Department of Geography, Environment and Geomatics
University of Guelph

Using a GIS-based Multi-Criteria Evaluation to Determine a Suitable Location for Implementing Roadside Conservation Infrastructure for Freshwater Turtles in Central Ontario

Sylvie Stewart Grantham
Nicole Carpenter
Isabelle Summers

Supervisor: Dr. Ben DeVries

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Contents

I. Abstract

With the ever-growing urbanisation and land fragmentation in Central Ontario, vulnerable turtle populations are increasingly at risk due to habitat loss and road mortalities. Based on current trends and slow reproductive rates, these native species are headed towards endangerment and extirpation (local extinction). This can lead to a decline in long term ecosystem health and sustainability. Our study aims to reduce the impacts of human-caused roadside mortality of native freshwater turtles in Central Ontario. To begin solving this issue, we developed a model with a GIS-based multi-criteria evaluation (MCE) to find the most suitable location to implement roadside turtle conservation infrastructure. This model includes relevant factors such as proximity to wetlands, traffic volumes and proximity to turtle species at risk. The output of the MCE is a suitability score map that highlights the best locations to implement conservation infrastructure such as ecopassages. The largest four sections of consecutive highly suitable roadside (over 0.9 suitability score) were identified, and measured to be 9.9 km, 4.7 km, 1.8 km and 5.1 km long. The longer stretches of highly suitable roads are deemed a higher need of conservation infrastructure. Comparing the suitability map to future road construction plans revealed certain locations that could combine implementation of infrastructure with current construction plans to minimize costs of implementation. The most promising site with planned future construction and highly suitable roadside occurred at 44.6682° N, 79.6292° W. This study could highly benefit turtle populations of Central Ontario by significantly decreasing roadside mortalities.

II. Problem Context

II. i) Definition and Significance

Seven among a total of eight freshwater turtle species in Ontario are categorized as threatened or endangered due to population declines in the last few decades. Midland painted turtles (*Chrysemys picta marginata*), snapping turtles (*Chelydra serpentina*), and Blanding's turtles (*Emydoidea blandingii*) are some of the freshwater species living at the northern periphery of their distribution, and they inhabit a variety of wetlands such as vernal pools, bogs and marshes (Millar and Blouin-Demers, 2011).

Many factors cause significant risk to turtle populations and conservation efforts are necessary. Langen et al. (2012) describes that turtles are particularly vulnerable to population declines because of their late reproductive maturity of around 20 years, and low egg and hatchling survival. Eggs are highly sensitive to changing environmental conditions like temperature, soil moisture or available oxygen as well as highly susceptible to predators (Markle and Chow-Fraser, 2014). Additionally, turtles characteristically traverse many kilometers which causes them to be susceptible as human development continues to fragment habitats with roadways (Ryan et al., 2014; Langen et al., 2012). The Canada Species at Risk Act (Government of Canada, 2020) identified roads as one of the highest threats to turtles in Ontario (Gunson et al., 2012).

As native species are in decline, this leaves the ecosystem at risk to invasive species, pests and pathogens. It is highly important to take these cases seriously and take precautions to avoid extinction or extirpation, ensuring that our natural ecosystem can continue to function.

II. ii) Knowledge and Research Gaps

The degree of mortality and its effect on local populations is not fully understood in Central Ontario. With respect to the spatial distribution of turtle deaths in relation to road output and wetland proximity, the following questions arise:

1) Are there specific locations that have clusters of turtle mortality within Central Ontario? If so, what factors are causing these?

2) Can conservation infrastructure have significant positive impacts on vulnerable turtle species in the Central Ontario area?

Dorland et al. (2014) found that proximity to roads did not affect the population composition in nearby ponds for painted turtles. It will be beneficial to find out if this is the same for at-risk species. It is possible to analyze these spatially, but difficult to reduce bias as it's challenging to quantify turtles when they are in wetlands. For this reason, and the fact that populations in wetlands could have been eradicated due to road mortalities prior to initial data collection, our understanding of the composition of turtles in wetlands is likely misrepresented.

II. iii) Importance of GIS

As there are many different factors involved in turtle roadside mortalities, determining the optimal solution is difficult. Possible conservation infrastructure efforts include ecopassages used to guide turtles with a fence to a culvert that runs under the road (see Appendix), (Langen et al., 2012). The location of conservation infrastructure is a crucial detail, requiring GIS softwares to find the optimal location for maximum conservation. For a problem such as this one, most of the influential factors are spatial such as proximity to wetlands, proximity to congregations of species at risk, proximity to high traffic areas and more. Therefore, GIS helps to solve this problem by employing a Multi-Criteria Evaluation (MCE) analysis to evaluate all spatial elements and the importance of each, and finding the most suitable locations given all considerations.

III. Purpose of Research

Determining the most suitable locations for implementing conservation infrastructure to decrease human-induced roadside mortality of freshwater turtles in selected Central Ontario districts using a GIS-based Multi-Criteria Evaluation.

