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Chapter 13

ROAD–WILDLIFE MITIGATION PLANNING CAN BE IMPROVED BY IDENTIFYING THE PATTERNS AND PROCESSES ASSOCIATED WITH WILDLIFE-VEHICLE COLLISIONS

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SUMMARY

Collisions between vehicles and wildlife impact human safety and wildlife conservation. Transportation planners are increasingly involved in planning and implementing road-wildlife mitigation measures to lessen the risk of wildlife-vehicle collision (WVC) as well as provide connectivity opportunities for safe wildlife movement. An understanding of where, when and why WVC occur is essential to avoid high-risk areas and design effective mitigation measures.

13.1 Information about when, where and why WVC occur along roads can be used to inform where mitigation would be most effectively placed to reduce WVC.

13.2 Global Positioning Systems are essential for the rapid and accurate collection of large volumes of WVC data for use in mitigation planning.
Animals move through the landscape for a variety of reasons and often interact with roads, traffic and other linear infrastructure. There is a risk of a collision with a vehicle if the animal attempts to cross the road, potentially resulting in injury or death (roadkill) to the animals and/or occupants of the vehicle. The rate of wildlife-vehicle collisions (WVC) has been increasing globally, and the number of WVC with deer in the United States that resulted in fatalities of motorists has increased from 131 in 1994 to 223 in 2007 (www.deercrash.com). The loss of wildlife from WVC is substantial (Chapter 28) and is one of the main human-caused sources of wildlife mortality (Forman & Alexander 1998). Furthermore, WVC are expensive, costing Americans an estimated US$8 billion annually in property damage and health-care costs (Huïjser et al. 2008; Chapter 42).

The location and timing of WVC are influenced by the location of the road in the landscape, traffic volume and vehicle speed (see review in Gunson et al. (2011)). Identifying spatial (hotspots) and temporal (hot moments; see Beaudry et al. (2010)) patterns of WVC and understanding the factors that influence their occurrence are essential to avoiding high-risk areas and designing effective mitigation measures. In this chapter, we discuss methods that are often used to measure where, when and why WVC occur along roads as well as the application of these methods to mitigation planning. It is important to distinguish between the use of WVC and roadkill data as opposed to where wildlife successfully cross roads in mitigation planning, because sometimes different factors, such as traffic volume, influence whether animals cross a road safely or not (Fig. 13.1) (Clevenger & Ford 2010; Neumann et al. 2012).
motorists or transportation planners (Chapters 37 and 52), these measures are typically only implemented for limited time periods.

13.2 Global positioning systems are essential for the rapid and accurate collection of large volumes of WVC data for use in mitigation planning

The location accuracy of WVC data is extremely important because it determines the confidence in its use to place mitigation measures along roads (Gunson et al. 2009). Some studies in North America and Europe have used over 30 years of WVC data collected by natural resource, police and transportation agencies to detect patterns in WVC occurrence (e.g. Nielsen et al. 2003; Seiler 2005). Frequent limitations in the data are that WVC location is typically only collected for large animals and its spatial error can vary from 800 to 6500 m, when locations are referenced to the closest road distance marker or landmark, respectively (Gunson et al. 2009).

The timing and location of WVC can now be accurately recorded with Global Positioning System (GPS) technology included with cellular phones and digital cameras. Location information can be uploaded to a centralised database as part of a citizen science awareness or research project or entered into specific online databases (e.g. Textbox 50.1, Chapter 62). Other studies have integrated personal digital devices with GPS technology for road maintenance crews (Ament et al. 2011) and truckers (Hesse et al. 2010) to collect WVC data.

An advantage of these initiatives is the potential to collect accurate and abundant WVC data for a broader range of species. However, the ease of using a GPS device has led to an explosion of uncoordinated efforts among academic and citizen science projects. Data is collected to meet the needs of each project; however, it is rarely integrated into centralised databases for use by transportation agencies for mitigation planning. Furthermore, reliability and accuracy of the data need to be established before it can be used for mitigation planning (Chapter 12, Chapter 62). Coordinated programmes accompanied with education and awareness campaigns have the potential to maximise the accuracy and amount of WVC data collected for large and small species to inform mitigation planning.

