THE EFFECTS OF BIOGEOGRAPHIC FACTORS ON THE PERSISTENCE AND DISTRIBUTION OF THE COMMON FIVE-LINED SKINK IN SOUTHERN ONTARIO

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An undergraduate thesis submitted in partial fulfilment of the requirements for the degree of Honours Bachelor of Environmental Management

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February 18, 2018

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ABSTRACT

Sowers, R. M. 2018. The effects of biogeographic factors on the persistence and distribution of the Common Five-lined Skink in southern Ontario. 48 pp.

Keywords: biogeographic factors, Carolinian, conservation, Common Five-lined Skink, Great Lakes – St. Lawrence, habitat management, non-equilibrium metapopulation, Ontario, prairie, species at risk.

The management of biogeographic factors associated with species at risk populations is an excellent conservation tool if the effects of such factors are thoroughly understood. Biogeographic factors, or habitats, such as prairie/savannah remnants and sandy shorelines, and their effects on the distribution of the Common Five-lined Skink populations in Ontario, were analyzed. Results indicate strong effects of varying degrees from both biogeographic factors on the two skink populations, the Great Lakes – St. Lawrence and the Carolinian population, indicating that these habitats influence the distribution of this lizard species. The effects of said biogeographic elements changed between each population, implying that variations in latitude lead to changes in critical habitat. Within each population extant and extirpated/historical locations showed no significant variation in proximity to sandy shoreline and prairie/savannah habitat. This indicated that extant populations have not survived due to closer proximity to essential habitat, and the isolation of local populations has remained consistent, leading to long-term extinction rates which prevent recolonization (non-equilibrium metapopulations). Considering these biogeographic elements as critical requirements allows for more effective habitat management tactics for the Common Five-lined Skink to prevent future population losses. Ultimately, biogeographic components associated with species at risk can be a useful addition to habitat management used in the conservation of any species.

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ACKNOWLEDGEMENTS

I would like to extend my deepest appreciation to my supervisor, Dr. Stephen Hecnar, for bearing with me through my questions, roadblocks, setbacks, and inconsistencies. Patience is truly a virtue and it has been greatly appreciated throughout this entire process. I would like to thank Dan Brazeau for being an excellent mentor and helping me through much of this process. I would also like to express my gratitude to Dr. Stephen Hart for walking me through the many challenges and pleasant surprises associated with ecological data, and for encouraging me to tackle each problem with new perspectives. A shout-out must also go to Benjamin Kissinger, who assisted me with many of the statistical analyses and truly broadened my knowledge on interpreting ecological data. I must also thank my dearest friends and family (you know who you are) for listening to my many hours of discussions, rewrites, and rants throughout this past year. The support you have showed me is truly incredible and I am forever grateful.

INTRODUCTION

The present geographic distribution of a species often exposes the spatial configuration of its critical habitat and can provide insight into the historical aspects of its biogeography. Species tend to disperse from their centres of origin across hospitable space until conditions limit suitable habitat and/or other niche requirements (Lomolino et al. 2010). Thus, understanding ecological and biogeographic factors is critical for effective habitat management and protection of species at risk (SAR). Populations on the periphery of a species' range can undergo tremendous environmental strain, but persist where sufficient suitable habitat and associated biogeographic or environmental elements exist. To effectively conserve these species throughout their entire range, existing biogeographic factors, and the effects of such factors, must be studied. The current extinction rate of wildlife species surpasses that of historical rates, suggesting that a sixth mass extinction in Earth's history may be approaching (Barnosky et al. 2011; Ceballos et al. 2015). Many species around the world have already been lost or have an incredibly high risk of extinction due to loss of habitat on both local and landscape scales. Applying knowledge of biogeographic characteristics of SAR habitats will allow us to create appropriate conservation and protection strategies to prevent population losses in the future. Research in this field will contribute to rehabilitating SAR populations by utilizing knowledge of biogeographic elements critical to their survival. By first filling in knowledge gaps of key biogeographic elements for a species, it may be possible to estimate presence probability in key habitat areas, resulting in more effective sampling methods, and ultimately more effective conservation, for these species.

Previous studies conducted by Sheffield et al. (2015) on the importance of biogeography in the conservation of the western bumblebee, and Ha and Lui (2014) on the use of biogeography to conserve endangered bird species and analyze the effects of climate change, shed the light on the topics being investigated regarding species at risk and the importance of biogeographic factors for conservation actions. Few studies exist pertaining to the significance of these factors on at-risk wildlife populations. A comprehensive analysis of these factors and their influence on the distribution of species at risk will be a valuable addition to the knowledge necessary to progress in this field.

Deterioration, fragmentation, or loss of habitat can cause regional population declines which eventually lead to local extinctions (Harrison 1991). Non-equilibrium metapopulations occur as a result of these declines when the rate of extinction cannot be balanced due to insufficient or absent recolonization (Harrison 1991). Drastic changes in habitat lead to population isolation, which exceed a species' dispersal capability, preventing immigration and overall recolonization of local populations (Harrison 1991). Many species at risk are considered non-equilibirum metapopulations which do not have the ability to recolonize lost or deteriorating local populations, leading to extinctions of these species on regional and global scales (Harrison 1991). Understanding the degree of isolation of populations can lead to more effective population and habitat management, both of which are key components in conserving species at risk.

I investigated the presence of a lizard species in relation to key biogeographic factors in the most northern part of its geographic range in southern Ontario, Canada. This species provides an example for SAR populations located in range peripheries. The Common Five-lined Skink (*Plestiodon* [formerly *Eumeces*] *fasciatus*) is the only lizard species present in the province, and has been deemed endangered or threatened in each of its two populations due to historical patterns of habitat loss (COSEWIC 2007; Hecnar and Brazeau 2016). The Five-lined Skink is a cold-adapted primary invader species that expanded its range after the retreat of the Wisconsin advance of the last glacial period (Holman 1995). This species' biogeographic past may be reflected by its current isolated distribution in Ontario's Carolinian ecozone and the apparent proximity of extant populations to tallgrass prairie/savannah remnants and to sandy shorelines. Presently, skink distribution appears to emulate the distribution of prairie remnants in Ontario, suggesting that this species may have dispersed into southern Ontario during the post-Pleistocene tallgrass prairie peninsula (Forsyth 1988; Hecnar et al. 2002) via the southwestern landbridge (pre-Detroit River drainage) (Hecnar and Brazeau 2016). The proximity of extant populations in the Carolinian zone may also suggest that shorelines of the Great Lakes, tributaries, or other large bodies of water, may have provided dispersal corridors and habitat.

The success of recovery efforts for this species would greatly improve if the complete effect of biogeographic elements, specifically prairie remnants and sandy shorelines, on the species' distribution were better understood. This study will indicate if a relationship exists between population persistence and remaining biogeographic elements in a species' range. It will also investigate the extent to which these biogeographic factors influence populations and test if these factors have a profound effect on the distribution of wildlife species.

LITERATURE REVIEW

SKINK BIOLOGY, DISTRIBUTION, AND HABITAT PREFERENCES

Natural History

The Common Five-lined Skink (*Plestiodon fasciatus*) is the only known lizard species to exist within Ontario's limits. This species has a smooth, slender body less than 20cm in length with prominent cream-tan lines spanning from head to tail, thus giving rise to its common name. Key identification characteristics include a prominent blue tail, present in hatchlings, juveniles and young adult females, and bright orange-red suffusion on the jaws and neck of adult males (Figure 1). Individuals rely on sufficient microhabitat of woody debris or rocky crevices for refuges and nesting, and rocky outcrops and sand dunes for basking sites to maintain an optimal body temperature of 28-36°C (Ontario 2017). These microhabitats are present in a variety of habitats including open forests, stabilized dunes, savannahs, and anthropogenic-dominated areas such as cottages (Brazeau 2016).

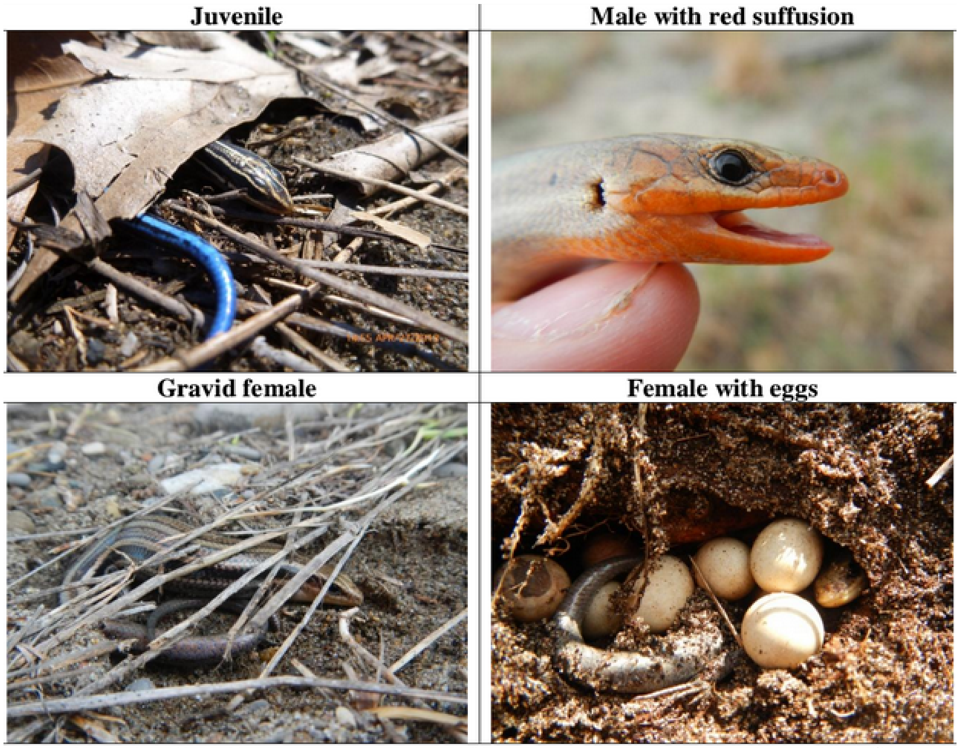

Figure 1. The appearance of the Common Five-lined Skink at various life stages. (Source: Brazeau 2016)