IV. Research Objectives

1. Identify factors and constraints that affect the suitability of locations for turtle conservation infrastructure
2. Develop a model using a GIS-based MCE and identify factors and constraints to find the most suitable location to implement conservation infrastructure
3. To determine more feasible locations to implement conservation infrastructure by comparing MCE outputs with future road construction plans of a subset county within the study area
4. To evaluate the strengths and limitations of the model in finding the most suitable locations for turtle conservation infrastructure

V. Study Area

Data were collected by Saving Turtles At Risk Today (S.T.A.R.T.) field researchers, based out of Scales Nature Park in Oro-Medonte, Ontario. The project area encompasses the district of Muskoka, Simcoe County, Kawartha District, Haliburton County and Parry Sound District (Fig. 1). In the study area, land use consists of urban sprawl, agriculture, crown land and protected forests (Fraser and Neary, 2004). This region is heavily influenced by the developing nature of “cottage country”, as there are many aquatic ecosystems that are used recreationally and commercially (Wetland Policy Paper, 2011; Kissel and Choi, 2018). This development trajectory can be highly detrimental to the natural environment and quality of life for inhabitant species such as freshwater turtles (Hadley et al., 2013; Hasler et al., 2015). In 2019, 649 turtles were found on/near roads of the project area, of which 302 were killed or injured (Canada Wildlife Federation, 2020). Based on the aforementioned issues, these five districts were studied to determine the most suitable location(s) for turtle conservation infrastructure (see Appendix).

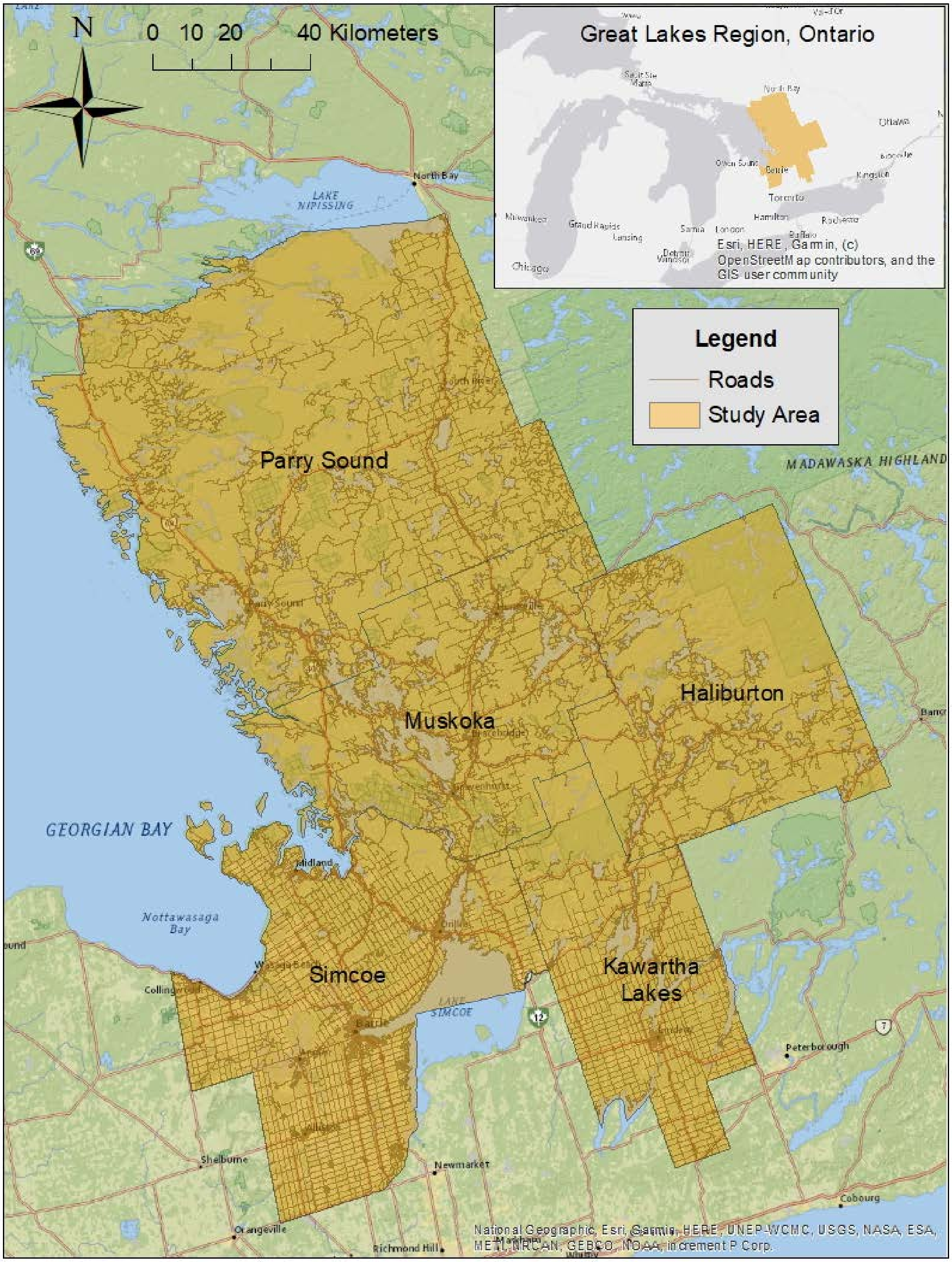


***Figure 1*:** Map of the study area with road network (Ontario GeoHub, 2020).

VI. Research Approach

The following objectives required several GIS analyses to address our research questions. These techniques are well defined methods that have been cited in the literature, and they're described below with justification.

