Determining the Significance of Various Variables on Wildlife Poison Exposure in Canada using GIS Spatial Analysis Tools

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Abstract

Human activities can have a harmful effect on the environment. Agriculture, industry, and anthropogenic climate change have threatened ecosystem stability and placed numerous species at risk. Furthermore, technological advancement, resource extraction, and human development expose wildlife to poisons, which reduces biodiversity and further imperils ecosystem stability. It is crucial that we improve our understanding of ways in which wildlife are exposed to poisons to maintain natural populations and support environmental health. We analyzed data from the Canadian Wildlife Health Cooperative (CWHC), who monitors wildlife mortality resulting from poison exposure across Canada. Based on current literature, we determined that road networks, agricultural land, pollutant-release facilities (PRFs), and protected areas are the variables that predominately affect exposure of Canadian wildlife to poisons. Using this information, in conjunction with CWHC data, we developed a Geographical Information Systems (GIS)-based model to determine the effect of each variable on wildlife poison mortality in Canada. We used a random sample of points to represent an expected distribution of wildlife mortality due to poisoning and compared this with the observed distribution of CWHC data. We calculated p-values to determine the significance of each variable and calculated chi-squared values to compare the magnitude of effect of each variable on Canadian wildlife mortality due to poisoning. Our results indicate that bird mortality in southern Ontario is directly correlated with proximity to waste removal sites, metal sites, and road networks. Alternatively, mammal mortality in southern Ontario and bird and mammal mortality in southern Saskatchewan are directly correlated with proximity to chemical sites, manufacturing sites, and waste

removal sites. Although wildlife poisoning represents a single threat that humans pose on the environment, our research will aid in determining ways in which we can alter our behaviour to reduce our impact. This report provides a foundation for determining how environmental management can reduce wildlife poison exposure.

Problem Context

Many researchers believe that ecosystem health is dependent on high levels of biodiversity; the more diverse an ecosystem, the less vulnerable it is to external pressures such as climate change, human influences, and other disturbances (Thompson et al., 2009). Ecosystem health and services can be maintained by conserving biodiversity, which further benefits social, economic, and cultural aspects of Canadian society (Galvani et al., 2016). However, anthropogenic climate change, agriculture, and industrialization alter wildlife vulnerability to disease and increase poisoning incidences (Ryser-Degiorgis, 2013).

Poisons are defined as any substance with damaging effects if ingested, inhaled or absorbed by an organism (Thomas et al., 2017). Although wildlife mortality from poison exposure is not the largest cause of death to Canadian wildlife, it is an area that has not been extensively studied and requires further research (CWHC, 2019). While wildlife poisoning can occur through natural or anthropogenic exposure, the latter is more concerning due to the unknown consequences (Wobeser et al., 2004).

Bayley et al. (2019) reported that metals, minerals, and industrial contaminants are the primary anthropogenic sources of reported wildlife mortality due to poison exposure. Pollutant-release facilities (PRFs) are industrial areas that release known pollutants and expose wildlife to chemical, mineral, or metal contaminants through industrial activity (Government of Canada, 2018; Markus & Mcbratney, 2001). Metal poisoning has many negative effects on organisms, such as physiological impairment, increased vulnerability to disease, and altered behaviour (Katavolos et al., 2007). For example, Franson & Russel (2014) reported that eagles exposed to acute levels of lead developed anorexia and a weakened immune system while eagles exposed to higher levels died.

Another prevalent anthropogenic source of poisoning is through agriculture, which exposes wildlife to pesticides, run-off, and compost toxins that promote disease outbreaks and mortality (Stone et al., 1999). The second most common poisoning agent in both birds and mammals in Canada are rodenticides and avicides, which are used for pest control on agricultural land but affect a wide variety of non-target organisms through direct consumption or indirect ingestion of poisoned prey (Bayley et al., 2019; Hindmarch et al., 2019). Additionally, road networks expose wildlife to chemicals and pollutants due to transportation vehicles, accidents, and spills (Stone et al., 1999).

Alternatively, protected areas, such as natural parks, are correlated with reduced poisoning events across landscapes given acts, regulations and policies that protect against destructive human interference with wildlife (Ntemiri et al., 2018). Based on these findings, we determined that the primary variables which influence exposure of Canadian wildlife to poisons are road networks, agricultural land, PRFs, and protected areas. PRFs are further divided into electrical sites, chemical sites, manufacturing sites, waste disposal sites, wood products, metals, and resource extraction sites (Government of Canada, 2018).

Previous research has focused on analyzing individual poisons (Markus & Mcbratney, 2001; Franson & Russell, 2014; Stone et al., 1999) but has not considered a spatial relationship to define areas associated with poisoning. Our GIS model could provide a holistic analysis of the type and significance of variables that influence exposure of wildlife to poisons in Canada. In doing so, our results could inform management decisions and support strategies that mitigate mortality due to poisoning (Douvere, 2008).

Purpose of Research

The purpose of this research is to develop and utilize a GIS-model to determine what variables affect poison exposure of birds and mammals in Canada, as well as the strength of these relationships.

Study area

Our research was performed in Canada, a very biodiverse country with 1,449 native vertebrate species (Word Wildlife Foundation [WWF], 2017). However, according to population trends, over half the species studied between 1970 and 2014 declined in abundance (WWF, 2017).