Population Distribution

The Common Five-lined Skink, *Plestiodon fasciatus*, previously *Eumeces fasciatus*, is the only lizard species present in Ontario and Eastern Canada (COSEWIC 2007). Its range comprises much of eastern North America, extending from the Atlantic seaboard and west into Texas and Minnesota, and from southern Ontario south to the Gulf of Mexico (Figure 2) (COSEWIC 2007; Powell et al. 2016). Two broad populations exist within the skink's range in Ontario: the Carolinian and the Great Lakes - St. Lawrence (or Southern Shield) populations (Figure 3) (COSEWIC 2007). The Carolinian population is located in southwestern Ontario along the coasts of Lake Erie, Lake St. Clair and Lake Huron, as well as inland areas east to the Niagara Peninsula. The Great Lakes - St. Lawrence (GLSL) population extends eastward from Georgian Bay to the St. Lawrence River, following the southern boundary of the Canadian Shield (COSEWIC 2007). Within the last decade approximately 70 extant subpopulations within the GLSL population and 15 extant subpopulations within the Carolinian population have been recorded and confirmed (COSEWIC 2007).

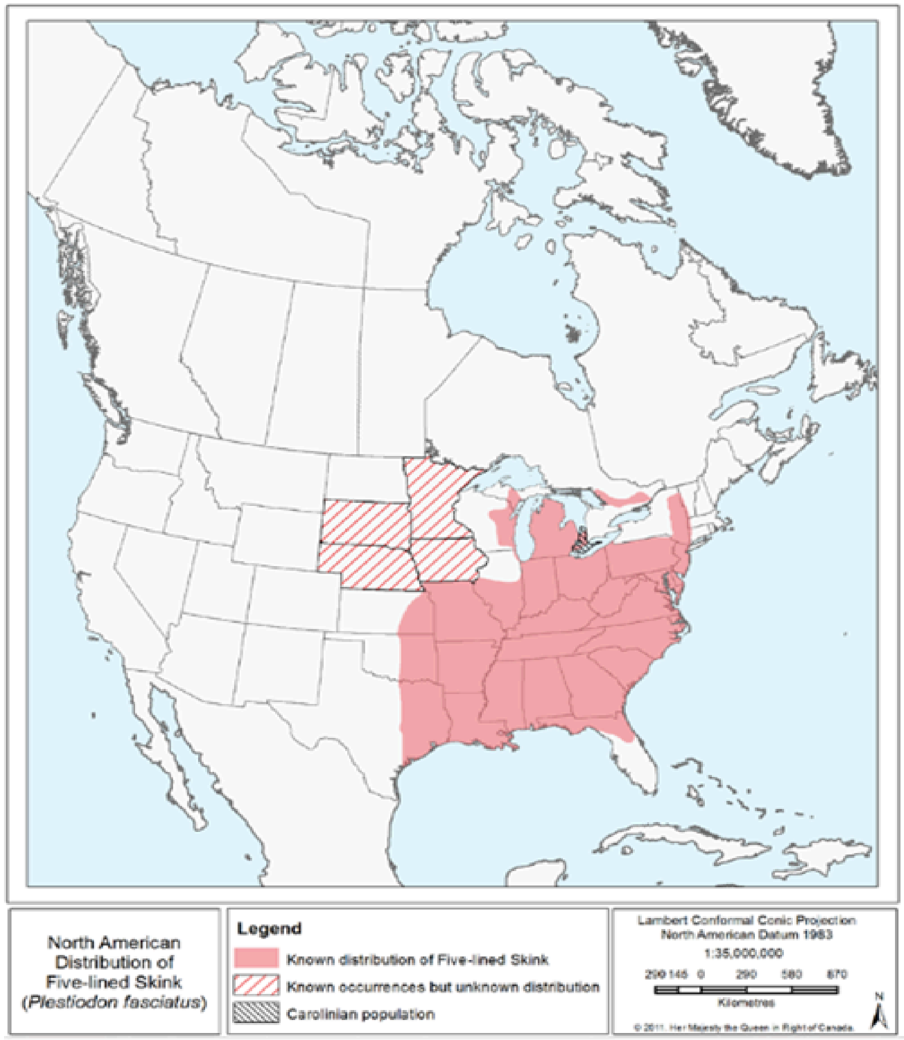

Figure 2. The geographic range of the Common Five-lined Skink where solid pink represents the known distribution, pink lines indicate occurrences with unknown distribution, and black lines over solid pink displays the Carolinian population. (Source: Ontario 2017)

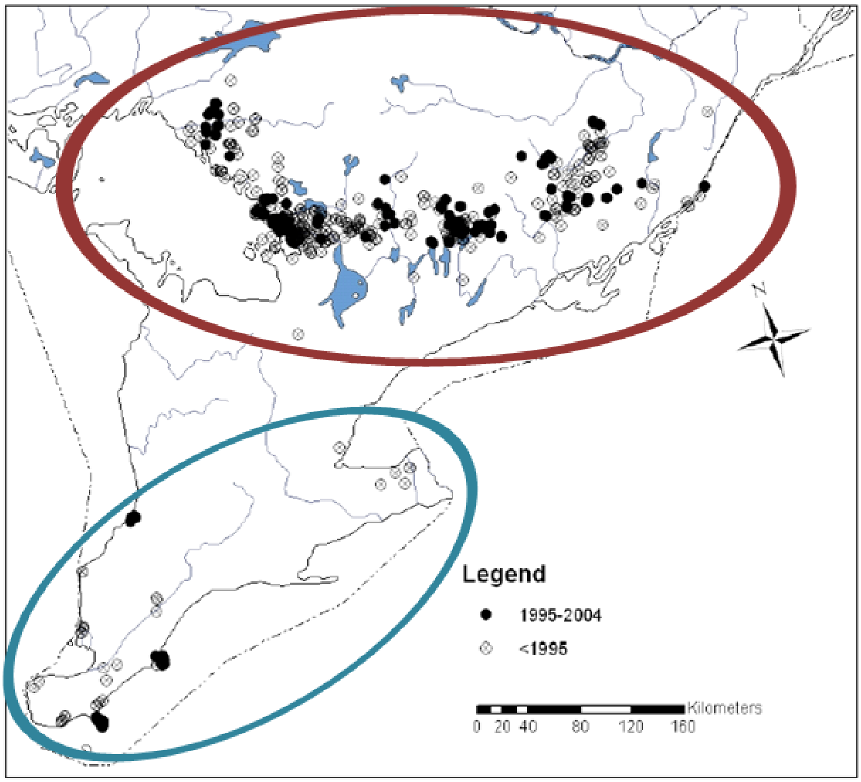

Figure 3. Distribution of the Common Five-lined Skink in Ontario with the Great-Lakes St. Lawrence population circled in red and the Carolinian population circled in blue - based on a distribution map from the COSEWIC Assessment and Updated Status Report on the Common Five-lined Skink.
(Source: COSEWIC 2007)

Skink Habitat Preferences and Requirements

Habitats, areas within a species' range that provide all elements necessary for survival, project distributional patterns of a given species (Hecnar and Brazeau 2014). Abundance structure and density tend to be positively correlated with habitat quality, quantity, and configuration due to species-specific habitat requirements (Gaston 2003; Lomolino et al. 2010). These requirements will vary throughout a species' range. Habitats of the Common Five-lined Skink range from rocky outcrops, to sand dunes and open deciduous forests (COSEWIC 2007). Habitat preferences for this species include low-moderate canopy cover within open forests mostly comprised of early successional vegetation (COSEWIC 2007). Habitat use varies with the amount of forest cover within a given area; skink habitat use declines in forests that contain more than 50% canopy cover (Hecnar and Brazeau 2014). Through the use of radio-telemetry, high levels of use of trees, grass tussocks, and underground refuges for skinks were discovered in the Carolinian population (Hecnar and Brazeau 2016). Despite the use of trees as cover, skinks strongly prefer more open dune, savannah, and rock outcrop habitat compared to forests in the northern portion of their range (Hecnar and Brazeau 2016). Other necessary elements found within skink habitats include suitable microhabitats to provide cover and protection against weather events and predation (COSEWIC 2007). Appropriate microhabitats include rock piles, or fissures in rocks, prone woody debris, standing snags or hollow trees, and human-provided cover boards which offer cover within optimal thermal environments (Hecnar 1991; Howes and Lougheed 2004; Hecnar and Brazeau 2016). General habitat requirements are known for both skink populations, but habitat quality will vary with changing environmental conditions between years or over time (Hecnar and Brazeau 2014).