13.3 There are numerous methods available to identify where and when WVC hotspots and hot moments are located along roads that can instruct mitigation planners

There are several methods used in road ecology to quantify the aggregation (or clustering) and distribution of WVC along roads. First, the Ripley’s K technique measures the aggregation or clustering of roadkill along a road and whether it is statistically significant, that is, differs spatially from a random
distribution (Ripley 1981). The amount of clustering along the road can be measured in units of distance (e.g. meter) and is often expressed as a peak distance to indicate the scale at which clustering occurs (Fig. 13.2). For example, Langen et al. (2012) found turtle-vehicle collisions were most clustered along 250 m-long sections of highway.

Once that clustering has been found to be statistically significant, a logical next step is to determine where this clustering occurs. Kernel density estimation (detailed in Bailey and Gatrell (1995)) is the analysis most often used, and it measures where along the road an aggregation of WVC occurs. The estimation requires a user-defined search distance to calculate the density of WVC along a specific road segment (e.g. Ramp et al. 2005; Krisp & Durot 2007; Mountrakis & Gunson 2009). Defining the search distance (length of road) to measure density can be guided by the objectives of the study (Krisp & Durot 2007) and by the biological movement scale of the target species (Ramp et al. 2005). Additionally, by conducting the Ripley’s K analysis first, a significant clustering distance can be used to inform the search distance.

A disadvantage of kernel density estimation is that it usually does not include a measure of statistical significance in the available software. A HotSpot Identification analysis recently developed by Coelho et al. (2014) compares the density of observed WVC along the road with a simulated Monte Carlo random distribution. Confidence intervals (similar to the Ripley’s K analysis) are used to determine significance, and clustering is considered significant when the density of observed WVC is above the upper confidence interval, thereby indicating where mitigation should be prioritised (Fig. 13.3).

In addition to being clustered in space, WVC may also be clustered in time (e.g. during seasonal migrations) and can be referred to as ‘hot moments’ (Beaudry et al. 2010). The same methods described earlier in this lesson to determine the spatial distribution of WVC can also be used to evaluate when WVC are aggregated (Mountrakis & Gunson 2009). The difference between measuring hot moments and hot spots is that WVC are plotted along a defined timeline (period) rather than along a length of road. To further illustrate this, in the kernel density analysis, the search distance is defined as a period of time relevant to when WVC occur (e.g. season). Space and time both influence the occurrence of WVC independently but can also interact to increase the risk of a collision (Mountrakis & Gunson 2009).

### 13.4 When WVC data is not available, models can be used to predict WVC hotspots and hot moments; however, more rigorous study designs are required for application to mitigation planning

WVC models are advantageous because they can predict likely roadkill patterns and the need for mitigation planning on proposed roads or on roads without data on WVC or wildlife movement. WVC-based models are typically applied to a species or group of species impacted by a road or road network. Relevant landscape- and road-related factors are grouped as independent variables into multivariate models, and the dependent variable is typically the number or presence/absence of WVC that have occurred along a road segment (Gunson et al. 2011). Landscape factors include anthropogenic land use, wildlife habitat and terrain, which influence animal distribution, abundance and movement patterns (e.g. Malo et al. 2004). Road factors such as traffic volume, road alignment, motorist visibility and road grades also influence the risk of WVC (e.g. Seiler 2005).

Unfortunately, there are few published examples that have applied the results of WVC models to mitigation planning on new or existing roads. One reason is that model validation is often conducted with WVC data collected from the same study area where the model was developed (but see exception in Seiler (2005)). These validation techniques are data driven and of limited application outside the study area because the reliability and scalability of model results are unknown.

Another reason that lessens model applicability for mitigation planning is that the more intuitive factors such as species-specific habitat are routinely modelled in different landscapes to explain where WVC occur. To build on what is already expected, more integral spatial relationships such as type, shape, size or configuration of a species preferred habitat with respect to roads should be included in models (Gunson et al. 2011). Selection of factors relevant to specific road–wildlife mitigation projects can be improved with preliminary consultation among transportation planners, engineers and ecologists before model development.