Figure 1 shows reported mortalities due to poisoning exposure; bird mortality is indicated by yellow points and mammal mortality is indicated by purple points. Mortality is not evenly distributed across Canada, indicating that there may be variables contributing to elevated or reduced mortality. The largest clusters of wildlife mortality due to poisoning in both birds and mammals occur in British Columbia, Saskatchewan, Ontario, Quebec, and Nova Scotia (Figure 1).

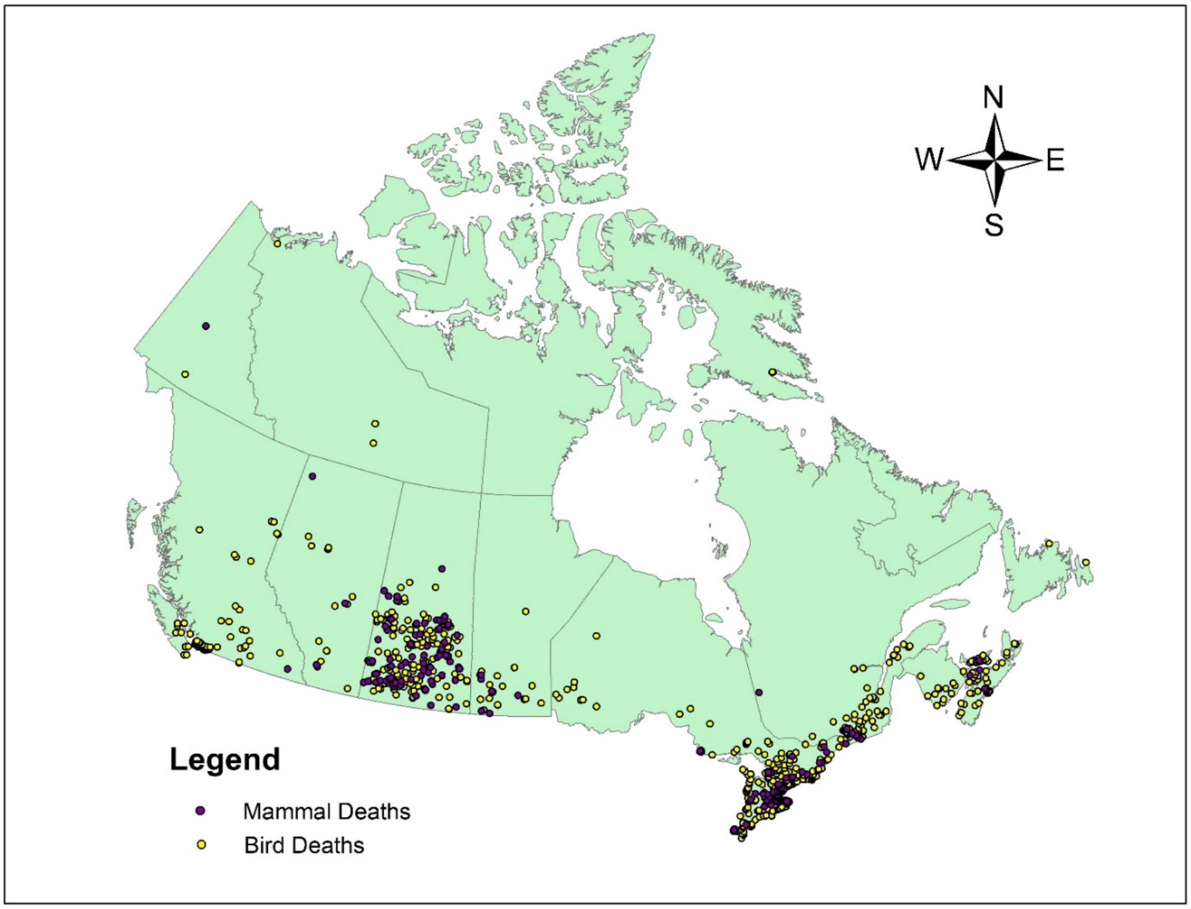

Figure 1: Map displaying CWHC wildlife mortality points due to poisoning across Canada.

The majority of the CWHC dataset displays bird and mammal mortality due to poisoning, within which there were 2,049 bird and 253 mammal mortalities due to poison exposure between 1998 and 2018. Based on our literature review summarized in the problem context, the predominant variables that influence bird and mammal mortality due to poison exposure in Canada are road networks, agricultural land, PRFs, and protected areas. Canada contains 2,233,140 road networks, 277 agricultural areas (229,373 farms), 14,000 PRFs, and 9,007 protected areas (Statistics Canada, 2006).

Table 1 provides the location of the datasets utilized for the above variables, all of which were retrieved from open-source databases.

Table 1: Data used for the GIS-model.

Data	Source	Year(s)	Description
Road Networks	Statistics Canada (2019)	2019	Line data of Canada's road networks including highways, roadways and laneways.
Agricultural land	Statistics Canada (Reichart, 2016)	2011-2016	Polygon data of agricultural sites, crop type, and area.
Pollutant-release Facilities (metals, minerals, oil, etc.)	Government of Canada (2018)	2017	Point data of recorded facilities (electricity, chemical, manufacturing, waste disposal, wood products, metals, and resource extraction sites) that release pollutants in Canada.
Natural Parks (Protected Areas)	Government of Canada (2020)	2019	Polygon data of natural parks and conservation areas. Includes xy coordinates, area, and park names.
CWHC Poison data	CWHC (provided by Jane Parmley, University of Guelph)	1998-2018	Point data of wildlife mortality due to poisoning across Canada, collected by CWHC.