CAUSES OF POPULATION DECLINES

Current suitable skink habitat consisting of prairies, oak savannas, stabilized dunes, oldfields, and woodlands (COSEWIC 2007) only occurs throughout Ontario in very small portions due to extensive agriculture (Bakowski and Riley 1994) and urbanization across the landscape (Hecnar and Brazeau 2016). Although loss of suitable habitat is the main cause of skink population decline, many other factors exist including: illegal collection of skinks for the pet trade, increased predation by cats, dogs and raccoons, road mortality, and loss and degradation of microhabitat, all of which contribute to the skink population's inability to increase (COSEWIC 2007). As a whole, ectothermic species are very sensitive to changes in structural microhabitat that is critical for behavioural thermoregulation and overwintering in higher latitudes (Hecnar and Brazeau 2014). Smaller sites with a higher degree of isolation are also much more susceptible to population fluctuations influenced by stochastic factors (COSEWIC 2007). Skink occupancy within a site is more likely to increase when suitable microhabitats, and preferred canopy cover and temperatures, are present (Hecnar and Brazeau 2014). A combination of population isolation, removal and destruction of microhabitat, road mortality, and predation, has contributed to the drastic decline in the Carolinian skink population since 1984 (COSEWIC 2007). Historical declines within the Carolinian population have reduced distribution from many localities to few locations which become increasingly isolated each year due to the Common Five-lined Skink's limited dispersal capabilities (Hecnar and Brazeau 2014). An individual Five-lined Skink is only able to disperse to a maximum of 100m/year, according to research conducted by Seburn (1990). Adults were found to travel a maximum of 68m for females, and 52m for males, whereas yearlings dispersed 25m (Seburn 1990). The largest dispersal distances, 68m-107m, were completed by hatchlings (Seburn 1990).

PRAIRIE AND SAVANNAH HABITAT REMNANTS

Fifteen extant populations of skinks presently exist throughout Southern Ontario; the three largest populations in the Carolinian region being the Pinery Provincial Park, Point Pelee National Park, and Rondeau Provincial Park (Hecnar and Brazeau 2016). Historically, these sites, once known as “Erie Spirits”, consisted of oak savannas, woodlands, prairie-like dune grasslands, and cottonwood and red cedar dune savannas (Bakowski and Riley 1994). Several large portions of southern Ontario were once covered by extensive prairies and savannas which extended from the west in the north central United States (Transeau 1935; Bakowski and Riley 1994). Prairie remnants were common in areas close to the shores of the lower Great Lakes near Windsor and Turkey Point and at inland sites near London, Brantford, and Peterborough; the persistence of these remnants are said to be influenced by natural fires and warm, dry site conditions, combined with the use of fire by Aboriginal Peoples (Bakowski and Riley 1994). Pre-settlement descriptions of the vegetation in southern Ontario estimate that open prairies occupied approximately 530km^2 across the landscape (Bakowski and Riley 1994). Palynological evidence from lakes throughout this area and paleoecological evidence both suggest that the development of oak savannas and prairies occurred north of Lake Erie between 4000-6000 years BP until European settlement in the region (Bakowski and Riley 1994). The current distribution of prairie and savanna remnants occur on the sandy lake plains of what are now Lakes Huron, Erie, and Ontario, as well as on shoreline bluffs of postglacial modern lakes (Bakowski and Riley 1994). Some small areas consisting of oak-pine woodland with minute intermittent prairie areas remain near

Turkey Point along the north shore of Lake Erie, which was once a landscape that supported an extensive range of prairies (Bakowski and Riley 1994).

MATERIALS AND METHODS

STUDY AREAS AND HABITATS

Southern Ontario is home to the most northern portion of the Common Five-lined Skink range with two populations persisting - one located at the southern boundary of the Canadian shield, and the other in the southwestern tip of the province bordering Lake Erie, Lake Huron, and Lake St. Claire (Figure 3). At the periphery of this species' range these populations face abiotic challenges such as the cold Canadian climate and habitat loss. The combination of these factors has led to the decline in both Ontario populations. The northern population (Great Lakes-St. Lawrence population) was listed as special concern and the southern population (Carolinian population) was listed as endangered under COSEWIC (2007).

I used skinks as an example of species at risk populations located in range peripheries, and analyzed the influence of biogeographic factors, such as presence of critical habitat, thought to be crucial to the survival of species at risk, and thus determined if these factors have had an effect on both past and present species distributions. I used sightings-only data, a common method of acquiring estimates of rare species, for both of the skink populations from historical records (Ontario Herpetofaunal Summary, Ontario Nature's Reptiles and Amphibian Atlas) and element occurrence data provided by the Ontario Ministry of Natural Resources and Forestry's

Natural History Information Centre (Hecnar and Brazeau 2016). The element occurrence data were updated by recent survey data which verified classifications as extant or historic for the Carolinian locations (Hecnar and Brazeau 2016). All population locations, both Carolinian and GLSL, were classified as either extant or historic before further analysis. The two major biogeographic elements, or habitat types, thought to be associated with Common Five-lined Skink distribution in Ontario are prairie/savannah habitat and sandy shorelines. These factors were chosen for investigation due to their historical association with skink populations in Ontario and present proximity to extant populations. To better understand this association, I examined distances between populations and nearest prairie/savannah and shoreline habitat. I then compared these different distances with distances to randomly selected points. If extant and historical populations are significantly closer to these habitats it suggests their importance and supports their historical influence before southern Ontario became forested and lands were converted to agriculture.

To assess the significance of these biogeographic factors on past and present skink populations, I compared distances from extant population locations in both the Carolinian and GLSL populations to biogeographic factors. This analysis will allow me to interpret if the extant populations have survived due to shorter distances to critical habitats, such as prairie/savannah and sandy shorelines.

GIS MAPPING

I used ArcMap 10.2.2 to map populations using coordinates of each skink population location. These points were overlaid on shapefile maps of prairie habitat remnants (Wasyl Bakowsky 1994) and shorelines of major waterbodies throughout southern Ontario. These shorelines consisted of Lake Huron, including Georgian Bay, as well as Lakes Ontario, Erie, and St. Clair. I used the Near function in ArcMap (Coverage Toolbox > Analysis Toolset > Proximity Toolset > Near) to measure distances from each population to the closest point (nearest neighbour) of each biogeographic factor (prairie/savannah or shoreline habitat). I created a polygon enclosing the skink distribution and generated a random set of points within for distance calculation.

To complete the second set of analyses to determine the various effects, if any exist, of habitat factors in extant versus historic populations, I used similar methods as discussed above. The Carolinian and GLSL populations were divided into extant and historic population locations and distances measured from each set of locations to the closest biogeographic factor, or habitat. These distances were then analysed and compared using various statistical analyses.

STATISTICAL ANALYSES

Distances were examined and compared using multiple paired t-tests (IMB SPSS Statistics 24) where a confidence level of 95% was used with a confidence interval of 0.05. The first test compared distances from the Carolinian population locations to prairie/savannah remnants with distances from the same population to random points. The next paired *t*-test compared the distances from the Carolinian population locations to shorelines with the distances measured from population locations to the random points. These two tests were repeated comparing the distances from the Great Lakes-St. Lawrence population locations to the biogeographic factors with the distances measured from the population locations to the random points. By comparing the distances from each population to the nearest biogeographic factor and the distances from the random points to these populations, I was able to assess if a significant statistical difference exists between the random distances and the habitat distances. The t-tests determine if the distance between each population and the random points are related. If the populations are highly associated with the random points (high significant values) it suggests that the populations are randomly dispersed and there is little relation between dispersal and these biogeographic factors. Similarly, if the distances from the populations to each of the two habitats of interest result in differing means compared to the distances to random points, significant results are present, providing evidence that the biogeographic factors are of importance for persistence and distribution of skink populations.

I next compared the population to habitat distances between the GLSL and Carolinian populations. A one-way ANOVA (IBM SPSS Statistics 24) was utilized to complete this comparison. I compared the biogeographic effects of the two Ontario populations. Through this I can determine which biogeographic factors contribute relatively more to the persistence of each population. The ANOVA was used to compare the distances from each population to shorelines, and again to compare the distances to prairie/savannah habitat. If a high variation of distances occurs between populations, it indicates that the effects of biogeographic factors on the persistence of each skink population differ. Through this analysis I will determine if the effect of the biogeographic factors is greater on one population versus the other, thus leading me to determine the importance of these critical habitats in the distribution and persistence of both the GLSL and the Carolinian populations.

Another set of ANOVA (IBM SPSS Statistics 24) tests were conducted, this time to determine if the extant populations have survived due to a closer proximity to habitat compared to the extirpated/historical populations. The first test compared the distances from the extant Carolinian population locations to prairie/savannah habitat with distances from the extirpated Carolinian population locations to the same habitat type. The next ANOVA compared the distances from both the extant and extirpated Carolinian population locations to sandy shorelines. Two more identical ANOVA tests were conducted to compare the extant and extirpated GLSL population location distances to each habitat type. If statistically significant, the hypothesis that the extant populations have persisted due to shorter distance to prairie/savannah and sandy shoreline habitat will be supported.

The final set of ANOVA tests compared distances between local populations within each metapopulation. The first test analyzed the distances between local extant and local historical/extirpated population locations within the Carolinian population (nearest neighbour comparison). The second test compared these same local population distances within the GLSL population. Completing this analysis will determine if travel between local populations has been variable from the historical population locations to those that are extant due to changing proximity to critical habitat, or if these populations have maintained an isolated state in through recent times.

RESULTS

EFFECTS OF BIOGEOGRAPHIC ELEMENTS

The biogeographic factors, or habitats, analyzed in this study, prairie/savannah remnants and sandy shorelines, are present throughout many parts of southern Ontario (Figure 4). The skink population locations vary throughout the province, tending to be clustered near prairie/savannah habitat and sandy shorelines (Figure 5). The random points created for use in the distance comparisons are located throughout the southern portion of the province in areas around and between the Carolinian and GLSL populations with no apparent clustering near the analysed habitats (Figure 6).

