Modeling Wildlife Roadkill Risk on São Paulo Highways Amidst Sugarcane Area

Rodrigo Ferreira da Silva, MSc[1]

Introduction

The issue of wildlife roadkill on highways is a highly relevant environmental concern, raising both biodiversity preservation and road safety issues. Wildlife roadkill has been highlighted in numerous studies due to its significant negative impact on biodiversity as well as its implications for operational safety and associated costs (Abra et al., 2019). Estimates indicate that the annual number of medium to large mammals hit by vehicles in Brazil reaches approximately 9 million according to Pinto et al. (2022), while an analysis by the Brazilian Center for Road Ecology Studies [CBEE], based on 14 scientific studies, reveals that 5 million large animals are killed annually on Brazilian highways (Vasconcelos, 2017).

The state of São Paulo, with a population of 44.4 million inhabitants (IBGE, 2023), combines the most diversified economy in Brazil with important forest remnants that harbor rich biodiversity. In the context of São Paulo's agribusiness, the beginning of this century was marked by a sugarcane expansion from the mid-2000s, leading to competition for land use with other agricultural activities (Camara and Caldarelli, 2016).

The limited understanding of the interaction between the expansion of sugarcane planting areas and highway infrastructure in the state of São Paulo has raised concerns among some highway concessionaires located in the western part of the state. This is because research and attention often focus on regions with more preserved vegetation, such as forest remnants and Conservation Units, which are predominantly located in the eastern part of São Paulo.

The discussions of the Working Group for the Wildlife Roadkill Mitigation Plan, conducted by CETESB, initiated the strategic analysis of this issue with the São Paulo sugarcane and highway sectors. CETESB's Board Decision number 141, dated August 2018 (DD 141/2018), established normative criteria for the disposal of dead animals on highways (CETESB, 2018). Highway Operators, responsible for highway management, are required to submit semiannual public reports to CETESB, detailing occurrences of wildlife roadkill within the highway domain and the disposal of live animals and removed carcasses. All reports are available for public consultation upon request.

This work aims to develop a mathematical model capable of predicting the occurrence of wildlife roadkill on highways, to be applied in the Northwest of São Paulo, a region characterized by long stretches of highways crossing agricultural areas, notably sugarcane. Such a model will enable the identification of critical sections, allowing the implementation of measures to mitigate occurrences and protect wildlife. The practical application of this model in road construction and maintenance projects in the region may help anticipate and minimize negative impacts on wildlife.

In this context, specific wildlife roadkill data provided by the concessionaires Triângulo do Sol and Entrevias, as well as the Department of Highways of the State of São Paulo [DER/SP], along with land use and occupation information provided by the MapBiomas Project, were analyzed. The highways selected for analysis are SP-310, SP-322, SP-326, SP-333, and SP-463, all located in the northwest region of the state of São Paulo.

The development of the work consists of an applied study with the development of a spatial prediction model for wildlife roadkill on highways in the Northwest of São Paulo, using a Poisson-type model, in order to classify and geolocate areas according to the risk of these events occurring.

For the predictive analysis, spatial analysis techniques were applied, with the definition of a regression model, aiming to identify areas with the highest risk of roadkill. The R software was used for data manipulation and analysis, in addition to the geoprocessing software ArcGIS and QGIS for spatial analysis and map generation.

1. Institution: Department of Development of Strategic Actions for Licensing, Directorate of Environmental Impact Assessment, São Paulo State Environmental Agency, CETESB, São Paulo, Brazil. E-mail address: rodrsilva@sp.gov.br.

Wildlife Roadkill Incident Database

Data collection was carried out using the tables sent by Highway Operators to CETESB. The dataset includes information such as road characteristics, surrounding area characteristics, affected species, the number of animals hit, and their condition after the incident. Figure 1 illustrates the spreadsheet model presented semiannually, according to DD 141/2018.