Research objectives and approach

To accomplish the aim of this study, the following objectives were identified and supported by the accompanying approach, as seen below:

Objective 1: To identify potential variables that could explain the spatial distribution of reported wildlife mortality in Canada.

We assessed the current literature to identify potential variables that influence wildlife mortality due to poison exposure and acquired respective spatial data from open source databases (Markus & Mcbratney, 2001; Franson & Russell, 2014; Stone et al., 1999).

Objective 2: To identify areas with the greatest proportion of reported bird and mammal mortalities due to poisoning across Canada. This step involved data preprocessing.

We used an optimized hotspot analysis, which identifies statistically significant clusters of point features, and produced a map of these clusters to determine areas of focus (Esri, 2020; Sillero, 2008). The steps we pursued to address objective 2 are as follows:

a. Isolate bird and mammal mortality from CWHC data, creating two separate shapefiles.
b. Use optimized hotspot analysis to identify hotspots for bird and mammal mortality from poisoning across Canada.
c. Use the identified hotspots to select specific areas of focus.
d. Select data from variables identified in objective 1 and clip this data, along with bird and mammal mortality data, to each area of focus.

Objective 3: To develop a GIS-based model that defines the spatial relationship of reported wildlife mortality with the variables identified in Objective 1.

We used model builder to develop a GIS-model and determine the spatial relationship between bird or mammal mortality and each variable (Figure 2). The process ran multiple times for each area of study, species, and buffer size. We used a 5m buffer around road networks to represent the average width of Canadian roads (Transportation Association of Canada, 2007). We used 2.5km, 5km and 10km buffers around point features to provide an accurate depiction of the varying sizes and poisoning effects of these features. As seen in Figure 4, the larger the buffer size, the greater number of points affected by each variable. All buffers were created using the dissolve function to eliminate overlap between adjacent buffers. Figure 3 shows an example of the outputs for the model in southern Ontario for each variable of interest: road networks, agricultural land, PRFs, and protected areas. Orange points indicate bird mortalities within the defined variable area and black points indicate bird mortalities outside the variable area. Note that due to the size and resolution of the provided image, individual road networks are not clearly depicted.

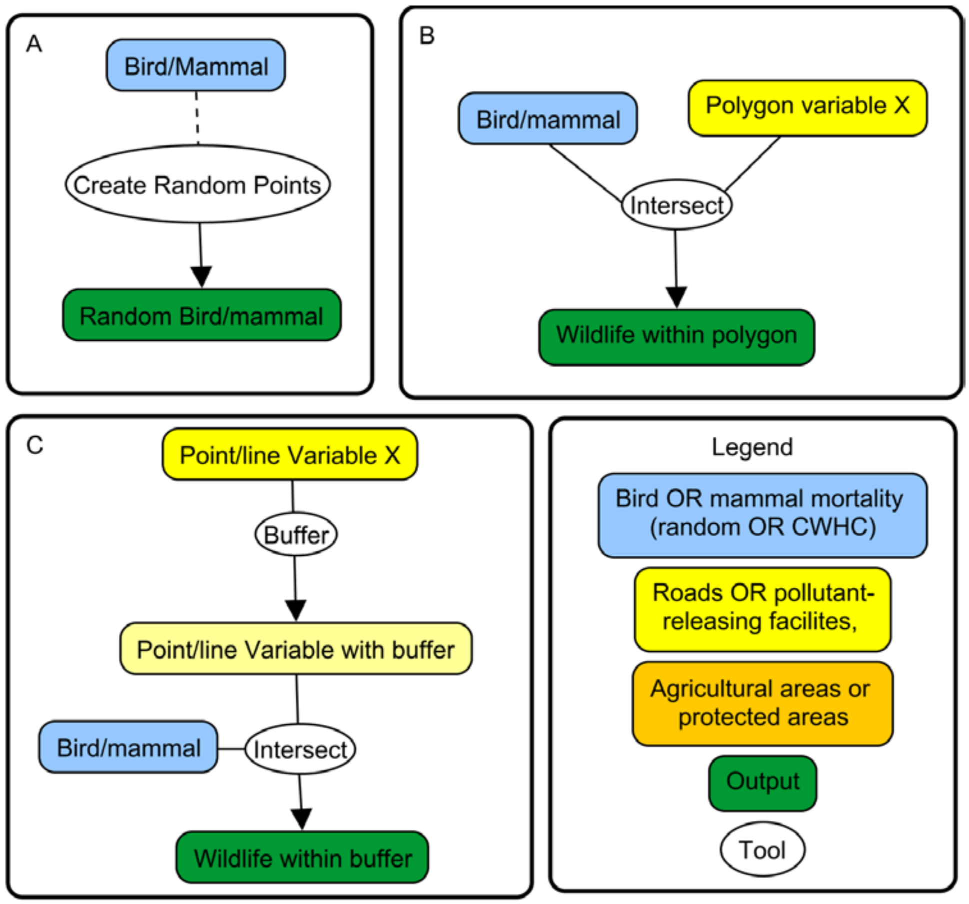

Figure 2: Flowcharts demonstrating steps of the GIS-model; (A) refers to the process for making a random distribution of points using the raw CWHC data as a parameter, (B) refers to the process for polygons data, and (C) refers to the process for point or line data.