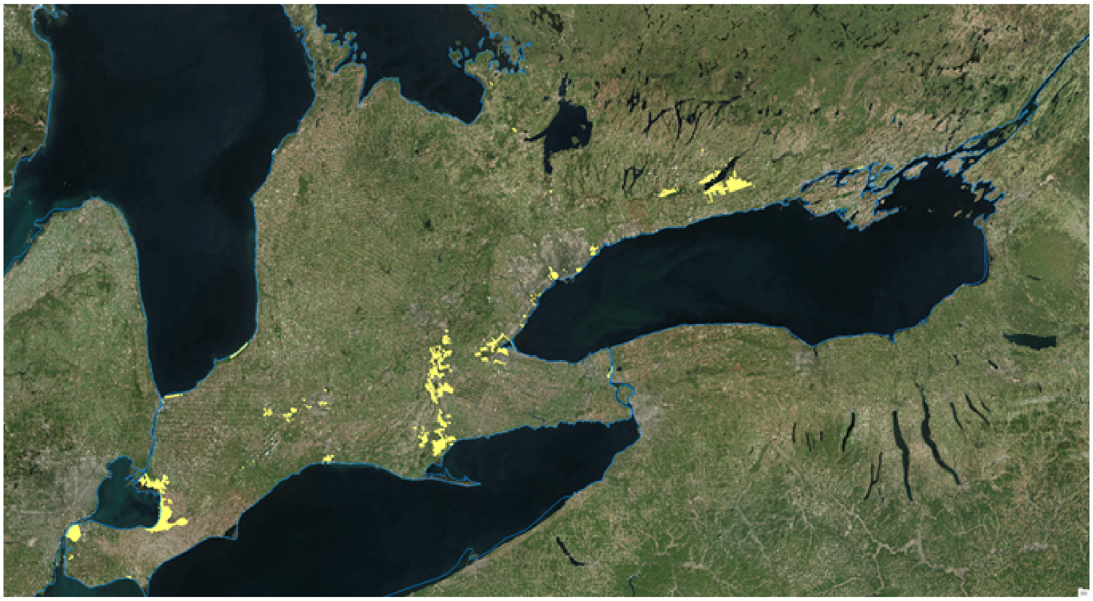

Figure 4. A map depicting the biogeographic factors in question; prairie remnants are displayed by the yellow polygons and sandy shorelines are portrayed by the blue lines. (Source: Rayelle Sowers 2017)

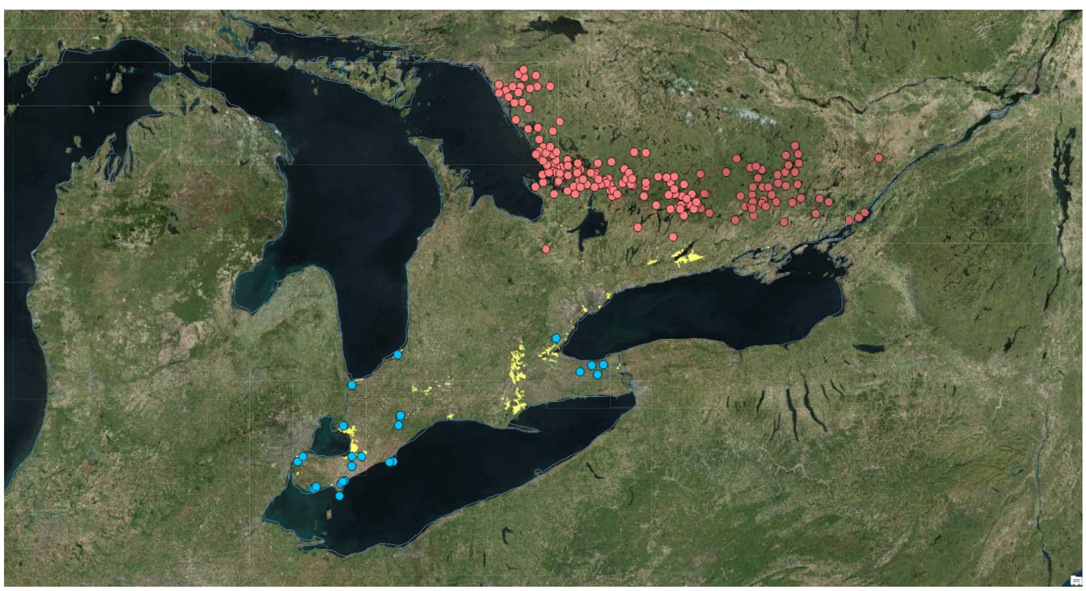

Figure 5. A map displaying the habitat types, prairie remnants – yellow, sandy shorelines – dark blue, and occurrences of skinks in the Carolinian (light blue dots) region and the Great Lakes - St. Lawrence (bright pink dots) region.
(Source: Rayelle Sowers 2017)

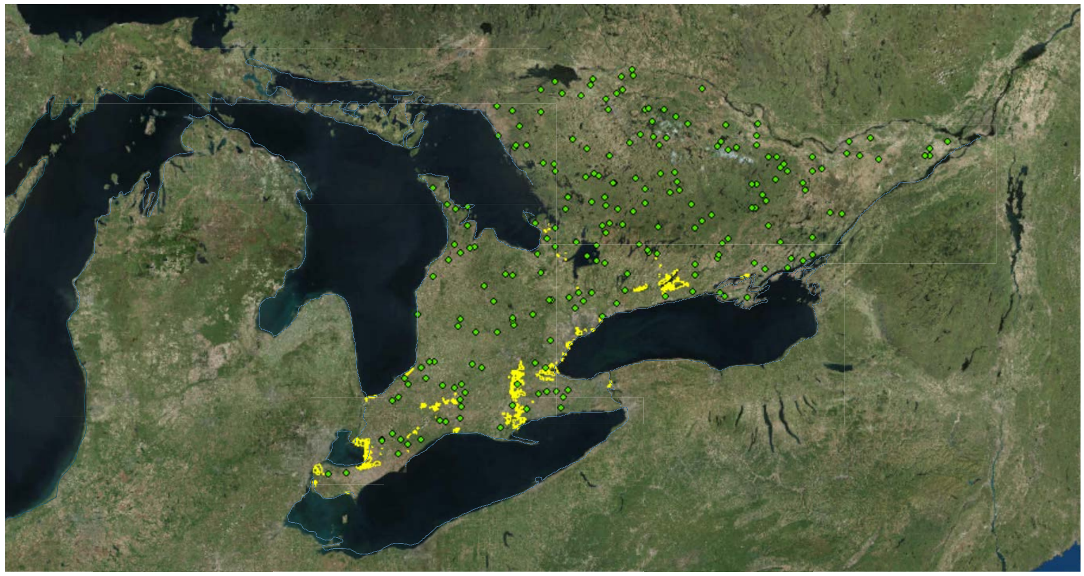

Figure 6. A map displaying the study area which includes the randomly generated points (bright green dots), and the two biogeographic factors: prairie/savannah (yellow) and sandy shores (dark blue).
(Source: Rayelle Sowers 2017)

The distances measured from the Carolinian and GLSL population locations to the randomly generated points, prairie remnants, and shorelines are displayed below in various scatter graphs. The GLSL population distances to prairie habitat remnants indicate clustering of population locations 20-60km away from prairie habitat (Figure 7). The GLSL population distances to shorelines also indicate clumping, but occurring within 10km from sandy shorelines (Figure 8). The random points measured all occurred within 35km of each GLSL population location (Figure 9). The Carolinian population distances to prairie habitat (Figure 10) and shorelines (Figure 11) show that all population locations occur within 25km for both biogeographic factors/habitats. Similar to the GLSL population distances to random points, all of the distances measured from the Carolinian population locations to the random points were within 35km (Figure 12).

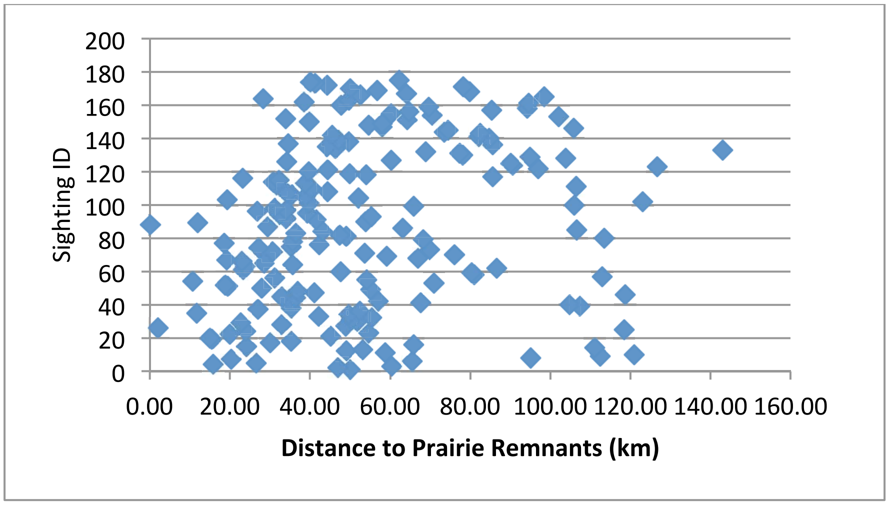

Figure 7. Measured distances from the GLSL population locations to the closest prairie habitat remnants.
(Source: Rayelle Sowers 2017)