i) Objective 1: To identify factors and constraints that will affect the suitability of locations for turtle conservation infrastructure

To construct a GIS-based MCE analysis, first we identified characteristics that will either improve or worsen the suitability of a particular location (factors), and binary characteristics that are fully suitable or unsuitable (constraints) (Hassan et al., 2015). Factors relevant to our analysis include the proximity to wetlands, road types, construction costs, and the threatened status of live turtle samples (Langen et al., 2012; Gunson et al., 2012). Relevant constraints for suitable locations include the necessity that locations are on a road and within the boundary of the study area.

Proximity to wetland habitat correlates with a higher occurrence of turtles, so as our first factor, closer proximity to wetlands will have a higher suitability score (Langen et al., 2012). We used the Euclidean Distance tool to rasterize the wetland data and assign a value to each cell denoting the distance to the nearest wetland. Using the Raster Calculator, we assigned 0 to everything over 2 km from the wetlands, representing the boundary of likely turtle travel distance. The next two factors take into consideration traffic volume and construction costs on roads in the study area. Traffic volumes on roads were divided into highways for high traffic occurrences, and non-highways for low traffic occurrences. In terms of higher mortality risk based on traffic volume, highways are more suitable locations and non-highways are less suitable. Road data also indicates construction costs as highways will be less operationally and financially feasible to construct infrastructure, and are therefore less suitable. Non-highways are more suitable as they would cost less to build on. The fourth factor is the proximity to threatened turtle congregations. To begin, the Create Thiessen Polygons tool was used to make polygons around each live turtle occurrence point that includes all cells nearest to that point. Then, the Polygon to Raster tool rasterizes and assigns each polygon an ‘at risk’ or ‘not at risk’ status. In the MCE a higher weighting is assigned to species at risk for protection priority.

Along with factors affecting the suitability of locations for conservation infrastructure, constraints were included in our analysis. The first constraint is that the MCE must only assign a suitability score to cells within the study area (Fig. 1), and everything outside our area of interest is unsuitable. The second constraint is that suitable locations can occur only along a road network, all areas off the roads are considered unsuitable.

ii) Objective 2: Develop a model using a GIS-based MCE and the constraints and factors previously identified to find the most suitable location to implement conservation infrastructure

Factor layers were standardized onto a common scale of 0-1 by the Raster Calculator tool using Eq. (1) in order to be comparable. They were assigned weights based on their relative importance by the pairwise comparison chart in Table 1 (Abdul Rasam et al., 2016). These weights were used to prioritize factors in the process of finding suitable locations for implementing turtle conservation strategies (Hassan et al., 2015). The standardized and weighted factors were then input into an MCE equation as shown in Eq. (2) which was input into the Raster Calculator to give the suitability score raster layer (Cromley and Hanink, 2003). This layer allowed us to see the most suitable areas for conservation infrastructure and we selected everything over 0.9 suitability score to identify the most highly suitable spots. Using the Region Group tool and the Raster to Polygon tool we selected the four largest groupings of highly suitable roads as optimal locations (Fig. 4).

Table 1: Pairwise comparison chart to determine weights of each factor in the MCE.

	Pairwise Ranks				**Individual Weights**				**Final Weight**
	Roads Cost	Roads Benefit	Wetlands	Species Type	Roads Cost	Roads Benefit	Wetlands	Species Type	
Roads Cost	1	1/5	1/9	1/5	0.05	0.05	0.07	0.02	**0.04**
Roads Benefit	5	1	1/3	5	0.25	0.23	0.21	0.38	**0.27**
Wetlands	9	3	1	7	0.45	0.68	0.63	0.53	**0.57**
Species Type	5	1/5	1/7	1	0.25	0.05	0.09	0.08	**0.12**
Total	20	4.40	1.59	13.20	1.00	1.00	1.00	1.00	**1.00**

Eq (1) $X' = \frac{X \,/\, X_{min}}{X_{max} - X_{min}}$

Equation (1): Standardising equation for factors input into MCE Eq. (2)

