. Evans. 2003. The value of marine ecological data collected by volunteers. Biological Conservation 113:199-213.

Gagnon, J. W., T. C. Theimer, N. L. Dodd, S. Boe, and R. E. Schweinsburg. 2007. Traffic volume alters elk distribution and highway crossings in Arizona. Journal of Wildlife Management 71: 2318-2323.

Galloway, A. W. E., M. T. Tudor, and W. M. Vander Haegen. 2006. The reliability of citizen science: A case study of Oregon white oak stand surveys. Wildlife Society Bulletin 34:1425-1429.

Genet, K. S., and L. G. Sargent. 2003. Evaluation of methods and data quality from a volunteer-based amphibian call survey. Wildlife Society Bulletin 3:703–714.

Gibeau, M. L. 2000. A conservation biology approach to management of grizzly bears in Banff National Park, Alberta. Dissertation, University of Calgary, Alberta, Canada.

Gibeau, M. L., A. P. Clevenger, S. Herrero, and J. Wierzchowski. 2001. Effects of highways on grizzly bear movement in the Bow River Watershed, Alberta, Canada. Pages 458–472 *in* G. Evink and K. P. McDermott, editors. Proceedings of the 2001 International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, USA.

Goosem, M. 2001. Effects of tropical rainforest roads on small mammals: inhibition of crossing movements. Wildlife Research 28:351–364.

Goread, F., and R. Pelissier. 2003. Avoiding misinterpretation of biotic interactions with the intertype K12-function: population independence vs. random labeling hypothesis. Journal of Vegetation Science 14:681-692.

Gouveia, C., A. Fonseca, A. Camara, and F. Ferreira. 2004. Promoting the use of environmental data collected by concerned citizens through information and communication technologies. Journal of Environmental Management 71:135-154.

Haikonen, H. and H. Summala. 2001. Deer-vehicle crashes- Extensive peak at 1 hour after sunset. American Journal of Preventive Medicine 21:209-213.

Heiman, M. K. 1997. Science by the people: Grassroots environmental monitoring and the debate over scientific expertise. Journal of Planning Education and Research 16:291-299.

Hubbard, M. W., B. J. Danielson, and R. A. Schmitz. 2000. Factors influencing the location of deer-vehicle accidents in Iowa. Journal of Wildlife Management 64:707-713.

Insightful Corp. 2005. S-PLUS. Enterprise Developer Version 7.0.0 for Microsoft Windows.

Kammermeyer, K. E., and R. L. Marchinton. 1977. Seasonal change in circadian activity of radio-monitored deer. Journal of Wildlife Management 41:315-317.

Lee, T. 2007. Evaluating the contribution of citizen participation in research to understand wildlife movement across Highway 3 in Crowsnest Pass, Alberta. Thesis, University of Calgary, Alberta, Canada.

Lee, T., M. S. Quinn, and D. Duke. 2006. Citizen science, highways, and wildlife: using a web-based GIS to engage citizens in collecting wildlife information. Ecology and Society 11(1):11. <http://www.ecologyandsociety.org/vol11/iss1/art11/>. Accessed 15 October 2007.

L-P Tardif and Associates. 2003. Collisions involving motor vehicles and large animals in Canada. Prepared for Transport Canada Road Safety Directorate, Ottawa, Ontario, Canada. [online] URL: http://www.wildlifeaccidents.ca/reports.htm.

Lloyd, J., and A. Casey. 2005. Wildlife hot spots along highways in Northwestern Oregon. Oregon Department of Transportation, Salem, Oregon, USA.

Long, R. A., T. M. Donovan, P. Mackay, W. J. Zielinski, and J. S. Buzas. 2007. Effectiveness of scat detection dogs for detecting forest carnivores. Journal of Wildlife Management 71:2007-2017.

Lotwick, C. G., and B. W. Silverman. 1982. Methods for analyzing spatial processes of several types of points. Journal of the Royal Statistical Society B 44:406-413.

Malo, J. E., F. Suarez, and A. Diez. 2004. Can we mitigate animal-vehicle accidents using predictive models? Journal of Applied Ecology 41:701-710.