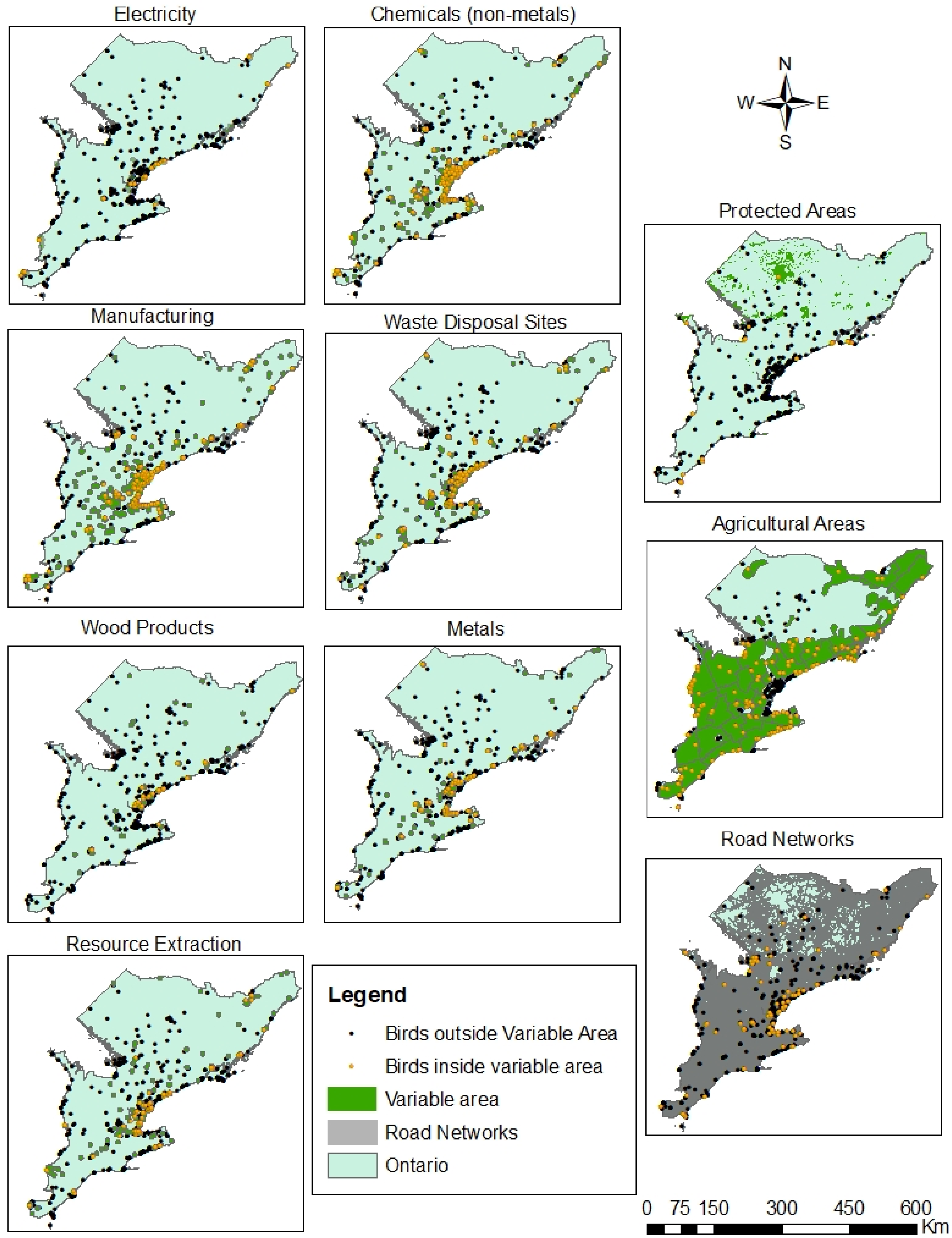

Figure 3: Example of the outputs for each variable in southern Ontario. The variable being analyzed is indicated by the title above each map.