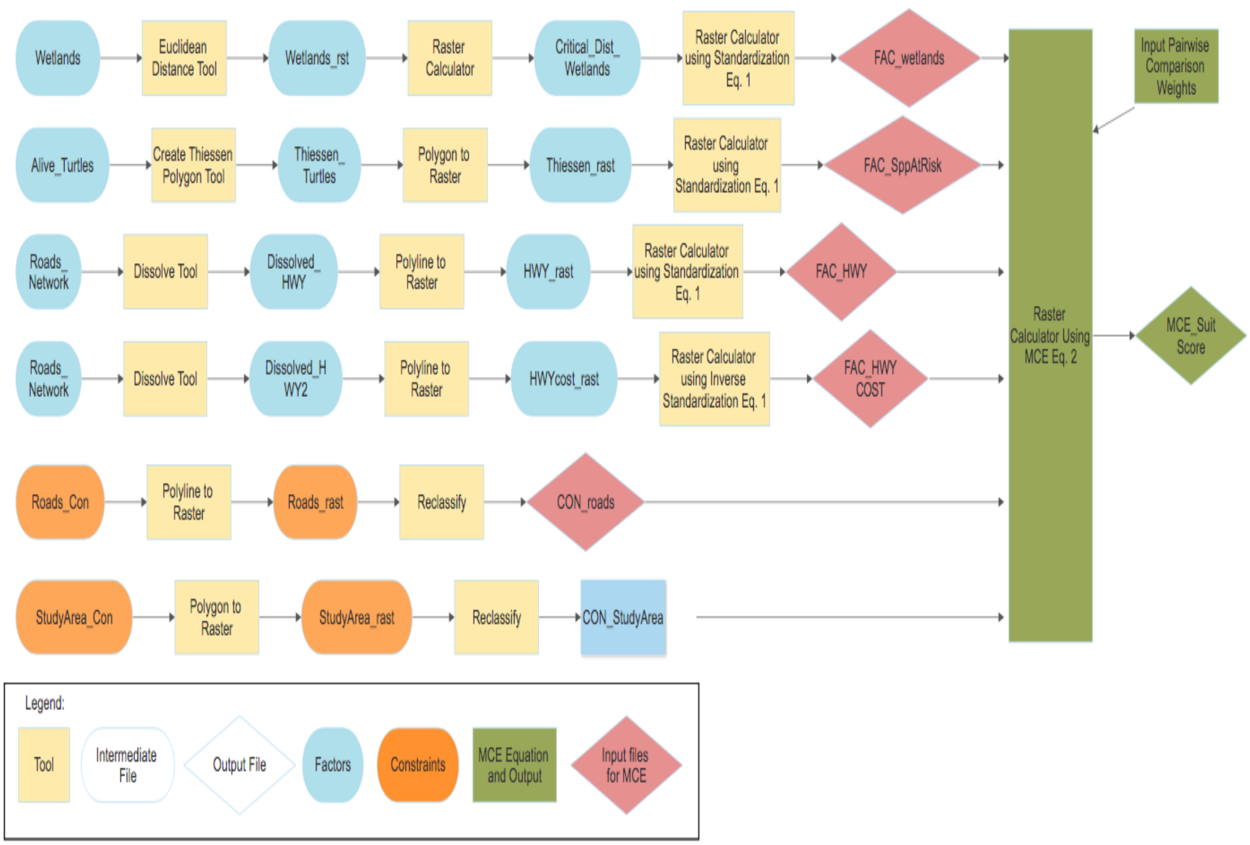
For the variables in Eq. (1), *X*' is the standardised value for the cell in question, ranging from 0-1. Variable X is the original value of the cell in question. Variables Xmin and Xmax are minimum and maximum values of that factor.

Eq (2) $Suitability = Con1 * Con2 * ((W1 * Fac1) + (W2 * Fac2) + (W3 * Fac3) + (W4 * Fac4))$

Equation (2): Multi-Criteria Evaluation equation taking into consideration factors with their relative weights and constraints

In Eq. (2), Variables "Con" represent constraints, variables "Fac" represent factors, and variables "W" are the relative weightings assigned to each factor.

Figure 2:Visualization of the workflow of our GIS-based model



iii) Objective 3: To determine more feasible locations to implement conservation infrastructure by comparing MCE outputs with future road construction plans of a subset county within the study area

The Central Ontario region has seen an increase in human development as it is located close to the Greater Toronto Area and has desirable outdoor space for living and visiting (Fraser and Neary, 2004; Gallant and Boluk, 2017). Building conservation infrastructure in these locations while construction projects occur would be ideal and efficient because it would significantly minimize costs. For this evaluation, we overlaid the suitability score raster with site plans for road construction in the near future, and highlighted 10 areas in which high suitability and road construction overlap.

iv) Objective 4: To evaluate the strengths and limitations of the MCE analysis in finding the most suitable locations for turtle conservation infrastructure

In order to assess the effectiveness of our suitability model we overlaid turtle mortality occurrences with the suitability score raster layer. In doing this we were able to observe if the locations of high turtle death correlated with regions of high suitability for conservation infrastructure. The idea is that regions of high turtle mortality should be the ideal locations for conservation infrastructure. Since we can't depend alone on the sampled data from Scales Nature Park, zooming into a region that was highly sampled can indicate the effectiveness of the model.

VII. Research Findings

Figure 3 shows two of the datasets that were used as inputs in the MCE equation. Map A shows a constraint layer, in which cells within the study area were assigned 1 representing suitable, and cells outside of the study area were assigned 0 representing unsuitable. Map B shows a factor layer, in which there is a range from 0-1 where close to 0 represents further from wetlands, while closer to 1 is nearer to wetlands. Since turtles tend to travel up to 2 km from wetlands, we designated all cells more than 2km away equal to 0.