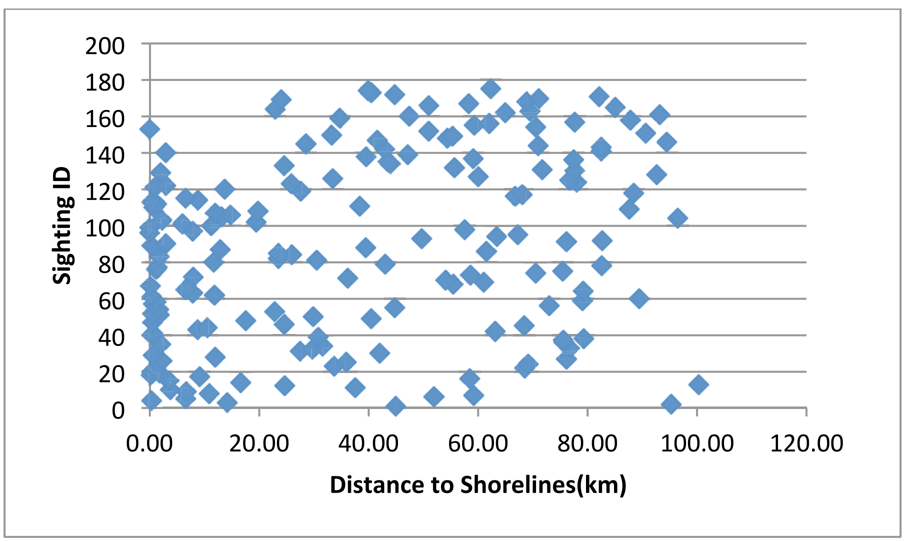

Figure 8. Measured distances from the GLSL population locations to the sandy shoreline.
(Source: Rayelle Sowers 2017)

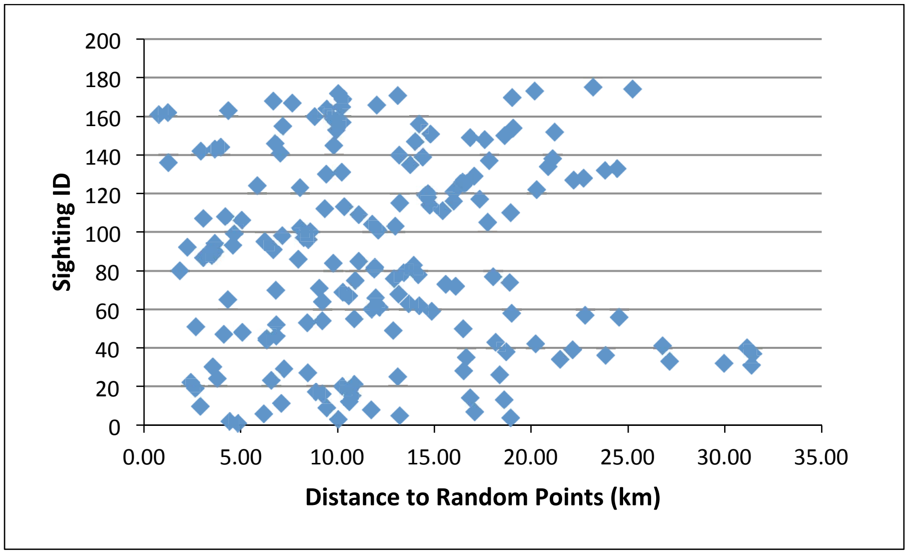

Figure 9. Measured distances from the GLSL population location to the closest random points.
(Source: Rayelle Sowers 2017)

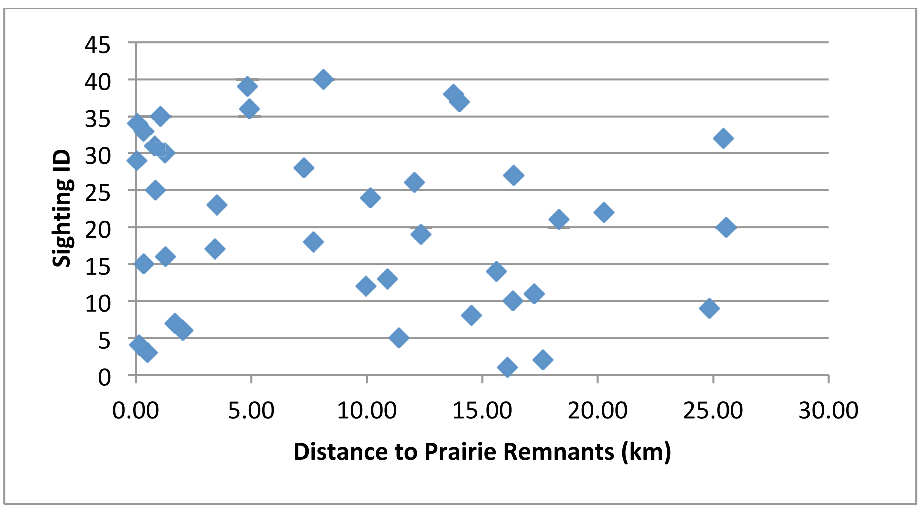

Figure 10. Measured distances from the Carolinian population locations to the closest prairie habitat.
(Source: Rayelle Sowers 2017)

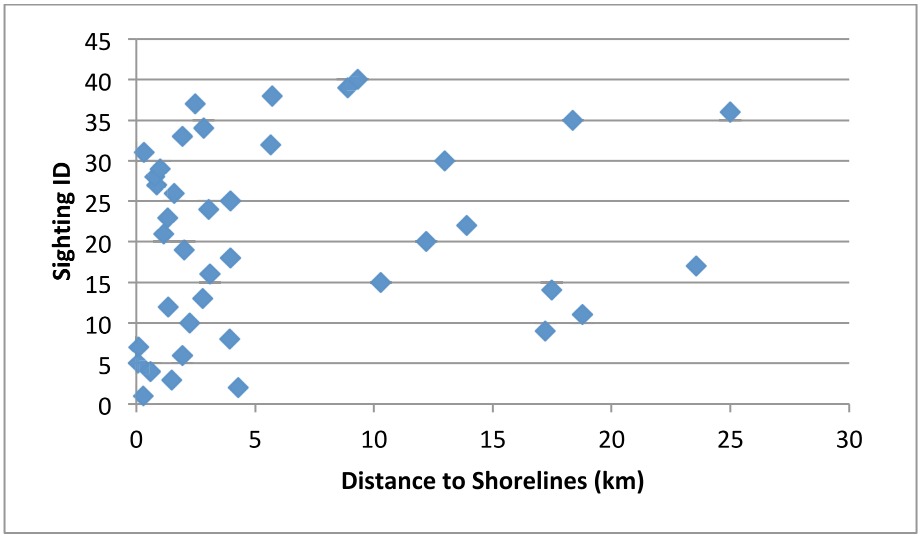

Figure 11. Measured distances from the Carolinian population locations to the closest shoreline.
(Rayelle Sowers 2017)

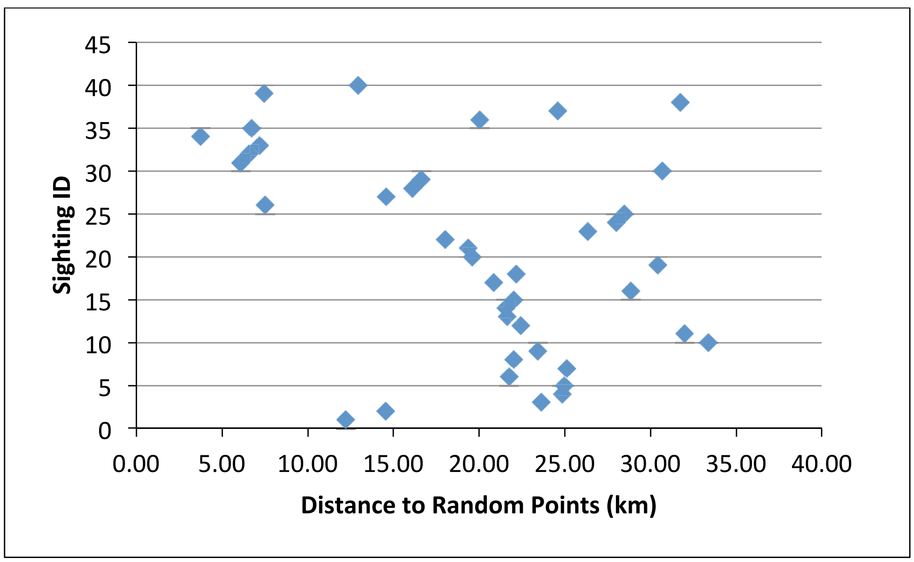

Figure 12. Measured distances from the Carolinian population locations to the closest random points.
(Source: Rayelle Sowers 2017)

The distances from the Carolinian population locations to random points generated the highest mean, twice the mean of distances to shorelines, and more than three times the mean generated from distances to prairie/savannah habitat (Table 1).

Distances to prairie/savannah habitat were significantly closer than to random points (t=6.83, df=39, P = <0.001) (Table 2). Similarly, distances to sandy shorelines were also significantly closer than random points (t=7.04, df=39, P = <0.001) (Table 2). This indicates a positive association of Carolinian populations with each type of habitat.

Table 1. Means utilized in the t-tests used to analyze the distances from the Carolinian population locations to each biogeographic factor, and resulting standard deviations and standard error of each mean.

Distance Analysed	Mean (m)	Std. Deviation	Std. Error Mean
Carolinian - Random	20004.36	8129.13	1285.33
Carolinian - Prairie	9319.66	7912.13	1251.02
Carolinian - Shorelines	6222.25	6992.32	1105.58

(Source: Rayelle Sowers 2017)

Table 2. Results from the two paired t-tests utilized to compare the distances from the Carolinian population locations to each habitat type.

t-test	Mean (m)	Std. Deviation	Std. Error Mean	t	df	P (2-tailed)
Carolinian – Prairie vs. Random	10684.70	9896.91	1564.84	6.83	39	0.00001
Carolinian – Shoreline vs. Random	13782.11	12383.80	1958.05	7.04	39	0.00001

(Source: Rayelle Sowers 2017)

Distances from the GLSL population locations to the closest random points generated the lowest mean, less than one third of the mean to prairie/savannah remnants, and less than a quarter of the mean to sandy shorelines from the population points (Table 3). Distances from the GLSL population locations to prairie/savannah habitat remnants were significantly further than to random points (t = -19.39, df = 174, P = <0.001) (Table 4). Similarly, distances from the population locations to sandy shorelines were significantly further than to random points (t = -11.15, df = 174, P = <0.001) (Table 4).