Mata, C., I. Hervas, J. Herranz, F. Suarez, and J. E. Malo. 2005. Complementary use by vertebrates of crossing structures along a fenced Spanish motorway. Biological Conservation 124:397-405.

McCoy, K. 2005. Effects of transportation and development on black bear movement, mortality, and use of the Highway 93 corridor in NW Montana. Thesis, University of Montana, Missoula, USA.

McCown, W., and T. Eason. 2001. Black bear movements and habitat use relative to roads in Ocala National Forest: preliminary findings. Pages 397-404 *in* C. L. Irwin, P. Garrett, and K. P. McDermott, editors. Proceedings of the 2001 International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC, USA.

Moskowitz, D. 2007. Cascade wildlife monitoring project; Winter 2006-2007 field season report. Wilderness Awareness School, Duvall, Washington. <www.wildernessawareness.org/PDFs/CWMP_2006-2007_Final_Report.pdf> Accessed 27 October 2007. 25pps.

National Research Council Canada (NRCC). 2007. Herzberg Institute of Astrophysics <http://www.hia-iha.nrc-cnrc.gc.ca/sunrise_e.html>. Accessed 10 May 2007.

Neal L., T. Gilbert, T. Eason, L. Grant, and T. Roberts. 2004. Resolving landscape level highway impacts on the Florida black bear and other listed wildlife species. Pages 226-233 *in* C. L. Irwin, P. Garrett, and K. P. McDermott, editors. Proceedings of the 2003 International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC.

Newman, C., C. Buesching, and D. Macdonald. 2003. Validating mammal monitoring methods and assessing the performance of volunteers in wildlife conservation. Biological Conservation 113:189-197.

Ng, S.J., J. W. Dole, R. M. Sauvajot, S. P. D. Riley, and T. J. Valone. 2004. Use of highway undercrossings by wildlife in southern California. Biological Conservation 115:499-507.

Nicholson, E., J. Ryan, and D. Hodgkins. 2002. Community data— where does the value lie? Assessing confidence limits of community collected water quality data. Water Science and Technology 45:193–200.

Proctor, M. F., B. N. McLellan, C. Strobeck. 2002. Population fragmentation of grizzly bears in southeastern British Columbia, Canada. Ursus **13**:153-160.

Proctor, M.F., B. N. McLellan, C. Strobeck, and R. M. R. Barclay. 2005. Genetic analysis reveals demographic fragmentation of grizzly bears yielding vulnerably small populations. Proceedings of the Royal Society Bulletin. <doi:10.1098/rspb.2005. 3246>. Accessed 21 October 2007.

Puglisi, M. J., J. S. Lindzey, and E. D. Bellis. 1974. Factors associated with highway mortality of white-tailed deer. Journal of Wildlife Management 38:799-807.

Putman, R. J. 1997. Deer and road traffic accidents: options for management. Journal of Environmental Management 51:43-57.

Ramp, D., J. Caldwell, K. A. Edwards, D. Warton, and D. B. Croft. 2005. Modeling of wildlife fatality hotspots along the Snowy Mountain Highway in New South Wales, Australia. Biological Conservation 126:474-490.

Ramp, D., V. K. Wilson, and D. B. Croft. 2006. Assessing the impacts of roads in peri-urban reserves: Road-based fatalities and road usage by wildlife in the Royal National Park, New South Wales, Australia. Biological Conservation 129:348-359.

Reed, D.F., T. N. Woodward, and T. M. Pojar. 1975. Behavioral response of mule deer to a highway underpass. Journal of Wildlife Management 39:361–367.

Ripley, B. D. 1977. Modeling spatial patterns. Journal of the Royal Statistical Society B 39:172-212.

Ripley, B. D. 1981. Spatial Statistics. Wiley, New York.

Rodriguez, A., G. Crema, and M. Delibes. 1996. Use of non-wildlife passages across a high speed railway by terrestrial vertebrates. Journal of Applied Ecology 33:1527–1540.

Romin, L.A. and J.A. Bissonette. 1996. Deer-vehicle collisions: Status of state monitoring activities and mitigation efforts. Wildlife Society Bulletin 24: 276-83.