Figure 3: (A) Shows a map of the study area constraint. (B) Shows a map of the proximity to wetlands factor.

As visualized in figure 4, our model's output shows areas of high suitability for turtle conservation infrastructure referred to as the suitability score. As the map shows, the dark blue sections of road are the most suitable, and therefore likely adjacent to wetlands, near congregations of species at risk, and on or nearby highways. These are the factors taken into consideration that affect the need for turtle conservation measures. We also highlighted in red the longest sections of highly suitable road, and based on our findings it would be most valuable to implement conservation infrastructure like ecopassages in these four areas to evade as many turtle mortalities as possible. Sections A, B, C and D are 9.9 km, 4.7 km, 1.8 km and 5.1 km respectively. This length refers to the number of consecutive kilometers with suitability scores over 0.9. These areas were therefore deemed the most in need of conservation infrastructure. Other dark blue regions are also significant, however they're smaller congregations of suitable area therefore we denoted them as less relevant to the aim of the study.

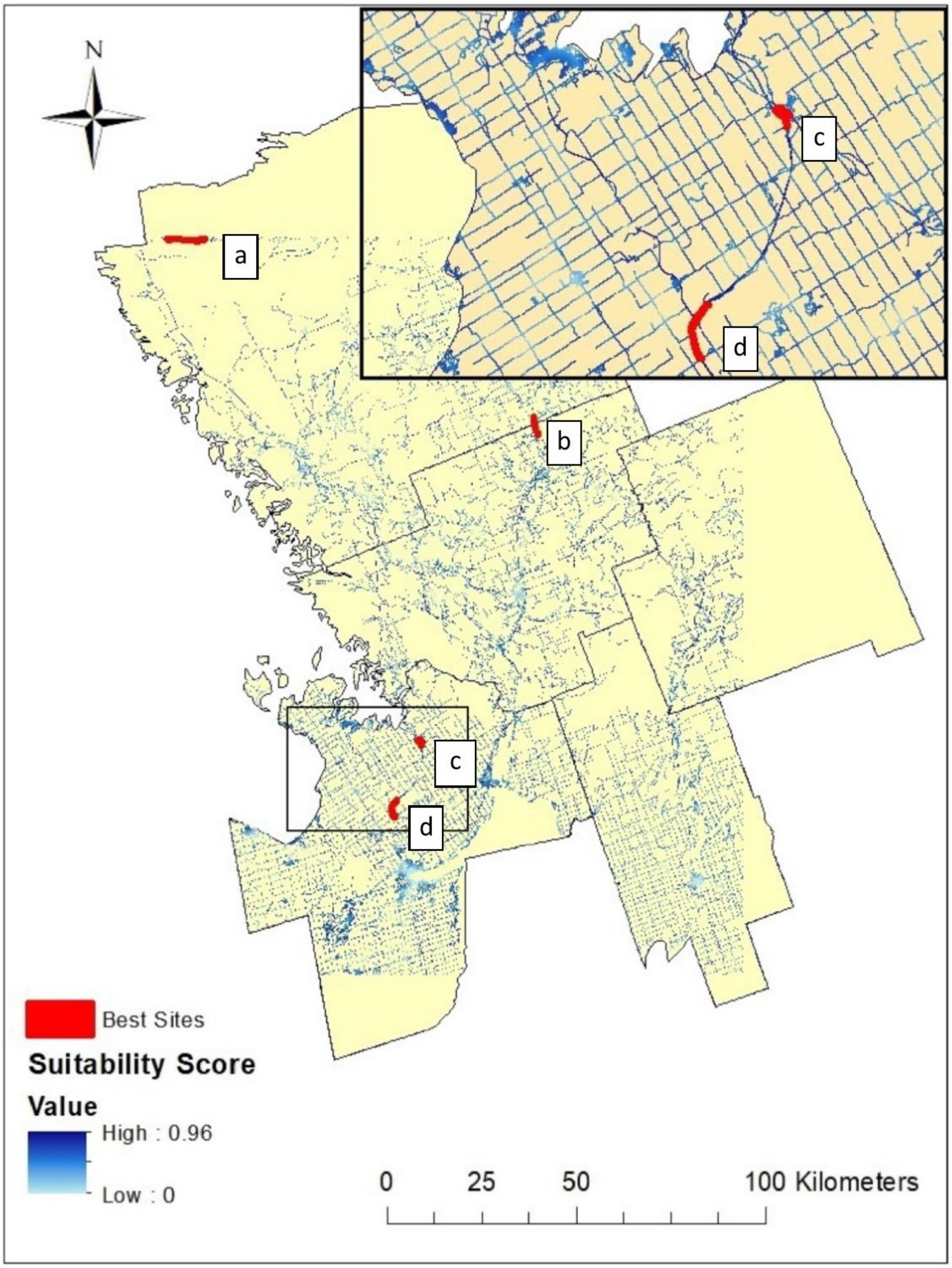


Figure 4: Output of MCE analysis, shown as a suitability score raster dataset. Inset map shows a zoomed in example portion which is more easily interpreted.