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Ocorrência[1]	Coordenadas Geográficas (UTM)[2]			Características da Via[4]	Características do Entorno[5]	Data[6]	Hora[7]	Rodovia[8]	Km[9]	Sentido[10]	Classificação[11]	Nome[12]			Quantidade[13]	Destinação[14]	Coordenadas Geográficas (UTM)[15]			Obs.:[16]
	X	Y	Fuso[3]									Grupo	Popular	Científico			X	Y	Fuso[3]	

Figure 1. Spreadsheet model with records of animal roadkill incidents. (CETESB, 2018)

Wildlife roadkill incidents were compiled to feed the model, restricted to data on wild animals and those collected over the years 2019, 2020, and 2021. This restriction limits the analysis to three complete seasonal cycles, covering both wet and dry periods, which greatly influence wildlife behavior. The result of this preparation was a spreadsheet with geographic coordinates, which was used to generate a “shapefile” named “Wildlife Incident Points.”

Land Use and Land Cover Database

The land use database used comes from the MapBiomas Project. The database is obtained from Landsat satellite image mosaics, with a spatial resolution of 30 meters, where classifications are made that result in land use maps. The classification methodology is dynamic and procedural, aiming to improve the classification of each typology. The classification performed by the MapBiomas algorithm is carried out at various levels of detail. In this study, four macro land use classes were defined (1 - Vegetation, 2 - Agriculture, 3 - Non-vegetated Areas, and 4 - Water), based on the general classification of the MapBiomas database.

Geographic Databases

Four geographic databases in “shapefile” format were used to develop the work. All databases were reprojected to be worked on in the Universal Transverse Mercator projection system, with a central meridian at 51º west, a scale factor (k) of 0.999600, and the SIRGAS 2000 Datum, zone 22. The databases consist of:

1. Wildlife roadkill incidents on São Paulo highways between 2019 and 2022, obtained from the data processed by CETESB;
2. The 2016 road database of the State of São Paulo, prepared by the National Department of Transport Infrastructure [DNIT];
3. The State Boundary of São Paulo, prepared by the Geographic and Cartographic Institute of the State of São Paulo [IGC];
4. Land use and land cover map produced by MapBiomas.

Cartographic Database Processing

The processing flow of the geographic databases for the model involves several steps. Initially, a 200-meter buffer is generated from the selected highways to serve as input for the model. This buffer is then divided into 1-kilometer segments. Subsequently, the buffer is intersected with the land use map to create a land use base surrounding the highways. Additionally, the buffer is intersected with the database of wildlife roadkill occurrences, establishing a roadkill occurrences base on the selected highways. Ultimately, these datasets are combined to generate the prediction model.

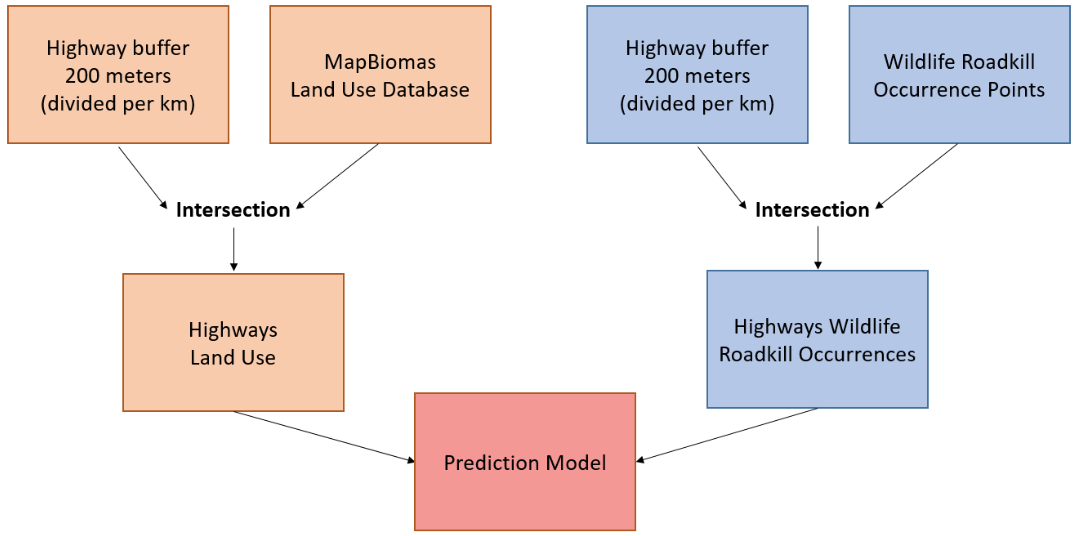

Figure 2. Flowchart of cartographic database processing

Prediction Model

In this study, a generalized linear regression model of the Poisson type for count data was selected, which falls under the group of Generalized Linear Models [GLM]. This model is appropriate for estimation when the dependent variable is quantitative with integer and non-negative values (count data).