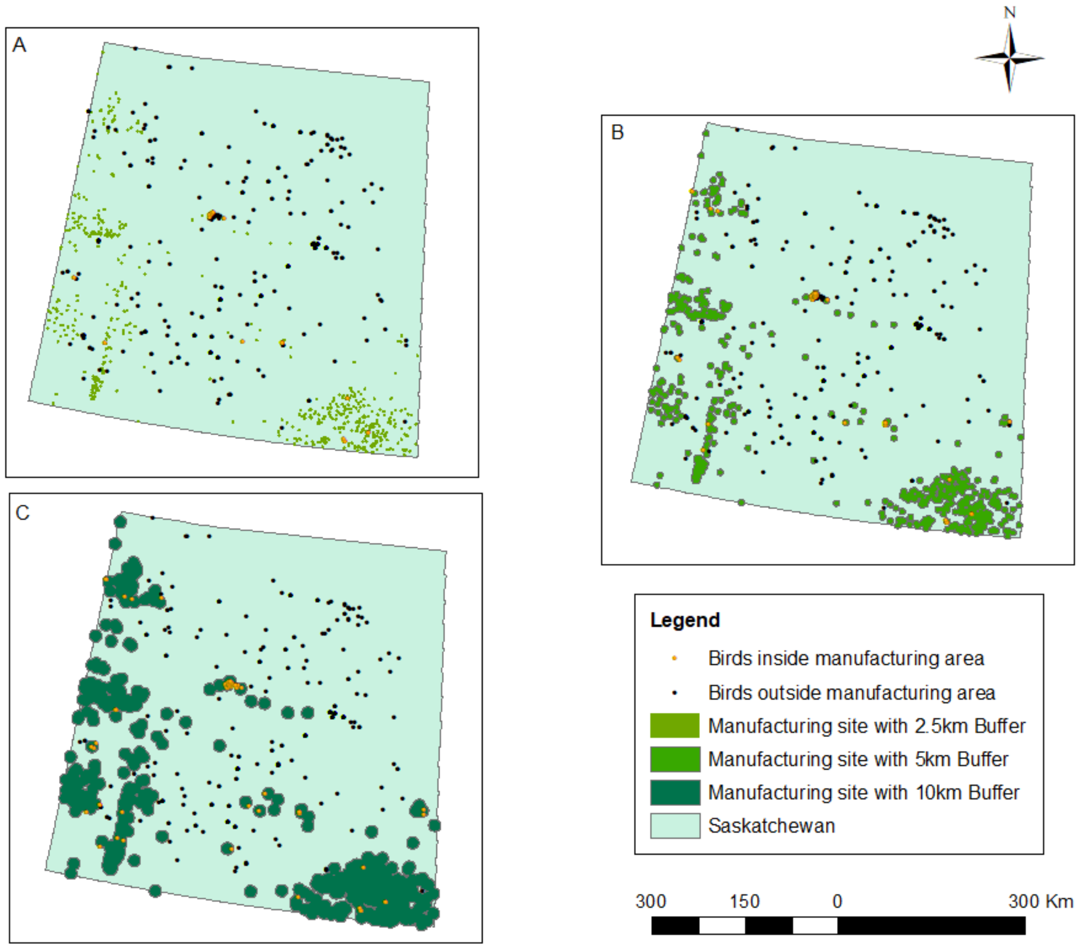

Figure 4: Example output maps of the three buffer sizes demonstrating manufacturing sites in southern Saskatchewan: (A) 2.5km buffer, (B) 5km buffer, (C) 10km buffer.

Objective 4: To create a statistical model that assesses the significance of each variable using the information collected in Objective 3.

We defined the number of bird or mammals found within each variable area, for example the number of birds found close to manufacturing sites, as observed points. The random points represent a generated distribution, where those found within each variable area are defined as expected points. To assess the significance of each variable to wildlife mortality events, we performed the following steps:

a. Create a CSV file of observed values and expected values
b. Use a Pearson's Chi-squared test to determine whether the distribution of observed values vary significantly from the expected values:

$$X^2 = \frac{(O_i - E_i)^2}{E_i}$$

c. Use chi-square values to calculate the p-value in R Studio, which identifies the significance of each variable.

This statistical method, as performed by Metzger et al. (2010) and McCance et al. (2015), allowed us to determine if our GIS model is viable based on the p-values. For example, we could not calculate the chi-square statistic if no random points were found within the variable area and returned a zero value. In such cases, we re-ran the "create random points tool" and increased the points by an arbitrarily large factor so there was at least one random point in the area. We then divided the count within the buffer by the same factor to maintain the correct sample size. The result gave us a number above zero to calculate the chi-square statistic.

Objective 5: To evaluate the strengths and limitations of the GIS-model and identify future research using the results of Objective 3 and 4.

To accomplish this objective, we will compare our findings to the information in the literature review in Objective 1. Additionally, we will propose future research based on our findings and the limitations of our model in the conclusion of our report.

Research Findings

Variables Affecting Wildlife Poisoning

Based on our literature review summarized in the problem context, we identified four major variables that had the potential to influence wildlife mortality through poisoning: road networks, agricultural areas, PRFs (manufacturing, chemical, metal, wood producing, electrical and waste removal sites), and protected areas.

Areas of Focus

For both mammal and bird species groups, we identified the two major hotspots of southern Saskatchewan and southern Ontario. The Ontario site consists of the southern 153,521 km^2 of the province, while the Saskatchewan site consists of the southern 349,904 km^2. These two areas of focus contained larger sample sizes relative to Canada, which would promote more reliable results with greater precision (Wade, 2018). In Figure 5, red grid cells in hotspot maps show hotspot locations, yellow points depict specific locations of bird mortality (A) and purple dots depict specific locations of mammal mortality (B) in southern Ontario and southern Saskatchewan.