As seen in figure 5, turtle mortality incidences are overlain onto the suitability score raster and the ‘best sites’. It is clear that mortality occurrences and highlighted ‘best sites’ don’t correlate, indicating discrepancy in the model. However, this doesn’t mean the model should be utterly discredited, as the data was not sampled evenly across the study area.

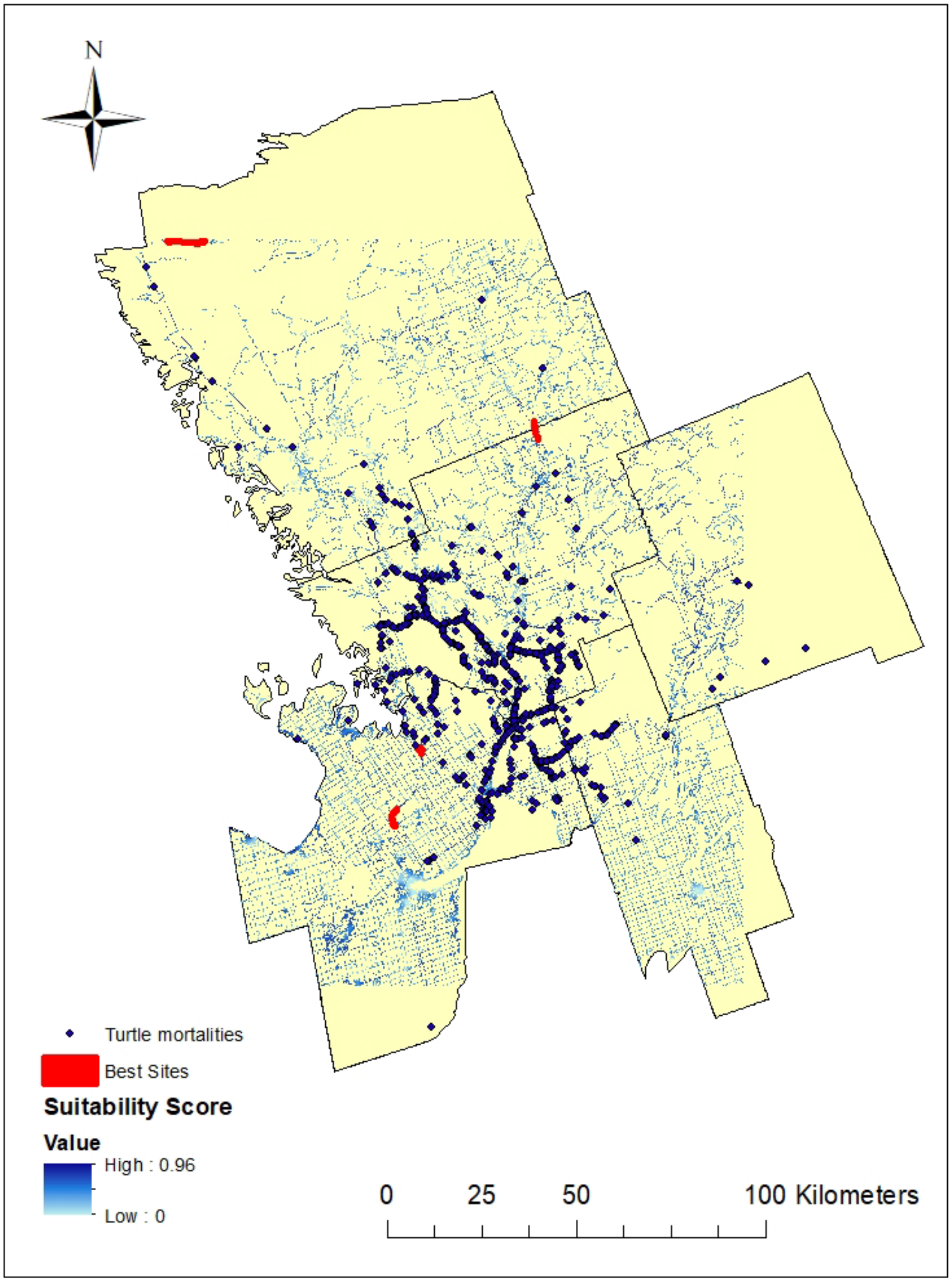


Figure 5*:* Suitability score raster with identified “best sites” and locations of turtle mortality incidences from Scales Nature Park dataset.

Looking further into feasibility of installing ecopassages in the area, overlapping construction of this infrastructure with existing road construction plans would be efficient. After having analysed Figure 6, it appears the construction zone with the most highly suitable section of road occurs at 44.6682° N, 79.6292° W. Implementing the conservation infrastructure simultaneously with construction plans could save costs and improve the chances of approval by local authorities.