Statistically significant models that include confounding and interacting variables provide mixed results and render interpretation and application to mitigation planning difficult. For example, it is difficult for a transportation planner to know whether clearing roadside vegetation will decrease WVC because motorist visibility is increased or be counterproductive.
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Textbox 13.1 Using free software to conduct spatial analyses of WVC along roads.

Coelho et al. (2012) explored the spatial patterns of frog and toad roadkill along a 4.4 km section of a two-lane highway in southern Brazil. This section of road neighbours a peri-urban reserve, the Itapeva State Park in the Atlantic Forest Biosphere Reserve. This protected area has high ecosystem diversity and high species richness of frogs and toads (28 species). A total of 1333 frogs and toads from 13 species and 6 families were found dead on the road during 18 months of road surveys conducted by foot (Coelho et al. (2012)). The data is summarised using a combination of Siriema software (Coelho et al. 2014; Lesson 13.5) and a spatial analysis tool for ArcGIS software (SANET; http://sanet.csis.u-tokyo.ac.jp; Okabe et al. 2006) to determine the spatial distribution and density of frog and toad roadkill.

A Ripley’s K analysis (a plot of the L statistic) shows that WVC are clustered more than expected by chance when the black line is above the upper confidence limit (grey line) (Fig. 13.2). In this case, the rate of frog and toad roadkill was greater than expected between 0 and 4.24 km along the road and less than expected between 4.25 and 4.41 km, and peak clustering occurred at approximately 1.8 km. In other words, the roadkill is aggregated on road segments ranging from 0 to 4.24 km in size. This information can be used to both inform the search distance in an analysis to identify the location of hotspots along the road and plan the scale at which mitigation is required along the road length.

The result of kernel density analysis performed with the SANET tool is plotted in Figure 13.3 and shows highest-density aggregations of roadkill in red and lowest density in yellow. A search distance (bandwidth) of 50 m was chosen for this kernel analysis because (i) the Ripley’s K analysis identified that roadkill was significantly clustered at a spatial scale of 50 m, (ii) 50 m is relevant to the movement scale of frogs and toads and (iii) 50 m is an appropriate scale for implementing mitigation measures. The results of the kernel density analysis are plotted on the road with a land-use layer to aid in interpretation (Fig. 13.3).

Last, we present the results from Coelho et al. (2012) who conducted a HotSpot Identification analysis to supplement the kernel density estimation used (Fig. 13.4). When the intensity of roadkill (black line) is above the upper confidence limit (grey line), then that road segment has more collisions than expected by chance. When using a search distance of 50 m, they found the highest frequency of frog and toad deaths occurred at approximately 1.5 and 3.2 km along the road.

Figure 13.2 L statistic (K observed – K simulated mean) as a function of scale distance (radius) and 90% confidence limits (grey lines) for frog and toad roadkills along a 4.4 km road section in southern Brazil. Source: Coelho et al. (2012). Reproduced with permission of Elsevier.
Figure 13.3 Kernel density estimates of frog and toad roadkill along a highway adjacent to Itapeva State Park in the Atlantic Forest Biosphere Reserve, Brazil. Light grey shading is human-modified areas and darker areas are more natural habitat. Source: Fernanda Zimmermann Teixeira.
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because ungulates are now attracted to roadsides for foraging (Gunson et al. 2011; Chapters 42 and 46). Study designs that control for interacting variables within models need to be more widely used (Chapter 10), especially when the objectives are for application to road mitigation planning projects.

13.5 There are several inexpensive and accessible tools that have been developed to measure when, where and why WVC occur

Once WVC data is collected, it is essential to plot, visualise and explore where they occur in relation to the landscape (Chapter 62). Google Earth (http://www.google.com/earth/index.html) is a free and useful tool that can be used to plot and visualise WVC on aerial imagery. These data can also be imported into a Geographic Information System (GIS) to conduct more sophisticated analyses. A commonly used commercial software is ArcGIS (ESRI 2011); however, a free alternative is Quantum GIS (QGIS; http://www.qgis.org/).