Table 3. Means utilized in the t-tests used to analyze the distances from the Great Lakes – St. Lawrence population locations to each biogeographic factor, and resulting standard deviations and standard error of each mean.

Distance Analysed	Mean (m)	Std. Deviation	Std. Error Mean
GLSL - Random	12236.24	6694.25	506.04
GLSL - Prairie	54960.63	28743.49	2172.80
GLSL - Shorelines	38605.03	30551.82	2309.50

(Source: Rayelle Sowers 2017)

Table 4. Results from the two paired t-tests utilized to compare the distances from the Great-Lakes – St. Lawrence population locations to each habitat type.

T-test	Mean (m)	Std. Deviation	Std. Error Mean	t	df	P (2-tailed)
GLSL – Prairie vs. Random	-42724.39	29152.82	2203.75	-19.39	174.00	0.00001
GLSL – Shorelines vs. Random	-26368.78	31289.61	2365.27	-11.15	174.00	0.00001

(Source: Rayelle Sowers 2017)

Two ANOVA tests were conducted to determine if the biogeographic factors, sandy shorelines and prairie/savannah remnants, affected the two populations in the same way. The first ANOVA indicated that the distances from the GLSL populations to sandy shorelines were greater than distances for Carolinian populations (F = 44.26, df = 214, P = <0.05) (Table 5). The second ANOVA also indicated that distances from each population to the closest prairie/savannah habitat were also significantly different (F = 98.81, df = 214, P = <0.05) (Table 6).

Table 5. ANOVA results comparing the GLSL and the Carolinian population location distances to shorelines.

T-test	Sum of Squares	df	Mean Square	F	P
Between Groups	34141912682.99	1.00	34141912682.99	44.26	0.00
Within Groups	164320747494.77	213.00	771458908.43		
Total	198462660177.76	214.00			

(Source: Rayelle Sowers 2017)

Table 6. ANOVA results comparing the GLSL and the Carolinian population location distances to prairie/savannah habitat.

T-test	Sum of Squares	df	Mean Square	F	P
Between Groups	67821808986.89	1.00	67821808986.89	98.81	0.00
Within Groups	146198217534.07	213.00	686376608.14		
Total	214020026520.96	214.00			

(Source: Rayelle Sowers 2017)

VARIATION IN EXTANT AND EXTIRPATED LOCATIONS

In both the Carolinian and GLSL populations, extant and extirpated locations appear to have similar clustering within their perspective populations (Figure 13, Figure 14). Within the Carolinian population the extant and extirpated locations appeared to have similar distances to the prairie/savannah habitat remnants (Figure 15). In both extant and historic locations, prairie/savannah habitat occurs within 26km from each location, but clustering is not apparent in either set of distances. Similarly, all distances from extant and extirpated population locations to sandy shorelines are less than 25km

(Figure 16). There does appear to be some clustering in the extant locations compared to the extirpated locations, however; twelve of fifteen extant locations occur within 5km of sandy shorelines, whereas only half (10/20) of the extirpated locations occur within the same distance to sandy shorelines. Within the GLSL population locations, both the extirpated and extant location distances are within 150Km of prairie/savannah habitat (Figure 17). There does not appear to be any clustering in either set of locations. The same scattered pattern is witnessed in the distances in the GLSL population from extant and extirpated locations to sandy shoreline habitat (Figure 18), however, all distances are less than 110km.

Figure 13. A map displaying the Carolinian population divided into extant (purple) and extirpated/historic (blue) locations.
(Source: Rayelle Sowers 2017)

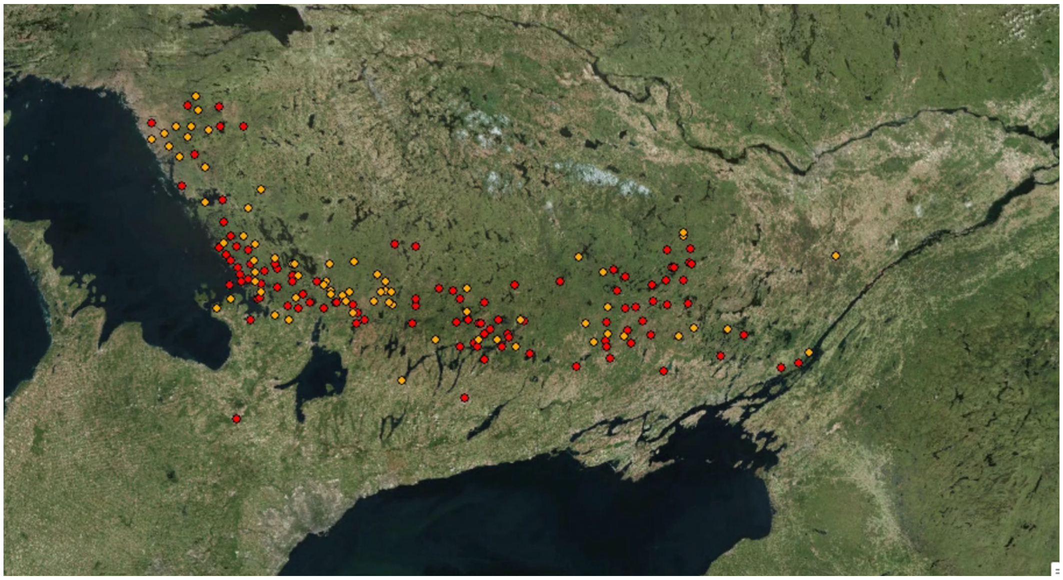

Figure 14. A map displaying the separation of the GLSL population into extant (orange) and extirpated (red) locations.
(Source: Rayelle Sowers 2017)

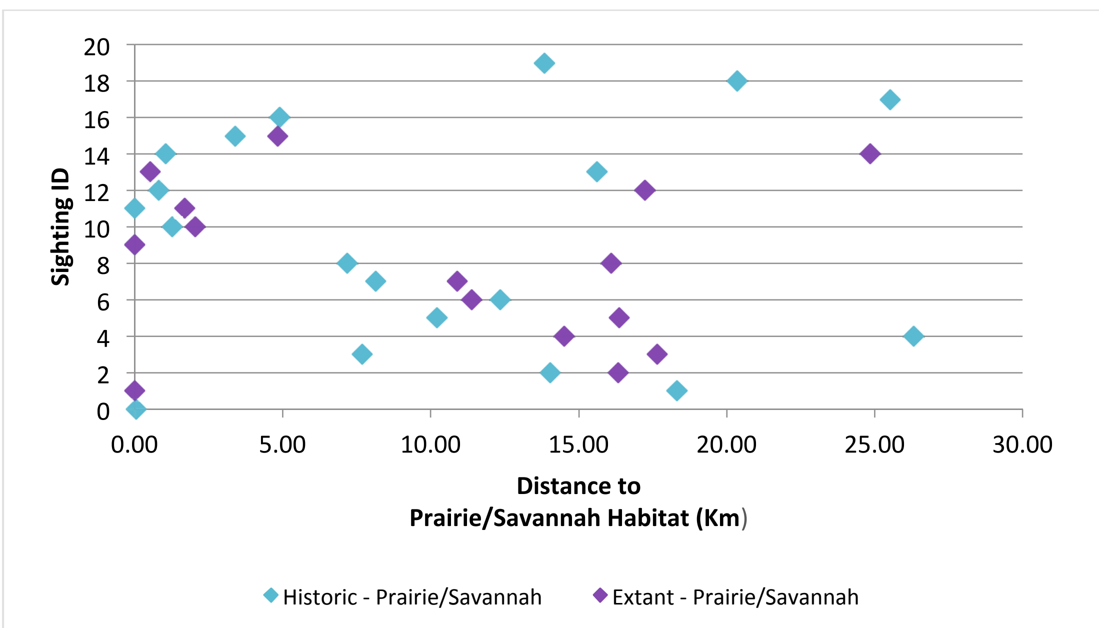

Figure 15. Measured distances from the extant (purple) and historic (blue) Carolinian population locations to prairie/savannah habitat remnants.
(Source: Rayelle Sowers 2017)