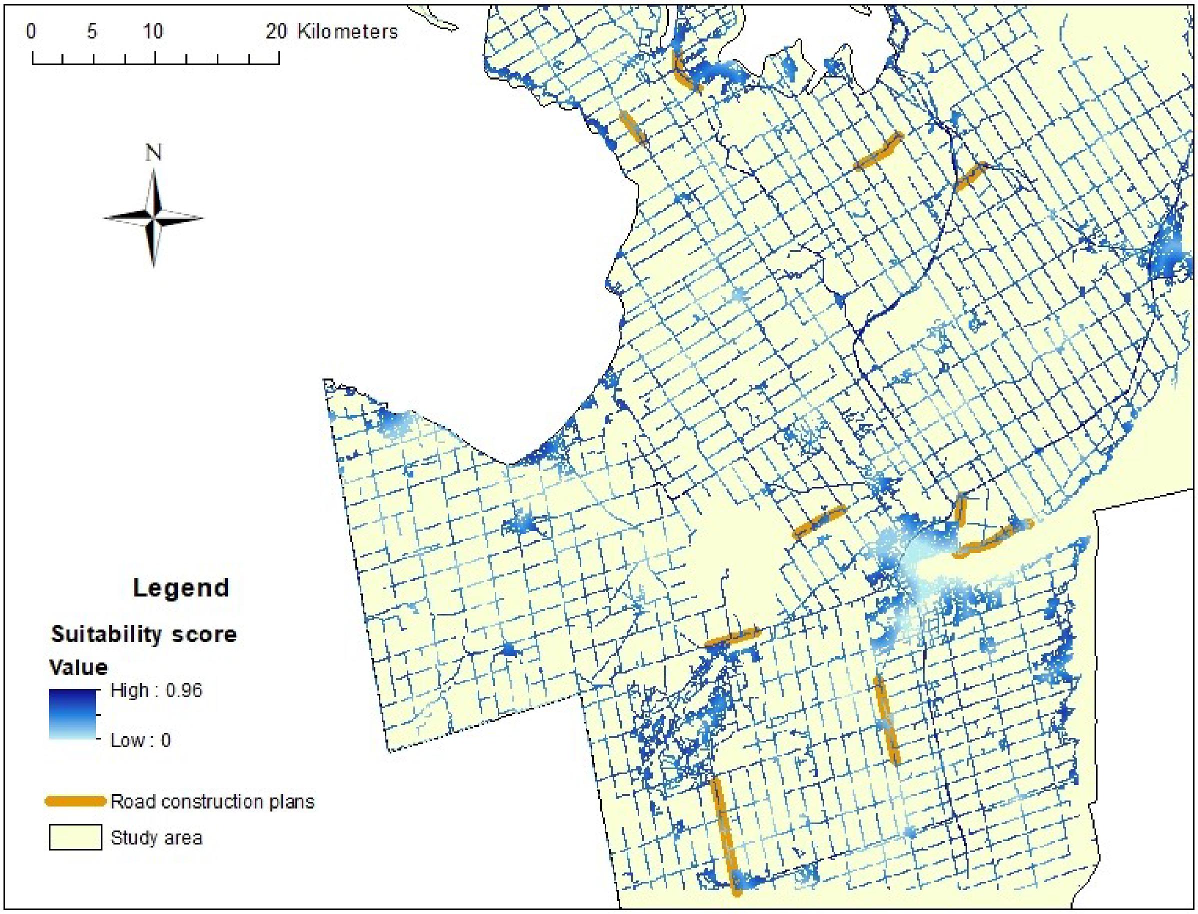


Figure 6: Large scale map of Simcoe County with suitability score dataset and sites of future construction, indicating some potential for combined construction projects.

Figure 7 demonstrates a closer illustration of the suitability score raster layer with the turtle mortality data overlaid to evaluate the effectiveness of the model. The two insets are each examples of locations where the model was effective (A) and ineffective (B) at finding locations particularly in need. As seen in map A, the darker blue areas (highly suitable) correlate significantly with areas experiencing high turtle mortality, therefore the model successfully identified regions needing conservation infrastructure. Map B shows an example of an area with low suitability, however there are clearly many turtles dying in this location.