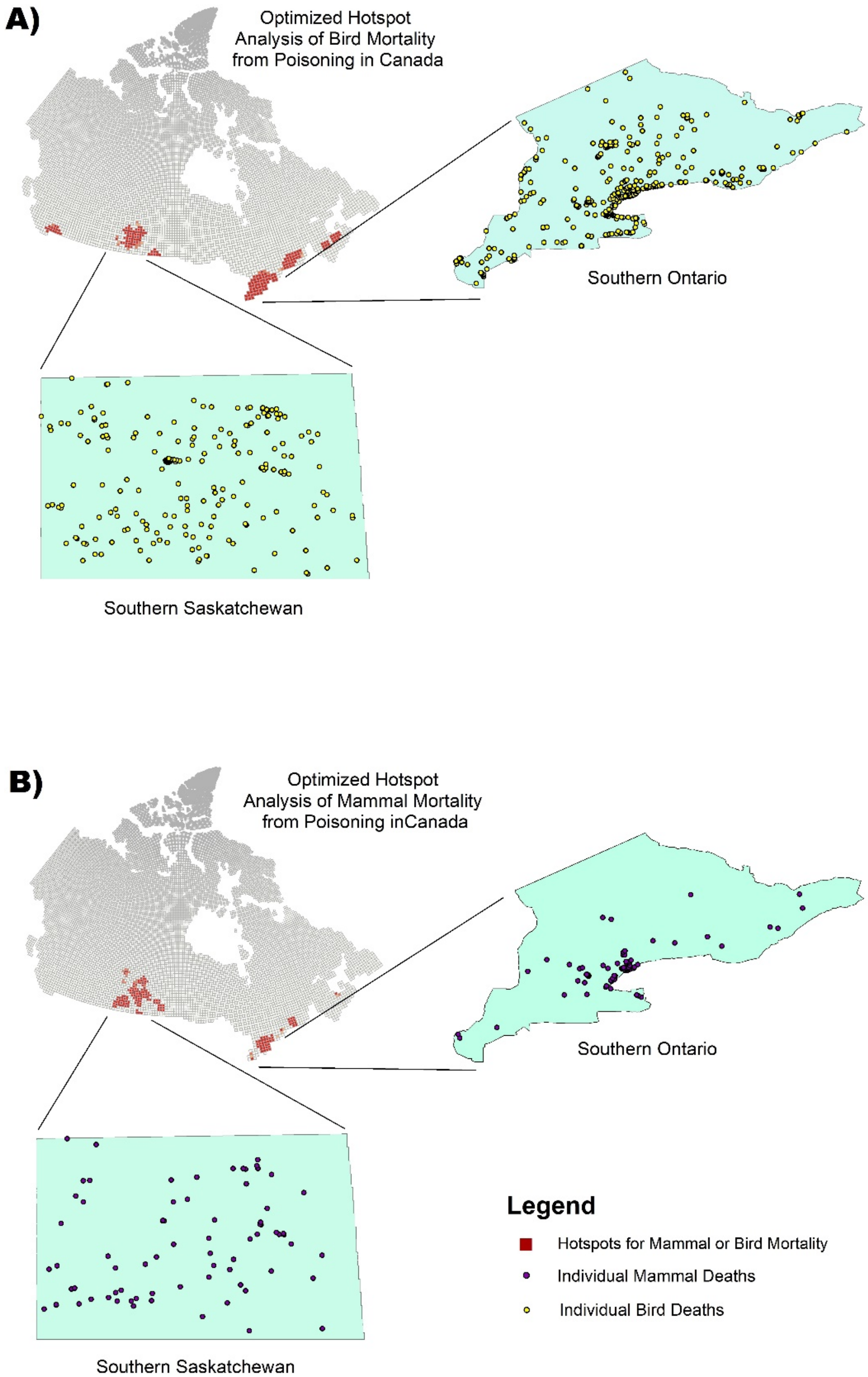

Figure 5: Output maps from the optimized hotspot analysis conducted on bird mortality locations (A) and mammal mortality locations (B) across Canada.

Model Outputs

We used chi-square tests with 1 degree of freedom to compare the observed distribution of wildlife mortality to the expected distribution. The chi-square tests were used to calculate p-values for each variable, and to determine their correlation with wildlife mortality. High chi-square values and low p-values indicate stronger correlations between wildlife mortality and each variable. The resulting p-values were generally very low because there was often a large difference between the number of observed and expected mortality events within each area of interest.

Table 2 and 3 display the results of the chi-squared tests for each variable against either birds or mammals in southern Ontario and southern Saskatchewan. The results are displayed using the p-values for all variables and relative buffer sizes, where a p-value of 0.05 or less indicates significance (Wasserstein et al., 2019). Variables were only considered to have a significant effect on mortality if the p-values indicated significance in all buffer sizes because this avoided statistical anomalies, such as if the variable was significant at the 10km buffer but not the 2.5km buffer.

Table 2: p-values indicating significance ($p<0.05$) relating distance of birds (right) and mammals (left) to variables in Southern Ontario for each buffer distance.