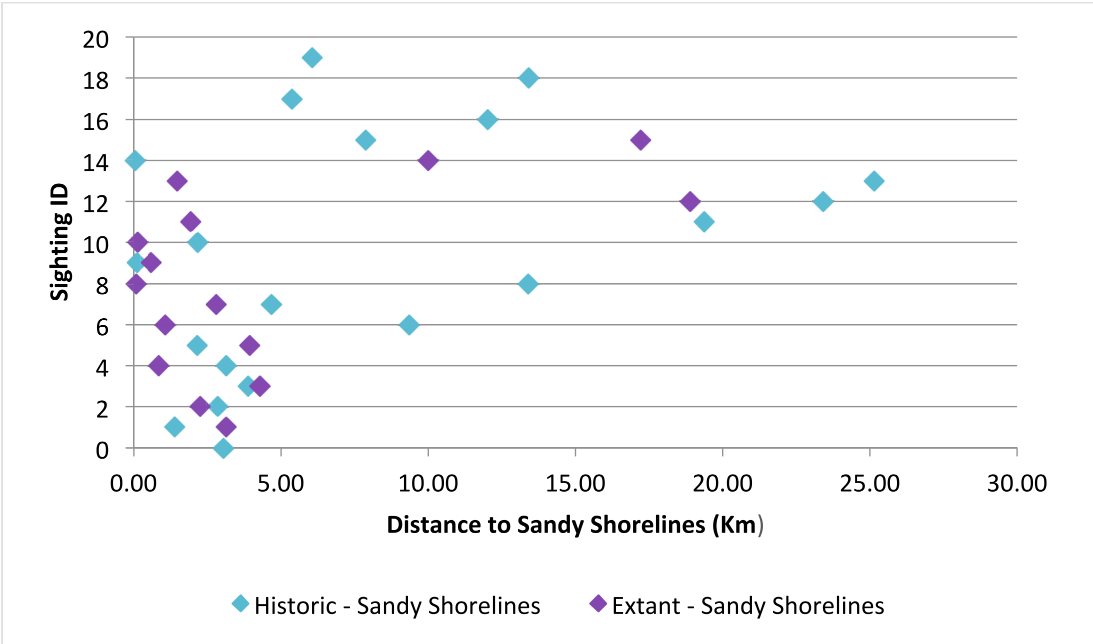

Figure 16. Measured distances from the extant (purple) and historic (blue) Carolinian population locations to the closest sandy shoreline.
(Rayelle Sowers 2017)

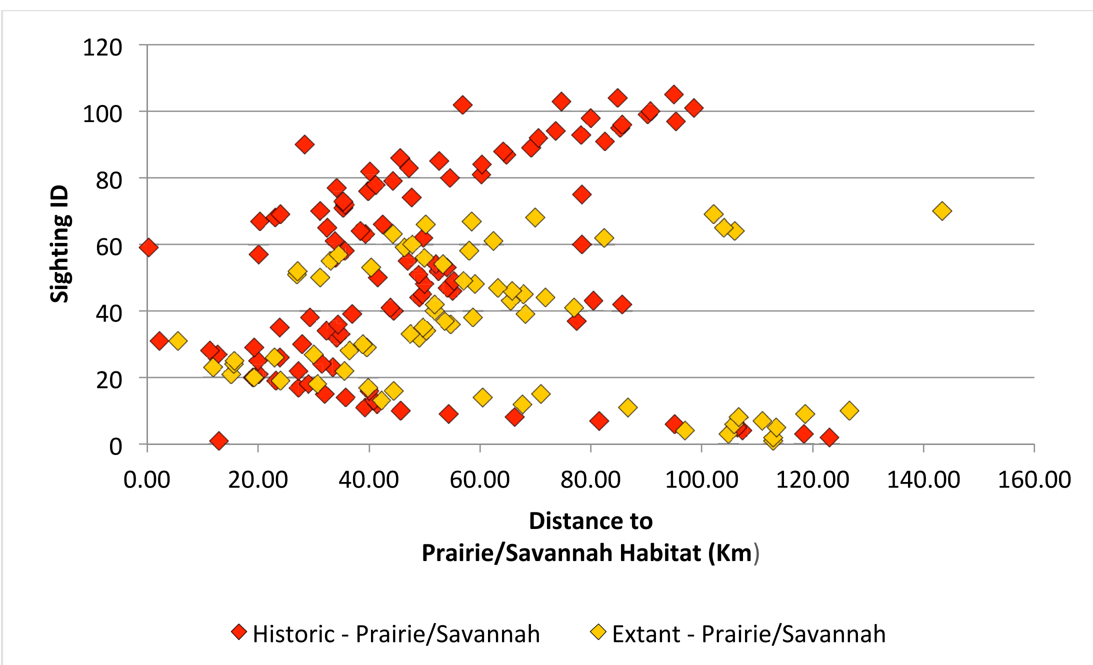

Figure 17. Measured distances from the extant (orange) and extirpated/historic (red) Great Lakes – St. Lawrence populations locations to the closest prairie/savannah habitat.
(Source: Rayelle Sowers 2017).

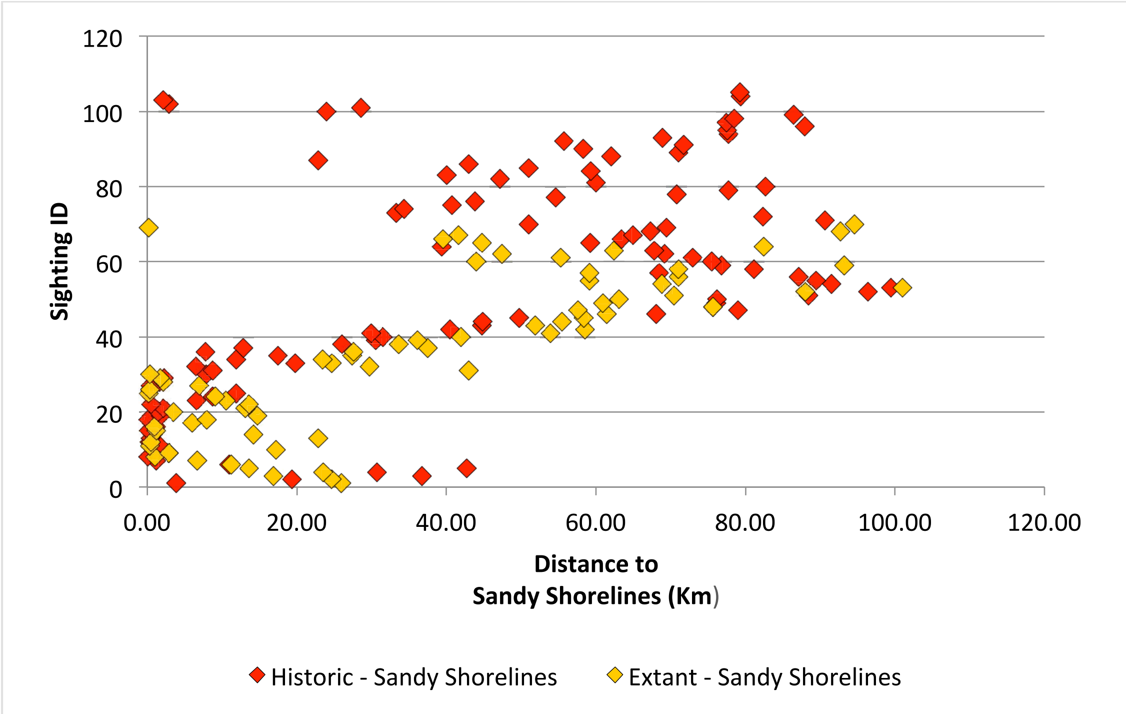

Figure 18. Measured distances from the extant (orange) and extirpated/historic (red) Great Lakes – St. Lawrence populations locations to the closest sandy shoreline. (Source: Rayelle Sowers 2017).

The next set of analyses, four ANOVA tests, examined if proximity to sandy shorelines and prairie/savannah habitat differed between the extant and extirpated population locations in both the GLSL and Carolinian population. This allows me to determine if the extant populations have survived due to better access to critical habitat. Distances between extant and extirpated/historic populations in the Carolinian did not differ (F = 0.07, df = 34, P = 0.80) (Table 7). Distances between the extant and extirpated Carolinian population distances to the closest sandy shoreline were not statistically significant (F = 2.01, df =34, P = 0.17) (Table 8). The same tests were conducted using the distances measured from the GLSL population locations (extant and extirpated) to the habitat types. Extant and extirpated distances to prairie/savannah habitat nearly resulted in statistical significance (F = 3.51, df = 174, P = 0.06) (Table 9). Similarly, extant and extirpated distances to sandy shorelines were not significantly different (F =2.18, df = 214, P = 0.14) (Table 10).

Table 7. ANOVA results comparing the distances from both the extant and extirpated Carolinian population locations to the closest prairie/savannah habitat.

T-test	Sum of Squares	df	Mean Square	F	P
Between Groups	4741990.64	1.00	4741990.64	0.07	0.80
Within Groups	2293044528.93	33.00	69486197.85		
Total	2297786519.57	34.00			

(Source: Rayelle Sowers 2017)

Table 8. ANOVA results comparing the distances from both the extant and extirpated Carolinian population locations to the closest sandy shoreline.

T-test	Sum of Squares	df	Mean Square	F	P
Between Groups	97091059.58	1.00	97091059.58	2.01	0.17
Within Groups	1591310504.08	33.00	48221530.43		
Total	1688401563.66	34.00			

(Source: Rayelle Sowers 2017)

Table 9. ANOVA results comparing the distances from extant and extirpated Great Lakes – St. Lawrence population locations to prairie/savannah remnants.

T-test	Sum of Squares	df	Mean Square	F	P
Between Groups	789317652805.70	1.00	789317652805.70	3.51	0.06
Within Groups	38923884023529.70	173.00	224993549268.96		
Total	39713201676335.40	174.00			

(Source: Rayelle Sowers 2017)

Table 10. ANOVA results comparing the distances from extant and extirpated Great Lakes – St. Lawrence population locations to the closest sandy shorelines.

T-test	Sum of Squares	df	Mean Square	F	P
Between Groups	2068337837.87	1.00	2068337837.87	2.18	0.14
Within Groups	164234874882.72	173.00	949334536.89		
Total	166303212720.59	174.00			

(Source: Rayelle Sowers 2017)

The final ANOVA tests were used to determine if proximity between population locations varied between extant and extirpated/historic populations. The first test compared nearest neighbour distances from extant locations with distances from the extirpated locations within the Carolinian population (Table 11). Nearest neighbour distances were nearly significantly different between extant and extirpated/historic populations in the Carolinian zone ($F = 3.82$, $df = 34$, $P = 0.06$). Conducting the same analysis with the GLSL population also resulted in no significant difference ($F = 3.08$, $df = 174$, $P = 0.08$) (Table 12). Through these last tests I will determine if dispersal rates of the Common Five-lined Skink have changed over time within each population.