Free software tools that perform spatial and temporal analyses are continually evolving and improving. In 2001, researchers used software developed to analyse spatial patterns of crime (CrimeStat; Levine 2000) (http://www.icpsr.umich.edu/CrimeStat/download.html) to evaluate spatial hotspots of WVC along roads in Canada (Clevenger et al. 2001). Soon after, more sophisticated spatial analysis toolkits, such as Ripley’s K statistics, were developed with use in a GIS (e.g. SANET; Okabe et al. 2006) to identify road. Similar results were also found in the SANET analysis (Fig. 13.2), and the HotSpot Identification analysis showed that these aggregations were significant. These peaks are obvious locations to prioritise more effective, localised and spatially explicit mitigation measures.

Collectively, these results can guide the scale of mitigation planning as well as where to place mitigation measures along a road. The majority of the road length has more roadkills than expected, and because the highest densities occurred at approximately 1.5 and 3.2 km, mitigation measures, such as crossing structures, could be focused at these locations. Other practical suggestions along the road length include a reduction in speed limits and temporary road closures during high crossing events that can be predicted by seasonal weather patterns.

Figure 13.4 Anuran roadkill intensity (black line) and 99% confidence limits (grey lines) along a 4.4 km road section in southern Brazil. Source: Coelho et al. (2012). Reproduced with permission of Elsevier.
spatial patterns of plants and animal occurrence along roads (Clevenger et al. 2003; Spooner et al. 2004; Ramp et al. 2005). More recently, researchers have programmed spatial and temporal analysis tools, for example, Ripley’s K in programming software such as Matlab 7.1 that determine spatiotemporal patterns of WVC along roads (Mountrakis & Gunson 2009).

Of particular note is Siriema, a free software package developed with a user-friendly interface that evaluates spatial distribution of WVC along roads (www.ufrgs.br/siriema). Analyses can be conducted along a road by first straightening it or by using the road as is and considering its sinuosity (Coelho et al. 2014). The software performs two options: a Ripley’s K function (see Coelho et al. 2008) and also a HotSpot Identification analysis (Lesson 13.3 and Textbox 13.1).

**CONCLUSIONS**

An understanding of when, where and why WVC occur is essential to inform management, retrofit mitigation on existing roads, avoid high-risk areas when building new roads and install mitigation on new or proposed roads. Wildlife mitigation research on roads has come a long way over the past 30 years and is benefiting from the rapid development of new tools and techniques. User-friendly tools such as Siriema software can substantially improve and facilitate integration of science into practical mitigation solutions for wildlife on roads.

The challenge ahead lies in improving the collection of WVC data and developing models that can be applied to mitigation planning. It is not practical or feasible to assume that accurate and systematic WVC data can be collected on all existing and newly planned roads, especially when wildlife populations are declining. As a result, there is a need for more rigorous models with predictive capabilities that can be applied to new roads. The integration of research with transportation planning requires a multidisciplinary approach that includes transportation planners, biologists and engineers through all planning stages of transportation projects.

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**FURTHER READING**

Coelho et al. (2012): This paper presents a more detailed description of the methods and results used for the Ripley’s K and the HotSpot analysis presented in the case study.

Coelho et al. (2014): This is the user’s guide for Siriema, a freely available software that outlines the Ripley’s K test and the HotSpot Identification analysis presented in the case study.

Gunson et al. (2011): Provides a thorough review of research studies that have created WVC hotspot models with a discussion of improved methodologies to meet the aims and objectives of mitigation planning.

Mountrakis and Gunson (2009): An in-depth study that combined both space and time to look at patterns and distributions of wildlife-vehicle collisions temporally and along roads.

Okabe et al. (2006): A user’s guide for the ArcGIS extension Spatial Analysis along Networks (SANET), which includes a set of analysis to evaluate spatial patterns along networks, including network K functions and kernel density estimation.

**REFERENCES**