Ontario					
Birds in Ontario			Mammals in Ontario		
Factors	Buffer Size	P-Values (p)	Factors	Buffer Size	P-Values (p)
Wood Products	2.5km	0	Wood Products	2.5km	5.80E-05
	5km	0		5km	5.00E-07
	10km	0		10km	0
Waste Removal	2.5km	0	Waste Removal	2.5km	0
	5km	0		5km	0
	10km	0		10km	0
Resource Extraction	2.5km	0	Resource Extraction	2.5km	0.387251
	5km	0		5km	0
	10km	0		10km	0
Metals	2.5km	0	Metals	2.5km	0
	5km	0		5km	0
	10km	0		10km	0
Manufacturing	2.5km	0	Manufacturing	2.5km	0
	5km	0		5km	0
	10km	0		10km	0
Electricity	2.5km	0	Electricity	2.5km	3.67E-10
	5km	0		5km	2.61E-06
	10km	0		10km	0
Chemicals	2.5km	0	Chemicals	2.5km	0
	5km	0		5km	0
	10km	0		10km	0
Roads	5m	0	Roads	5m	5.00E-07
Agricultural Areas	None	0.007108	Agricultural Areas	None	0.001989
Protected Areas	None	0	Protected Areas	None	0.041005

Table 3: p-values indicating significance ($p<0.05$) relating distance of birds (right) and mammals (left) in Southern Saskatchewan (bottom) for each buffer distance.

Saskatchewan					
Birds in Saskatchewan			Mammals in Saskatchewan		
Factors	Buffer Size	P-Values (p)	Factors	Buffer Size	P-Values (p)
Wood Products	2.5km	0.75181	Wood Products	2.5km	0.751722
	5km	0.342424		5km	0.65443
	10km	0.128648		10km	0.270716
Waste Removal	2.5km	0	Waste Removal	2.5km	0
	5km	0		5km	0
	10km	0		10km	1.67E-09
Resource Extraction	2.5km	0	Resource Extraction	2.5km	0.830295
	5km	0		5km	0.31996
	10km	0		10km	0.058539
Manufacturing	2.5km	0	Manufacturing	2.5km	0
	5km	0		5km	8.88E-16
	10km	0		10km	5.89E-07
Electricity	2.5km	1	Electricity	2.5km	0.112101
	5km	0		5km	0
	10km	0		10km	0.000216
Chemicals	2.5km	0	Chemicals	2.5km	0.751722
	5km	0		5km	1.84E-09
	10km	0		10km	0
Roads	5m	0	Roads	5m	0.475497
Protected Areas	None	0	Protected Areas	None	0.004618

All variables had a significant effect on bird mortality in Ontario (Table 1 and Table 2). Figure 6 displays the chi-square value for each variable on a graph that indicates the strength of correlation between each variable and wildlife mortality, where high chi-square values indicate a stronger correlation. Instances where there was a direct relationship between the variable and wildlife mortality (i.e. more observed wildlife deaths within the buffer zone than expected deaths), the bar representing the chi-square value for that variable was coloured orange. Instances where there was an inverse correlation between the variable and wildlife mortality (i.e. less observed wildlife deaths within the buffer zone than expected deaths), the bar representing the chi-square value for that variable was coloured blue.

With respect to birds in southern Ontario, agricultural areas had an inverse correlation, meaning that there were less observed bird mortality events in agricultural areas than would be expected if no correlation was present. All the other variables were directly correlated, meaning there were more observed bird mortalities located near each variable than would be expected if no correlation was present. Though all variables had a significant effect on bird mortality in Ontario, the variables with the greatest influence were waste removal sites, metal sites, and road networks.

With respect to mammal mortality in southern Ontario, all variables except for resource extraction sites had a significant effect. Agricultural and protected areas were found to have an inverse correlation with mammal mortality, while the rest of the variables had a direct correlation. However, waste removal sites, manufacturing sites, and chemical sites had the greatest influence.

For bird mortality in southern Saskatchewan, all variables except for wood products and electrical sites had a significant effect on wildlife mortality. All variables were found to have a direct correlation with bird mortality but waste removal sites, manufacturing sites, and chemical sites had the greatest influence.

For mammals in southern Saskatchewan, waste removal sites, manufacturing sites, and protected areas had a significant effect on wildlife mortality. Wood product and resource extraction sites had an insignificant effect. Protected areas had an inverse correlation with mammal mortality, while all other variables had a direct correlation. However, waste removal sites, manufacturing sites, and chemical sites had the greatest influence.