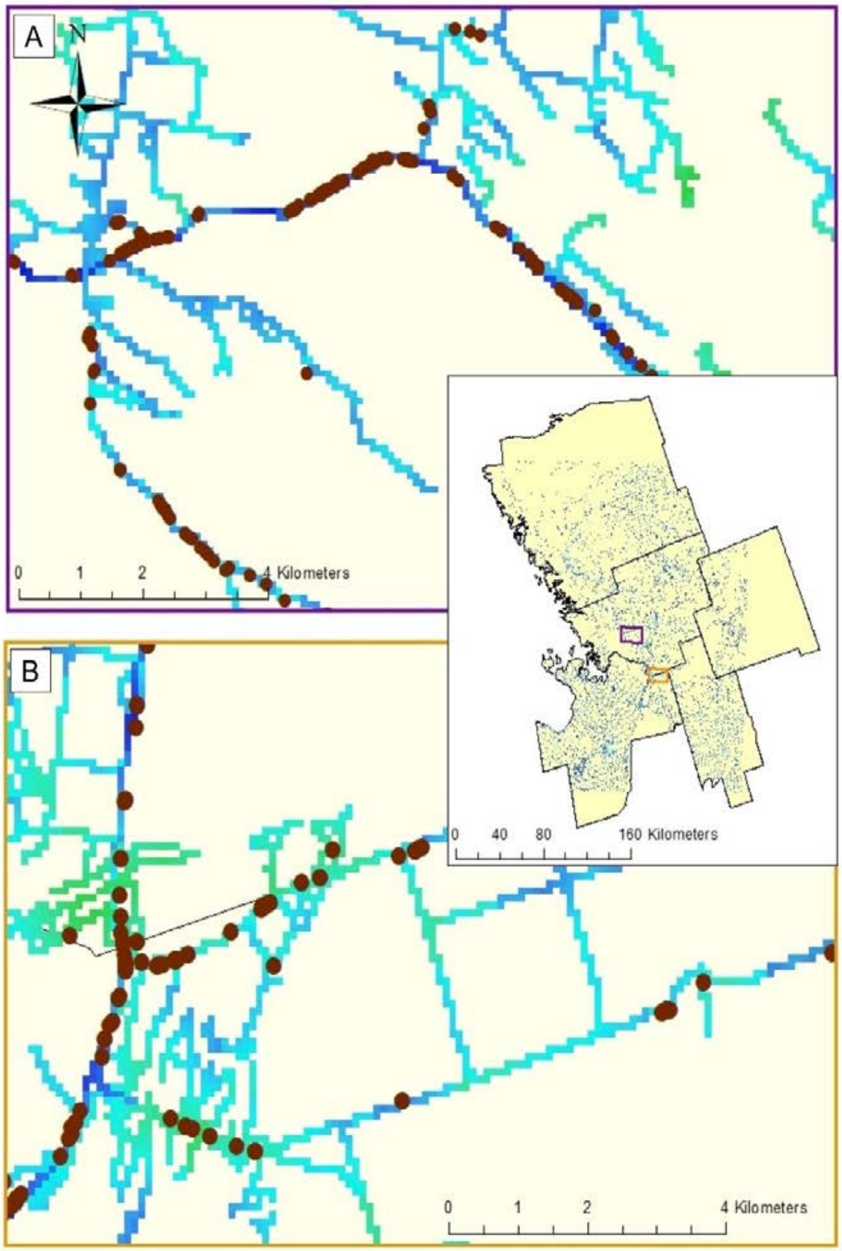


Figure 7: A demonstration of the turtle mortality points overlain onto the MCE suitability raster. Map A is an example of the mortality and suitability rasters correlate and the model was successful. Map B is an example of where the model did not adequately reflect areas of high need for conservation.

VIII. Conclusions

The majority of Ontario's turtle species are at risk due to habitat loss and roadside mortality from increased industrial development and urban expansion (Miller and Blouin-Demers, 2012). As the number of endangered native turtle species increases in Ontario, the importance of implementing conservation strategies continues to rise. The present study aimed to determine the most suitable areas for roadside infrastructure to prevent turtle mortalities using a GIS-based MCE. Results show that there are multiple ideal locations for roadside conservation infrastructure that can decrease the high numbers of mortalities caused by road traffic.

Despite having found some significant results, there are also some limitations to our methodology. One source of subjectivity comes from the MCE analysis, given the step of assigning weights, as different stakeholders may have varying opinions on which factors are the most important. Previously researchers have limited subjectivity by conducting surveys with the public to add democracy. Another limitation includes the skewness of turtle sampling points, which are concentrated centrally around the institute collecting data. The sampling area grew year-to-year as the organization grew and funding increased. It is highly likely turtle occurrences and mortalities occur in high numbers within the outer regions of the study area but were not sampled. Many of the highly suitable sites were in the outer regions but with little data on turtles in these areas, it poses limitations to deciding a best location for roadside infrastructure.

The methods used to input species at risk into the MCE could be another source of discrepancy in the results. The Thiessen Polygon tool created some very small polygons in the highly dense areas. A higher weighting was then assigned to individual cells apart of 'species at risk' polygons. This could create a scenario where neighbouring cells have significantly different weights, although it's not true to assume one is more in need of conservation infrastructure than the other. If we were to repeat this analysis, it would be beneficial to use a tool such as Kernel Density Estimation providing a map showing areas of high density of species at risk or not at risk. This would allow us to assign higher standardized values to areas that are highly dense with species at risk, rather than depending on a single occurrence of that species.

In the future, a similar modelling approach using additional factors and variables to determine the best location for roadside infrastructure would be beneficial. For example, more detailed road data with seasonal traffic volumes and speed limits could be more useful in determining risk to turtle populations. Incorporating more opinions to limit subjectivity on assigning factor weights could improve the results of the MCE through public surveys. In addition, more consistent and intensive sampling efforts within the study area should be done to better understand the turtle populations and their vulnerability to anthropogenic impacts.

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X. Appendix

Figure: An example of conservation infrastructure for freshwater turtles called an ecopassage. Photo A is the implementation of the short fence parallel to a road that used to guide animals towards the tunnel for safe crossing. Photo B is the ecopassage tunnel under a road.