Ruediger, B., J. Claar, and J. Gore. 1999. Restoration of carnivore habitat connectivity in northern Rocky Mountains. Unpublished paper, USDA, Forest Service, Northern Region, Missoula, MT.

Ruediger, W., and J. Lloyd. 2003. A rapid assessment process for determining potential wildlife, fish, and plant linkages for highways. Pages 205-225 *in* C. L. Irwin, P. Garrett, and K. P. McDermott, editors. Proceedings of the 2003 International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, North Carolina.

Savan, B., A. J. Morgan, and C. Gore. 2003. Volunteer environmental monitoring and the role of the universities: the case of Citizens' Environment Watch. Environmental Management 31:561-568.

Scheick, B. and M. Jones. 1999. Locating wildlife underpasses prior to expansion of Highway 64 in North Carolina. Pages 247-252 in G.L. Evink, P. Garrett. and D. Zeigler, editors. Proceedings of the Third International Conference on Wildlife Ecology and Transportation. FL-ER-73-99. Florida Department of Conservation, Tallahassee.

Servheen, C., Waller, J.S., Kasworm, W.F., 1998. Fragmentation effects of high speed highways on grizzly bear populations shared between the United States and Canada. In: Evink, G., Ziegler, D.,Garrett, P., Berry, J. (Eds.), Proceedings of the International Conference on Wildlife Ecology and Transportation, Publication FL- ER-69-98. Florida Department of Transportation, Tallahassee, USA, pp. 97–103.

Singer, F. J., and J. L. Doherty. 1985. Managing mountain goats at a highway crossing. Wildlife Society Bulletin 13:469–477.

Spellerberg, I. F. 1998. Ecological effects of roads and traffic: a literature review. Global Ecology and Biogeography Letters 7:317–333.

Stokes, P., and M. Havas. 1990. Public participation and volunteer help in monitoring programs: An assessment. Environmental Monitoring and Assessment 15:225-229.

Taylor, B. D., and R. L. Goldingay. 2003. Cutting the carnage: wildlife usage of road culverts in northeastern New South Wales. Wildlife Research 30:529–537.

Trombulak, S. C., and C. A. Frissel. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18–30.

Van Langevelde, F. and C. T. Jaarsma. 2004. Using traffic flow theory to model traffic mortality in mammals. Landscape Ecology **19**:895-907.

Waller, J. S., and C. Servheen. 2005. Effects of transportation infrastructure on grizzly bears in northwestern Montana. Journal of Wildlife Management 69(3):985-1000.

Waller, J. S., C. Servheen, and D. A. Patterson. 2005. Probabilistic measure of road lethality. Pages 503-508 *in* C. L. Irwin, P. Garrett, and K. P. McDermott, editors. Proceedings of the 2005 International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC.

Weaver, J. L. 2001. The Transboundary Flathead: A Critical Landscape for Carnivores in the Rocky Mountains. WCS Working Papers No. 18.

Wiles, G. J. and H.P. Weeks Jr. 1986. Movements and use patterns of white-tailed deer visiting natural licks. Journal of Wildlife Management 50:487-496.

Yanes, M., J. M. Velasco, and F. Suarez. 1995. Permeability of roads and railways to vertebrates: the importance of culverts. Biological Conservation 71: 217–222.

Zagata, M. D. and A. O. Haugen. 1974. Influence of Light and Weather on Observability of Iowa Deer. The Journal of Wildlife Management 38: 220-228.

APPENDIX A

Season	Number of transects driven
Fall	64
Spring	136
Summer	175
Winter	57

Month	Number of transects driven
1	22
2	16
3	21
4	20
5	40
6	87
7	87
8	57
9	16
10	23
11	21
12	22

Time section	Number of transects driven
Day	198
Dusk	64
Night	120
Dawn	50

Hour	Number of transects driven
0	19
1	17
2	15
3	17
4	16
5	16
6	19
7	18
8	17
9	18
10	18
11	18
12	19
13	18
14	19
15	19
16	18
17	21
18	18
19	19
20	19
21	18
22	19
23	17

APPENDIX B
Road segments with highest non-deer species frequencies for RW and systematic datasets