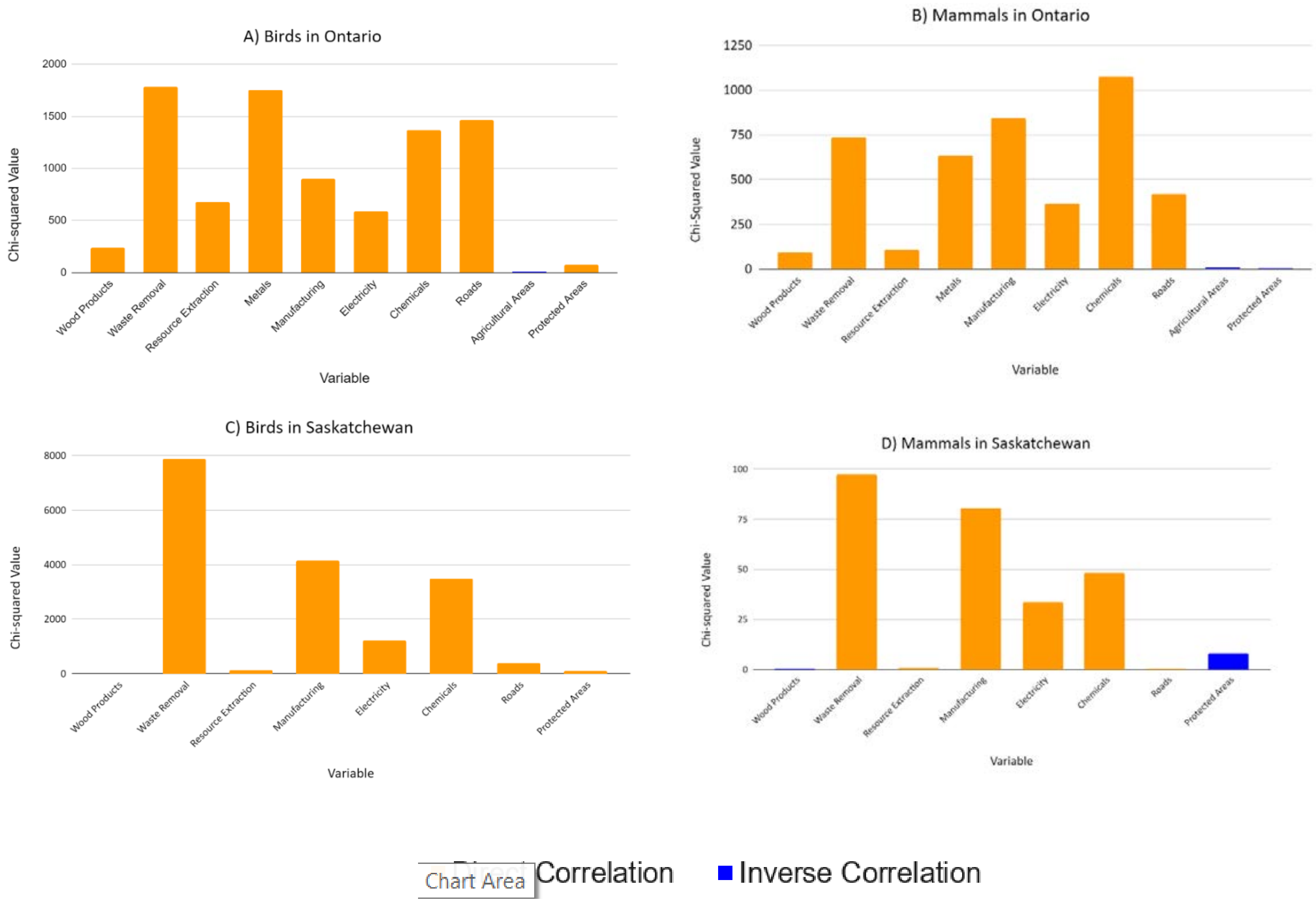

Figure 6: Strength of correlation (displayed as chi-square value) between bird mortality in southern Saskatchewan (bottom left) and in southern Ontario (top left), and mammal mortality in southern Saskatchewan (bottom right), and in southern Ontario (top right).

Strengths, Weaknesses and Future Research

The weaknesses of our research are data limitations, inaccuracies, and unavailable data. Data points were collected by laypeople who reported wildlife mortalities by indicating GPS coordinates or surrounding landmarks, while the coordinates were subsequently added by the CWHC. Therefore, some data points were estimated and might not represent the true distance to the variables. Additionally, data bias was introduced, because wildlife deaths were more likely to be detected and reported in populated areas than in remote areas, resulting in a greater point density in populated areas. Furthermore, data could not be collected from privately owned land, such as farms. This could mean our results are not a true reflection of wildlife poisoning across Canada.

Another weakness of our study is the unavailability of data on where living animals were in our study area. Having accurate living animal data would have allowed us to perform a regression analysis that would demonstrate a true distance-based relationship rather than a comparison to a random sample. However, having accurate locations of all living birds and mammals is not feasible in scientific study.

Despite these weaknesses, this research develops a strong foundation for GIS research relating to wildlife poisoning. By analyzing the distance of CWHC points to road networks, agricultural landscapes, PRFs, and protected areas, we were able to determine which of these factors have the strongest correlation with wildlife morality due to poison exposure in Canada. We developed a fundamental understanding of the primary factors that influence bird and mammal mortality in southern Ontario and southern Saskatchewan. Our findings can be taken into consideration when planning to increase or develop road networks, agricultural landscapes, PRFs, as well as for natural parks management.

Conclusion

Wildlife poisoning is a serious issue threatening ecosystem health and biodiversity. Our research focused on assessing what variables influence mortality due to wildlife poisoning and the significance of these effects. We identified the predominant variables that influence bird and mammal mortality due to poisoning as road networks, agricultural areas, PRFs, and protected areas. Our GIS-model compared a random distribution of points to the points provided by the CWHC. We found significance for all variables of interest, however, the variables with the greatest effect across both classes and study areas are waste removal sites, manufacturing sites and chemical sites.

Future research should develop a deeper understanding of the spatial patterns explored in this study. For example, bird mortality in Saskatchewan was directly correlated with protected areas and bird mortality in Ontario was inversely correlated with agricultural areas, which is the opposite to what would be expected. Future research could focus on the specifics of such discovered relationships to determine if there are other underlying spatial patterns influencing these results. Future research could also expand into other areas of Canada, as well as to aquatic and marine species, amphibians and reptiles. Finally, future research could actively sample wildlife mortality events in order to minimize the reporting bias of passively collected data.

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