According to Favero and Belfiore (2017), for a Poisson regression model to be valid, it is essential that the dependent variable follows a distribution with a mean equal to the variance, known as equidispersion. If this condition is met, it is feasible to estimate the corresponding regression model. Equation 1 presents the Poisson regression model:

$$\ln(\widehat{Y_i}) = \alpha + \beta_1 \cdot X_{1i} + \beta_2 \cdot X_{2i} + \cdots + \beta_k \cdot X_{ki} \quad (1)$$

In Table 1, the variables used to execute the prediction model and their respective measurement scales are presented.

Table 1 - Variables and Measurement Scale of the Prediction Model

Variable	**Type**	**Description**	**Scale**
Number of Animals	Dependent	Total number of individuals involved in wildlife roadkill incidents. Data sourced from the Highways Wildlife Roadkill Occurrences" database.	Ratio
Vegetation	Predictor	Land use class that includes all areas with vegetation formations present in the surroundings of highways (buffer of 200 meters). Data sourced from the "Highway Land Use" database.	Ratio
Non-vegetated areas	Predictor	Land use class that includes all areas not occupied by vegetation formations and water present in the surroundings of highways (buffer of 200 meters). Data sourced from the "Highway Land Use" database.	Ratio
Agriculture	Predictor	Land use class that includes all cultivated areas present in the surroundings of highways (buffer of 200 meters). Data sourced from the "Highway Land Use" database.	Ratio
Water	Predictor	Land use class that includes all areas occupied by watercourses and bodies of water in the surroundings of highways (buffer of 200 meters). Data sourced from the "Highway Land Use" database.	Ratio

Application of the Model

To apply the model, it is necessary to obtain the layout of the new highway and perform the following process. A 200-meter buffer is generated from the new highway and divided into 1-kilometer segments. This buffer is then intersected with the land use map, followed by running the prediction model. The output is a file containing predictions of wildlife roadkill per kilometer, which can be transformed into a map.

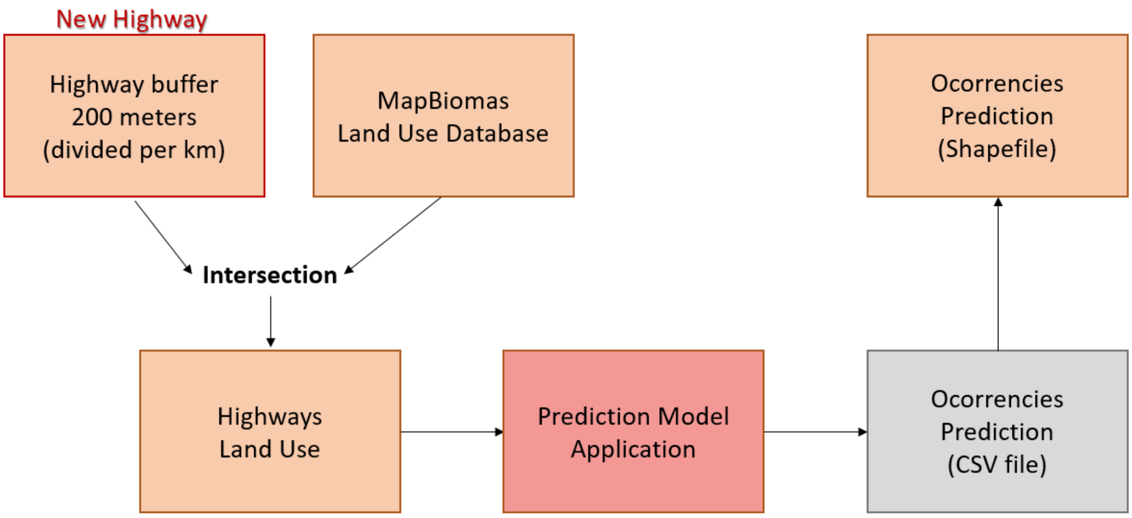

Figure 3. Flowchart of Prediction Model Aplication

This workflow was applied to generate predictions of wildlife roadkill occurrences on the road connecting Highway SP-310 to the city of Olímpia, spanning 42 kilometers.