Table 11. ANOVA results comparing nearest neighbour distances between the extant and extirpated/historic Carolinian population locations.

T-test	Sum of Squares	df	Mean Square	F	P
Between Groups	957390239.15	1.00	957390239.15	3.82	0.06
Within Groups	8279863746.67	33.00	250904962.02		
Total	9237253985.82	34.00			

(Source: Rayelle Sowers 2017)

Table 12. ANOVA results comparing nearest neighbour distances between the extant and extirpated/historic Great Lakes – St. Lawrence population locations.

T-test	Sum of Squares	df	Mean Square	F	P
Between Groups	999501676.57	1.00	999501676.57	3.08	0.08
Within Groups	56173161919.60	173.00	324700357.92		
Total	57172663596.17	174.00			

(Source: Rayelle Sowers 2017)

DISCUSSION

EFFECTS OF BIOGEOGRAPHIC ELEMENTS

When observing the distances between each population and the biogeographic factors, or habitats, in question, clumping was apparent in all analyses. The clustering of population locations within relatively short distances to habitat suggests a reliance on that habitat type. More populations are surviving closer to the habitat than further away. This relationship is especially evident when observing distances from the Carolinian population locations where more than half of all locations occur within 5km of sandy shoreline habitat (Figure 11) and within 15km of prairie/savannah habitat. The GLSL population points do present some clustering close to each type of habitat, however this relationship is not as strong as the Carolinian population.

The t-test results indicate that both of the populations are positively correlated with their proximity to shorelines and prairie/savannah habitat remnants. The GLSL population distances to each habitat type were significantly farther than to random points, suggesting that these habitat types are currently less important. The GLSL population and its distances to shorelines are positively correlated, but have the least significant relationship seen between the populations and the biogeographic factors in question. This could be due to other types of habitat that are more critical in the northern portion of the Five-lined Skink’s range, such as rocky outcrops. The GLSL population and prairie habitat have the second highest significance value, indicating a strong correlation, and prairie remnants have stronger effects on this population than water bodies/sandy shorelines. However, the correlation observed in the GLSL population is not as strong as the relationships between the Carolinian population and the biogeographic factors; the Carolinian population is more correlated with the biogeographic elements tested, observed by the low significance values when the distances from the population locations to the habitat types are compared to distances to random points in paired t-tests. This could be due to the recent change in habitat in northern latitudes where rocky outcrops are more widely distributed than prairie/savannah and sandy shoreline habitat. The Common Five-Lined Skink would have originated from the south, dispersing through the prairie/savannah and sandy shore habitats into more northern latitudes, later adapting to the use of rock outcrops as the original prairie habitat was succeeded by forest and urbanized lands (Hecnar et al. 2002).

The strong association between Carolinian populations and shorelines suggests the importance of sandy shorelines as habitat and that it likely played an important role as a dispersal corridor historically. This population's association with prairie habitat was also quite strong. This implies that prairie habitat also has a strong influence on the Carolinian skink population and proximity to each biogeographic factor is not due to random chance. The closer proximity and lower significance values observed in the Carolinian population compared to the GLSL population suggests that the Carolinian population is more dependent on these two habitat types than the northern population. This is supported by the origin of the prairie peninsula, which extended up to the southern boundary of the Canadian Shield, following the retreat of the Wisconsin ice sheet in the post-Pleistocene (Hecnar et al. 2002). Many herpetofauna, including the Common Five-lined Skink, would have utilized this new habitat as a dispersal corridor into more northern latitudes (Hecnar et al. 2002).

The ANOVA results indicate that the prairie habitat remnants and water bodies have varying effects on the two skink populations in southern Ontario. Significance values less than the confidence interval of 0.05 tell us that these biogeographic factors have variable impacts on the populations. Shoreline distances have a very low significance value, indicating that a high level of variation exists between the Carolinian and GLSL populations and the influence of biogeographic factors is not equal throughout the Five-lined Skink's distribution. The significance value observed from prairie/savannah remnants between the two populations is extremely low compared to the value discussed for shorelines. This indicates that prairie habitat remnants do not equally affect the two populations and prairie habitat has varying influences on the persistence of skink populations. Both of these F-scores are significantly higher than 1, indicating the means from the distances of the two populations are significantly different from one another, verifying that these biogeographic factors have varying influences on the two populations. This could be due to the unequal availability of these habitats throughout this species' range or the ability of each population to adapt to changing environments/habitats.

The discrepancies in the effects of biogeographic factors likely result from the differing habitat types observed in the two populations. The Carolinian population, is now comprised mostly of open farmland and large expanses of sand dunes along shorelines, providing open habitats necessary for skink survival, compared to the Great Lakes – St. Lawrence population, which relies on edges in forested habitats and open rocky outcrops critical for life in higher latitudes. Water bodies, although indicated as significant, are likely a proxy for other features associated with shorelines, such as sand dunes and open rocky areas, indicating that separate studies recognizing the unique features of each population should be conducted to further the effectiveness of conservation efforts for this species.

VARIATION IN EXTANT AND EXTIRPATED LOCATIONS

Comparing distances from extirpated/historic and extant populations with habitat factors suggests that local extant populations have survived due to closer proximity to critical habitat or their role in historical dispersal especially in the Carolinian zone. In the Carolinian population extant and extirpated population locations occurred within similar distances of prairie/savannah habitat remnants, suggesting that proximity to this type of habitat was not a factor in the survival of the extant populations. This hypothesis was confirmed with an ANOVA test which resulted in statistical significance; this tells me that there is no statistically significant difference between the distances of each population to prairie/savannah habitat. This same result occurred when comparing extant and extirpated distances to sandy shorelines in the Carolinian population. The GLSL population comparisons expressed similar results with no statistically significant differences portrayed in either of the habitat analyses. The statistical significance present in each analysis informs me that the distances from both historical and extant population locations to the biogeographic factors are similar and are not exclusive of one another. Although these results fail to reject my original hypothesis, proximity to these habitats did not influence the survival of extant populations in the northern or southern population.

The final analyses were used to determine if the proximity between population locations has varied from extirpated/historic locations to those that are extant. This will determine if the GLSL and Carolinian populations are non-equilibrium populations and if migration between local populations has changed over time. ANOVA tests compared the distances from the extirpated and extant locations in both the GLSL and Carolinian populations to each biogeographic factor. Within the Carolinian population, the nearest neighbour distances between extirpated and extant locations were compared using an ANOVA, which resulted in a significance value greater than the confidence interval, meaning statistical significance is present in the comparison. The same analysis was also conducted to compare the nearest neighbour distances in the extant and extirpated GLSL population locations. This test also resulted in statistical significance. In both cases, this indicates that distances between local populations have not significantly changed over time from the historic locations to the extant ones, thus local populations have not become increasingly isolated over time. However, this does not rule out the possibility of consistent isolation where long-term extinction and isolation rates exceed the rate of colonization necessary for the survival of the Common Five-lined Skink.

CONCLUSION

Being Ontario's only lizard species, it is critical to have an in-depth understanding of the habitat components necessary for the survival of the Common Five-lined Skink. Through this study I have gained insight on critical habitat effects, habitat needs based on population location, and variation in habitat over time, all of which have the potential to contribute to more effective conservation efforts for this species.

Both populations of the Common Five-lined Skink, the Great Lakes – St. Lawrence and the Carolinian, are influenced by the availability of two key biogeographic elements throughout its distribution – both sandy shorelines and prairie/savannah habitat have significant effects on the distribution of this species throughout the province. The Carolinian population still has a strong dependence on both habitat types, however a somewhat stronger effect was evident with sandy shoreline habitat. Prairie/savannah habitat had a more significant relationship with the Great Lakes – St. Lawrence population than did sandy shorelines, however both of these habitats resulted in less significance compared to the Carolinian population. The closer proximity and stronger significance values observed in the Carolinian population compared to the GLSL population suggest that the Carolinian is more dependent on these two habitat types than the population in the northernmost part of the Common Five-lined Skink's range.

I also conclude that, contrary to my original hypothesis, extant and extirpated/historic population locations do not differ significantly in distance to prairie/savannah habitat or to sandy shoreline habitat. This tells me that the proximity to these habitats has not changed significantly in recent times. Comparisons between extant and extirpated/historic populations did not result in statistical significance, concluding that distance to these biogeographic factors has not changed over recent times. Since isolation was already evident throughout the historical populations, I note that these local populations have faced long-term isolation where dispersal to other populations is no longer possible The Common Five-lined Skink's dispersal capabilities are not sufficient to keep up with the changing environment and loss of habitat surrounding its populations. Long –term extinction rates for this species have been historically greater than the rate of colonization, resulting in little to no migration among subpopulations over time, subsequently leading to their consistent decline. Both the Great Lakes – St. Lawrence and the Carolinian population are subject to many factors effecting the isolation of subpopulations, leading to the classification of both populations to be non-equilibrium metapopulations.

To provide sufficient conservation strategies for species at risk, especially those in non-equilibrium metapopulations, all factors pertaining to required habitat need to be explored and better understood. Biogeographic factors, such as prairie remnants and water bodies, are important features necessary for Common Five-lined Skink survival within this species' northern range. This knowledge can be applied to other species at risk to encourage appropriate habitat management, and ultimately more effective population management to prevent future losses of species at risk throughout North America.

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