A proposal for improvements to this road was then simulated, transforming it into a modern dual-carriageway highway with parameters similar to those used in the model training. The output shapefile "Occurrences Prediction" was used to develop the Wildlife Roadkill Prediction Map (Figure 4), which graphically illustrates the areas most sensitive to wildlife through a choropleth pattern. This pattern symbolizes the statistical surface with color-coded areas, ranging from cooler tones (green) to warmer tones (red), indicating increasing relative risk of roadkill events based on the expected numbers from the model.

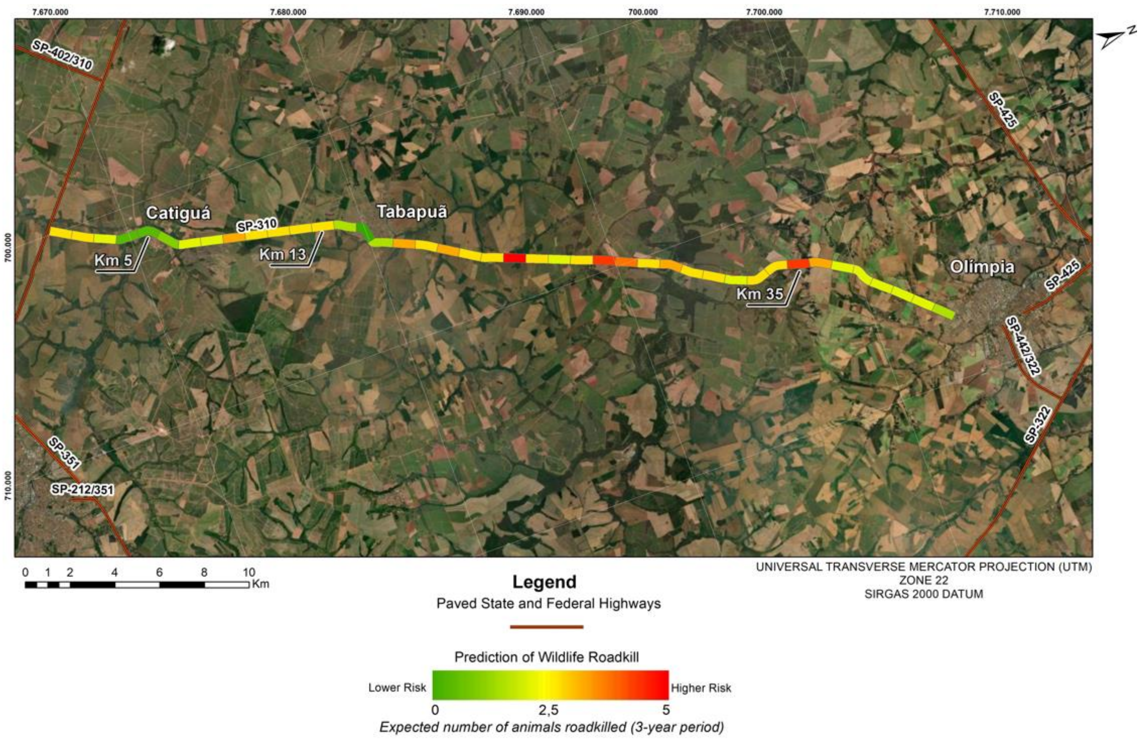

Figure 4. Map of Wildlife Roadkill Prediction Occurrences

The observed result on the map represents the predicted number of occurrences over a three-year period. By exploring these results, it is possible to identify how land use characteristics impact the model's response, as observed in Figure 5, which provides examples of areas classified into green, yellow, and red risk levels.

Figure 5. Examples of land use characteristics of road classified by risk levels

Analyzing the map during road layout definition and in the development of an executive highway project, with the identification of areas with high potential for roadkill occurrences, can contribute to defining areas of greater importance for implementing wildlife crossing devices. This facilitates landscape connectivity and safe passage for these animals. Risk mitigation planning may also include strategies to modify driver behavior, such as appropriate signage, installation of speed reducers (like speed bumps, signs, radar, and rumble strips), and environmental education programs.

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