Changes in the critical habitat of Blanding's Turtles on Grenadier Island, Thousand Islands National Park, through time

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Habitat change, often due to anthropogenic impacts, is the largest threat to biodiversity worldwide. Canada hosts a quarter of the world's wetlands, which provide essential habitat for many species. The Blanding's Turtle is listed as endangered in Canada and is one of many species at risk that inhabit wetlands. Critical habitat delineation and protection is important for conservation, but it is often not a sufficient solution for maintaining populations. The creation of static protected areas in a dynamic world renders them particularly vulnerable to human disturbance. The goal of my study was to evaluate how Brooker's Pond, a critical habitat for Blanding's Turtles on Grenadier Island, Thousand Islands National Park, has evolved since 1924. I used remote sensing to identify historical trends from aerial photographs. I observed considerable changes in both the area of the wetland and the proportion of forest that surrounds it over time. These changes appear to be due, at least in part, to human activities, notably dam construction on the St. Lawrence River. My study highlights the need for continued monitoring of protected natural areas, especially of critical habitat for species at risk, to inform management practices, maintain ecological integrity, and meet long-term conservation goals.

Keywords: wetland, conservation, protected areas, satellite imagery, air photos, forest cover

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1.0 INTRODUCTION

Habitat change is the primary driver of global biodiversity loss, which is perhaps the most significant of global environmental crises (Ceballos et al., 2015; Gardner et al., 2007; Wilson et al., 2016). In Canada, habitat degradation, destruction, and fragmentation are the main threats to wildlife (Kraus & Hebb, 2020). The major ecosystem types that constitute Canada and harbour much of its flora and fauna include grasslands, forests, lakes and rivers, tundra, marine areas, and wetlands (Statistics Canada, 2015).

My study focuses on wetlands and the essential habitat they provide for a myriad of species. As some of the most productive ecosystems on Earth, many species of birds, fish, amphibians, reptiles, mammals, and plants rely on the habitat provided by wetlands. Wetlands also provide various ecosystem services, such as flood, drought and erosion prevention, pollutant filtration, and carbon absorption from the atmosphere (CWF, 2020; Ducks Unlimited Canada, 2021; ECCC, 2016). Despite these benefits, however, wetlands are declining worldwide. More than 64% of the world's wetlands have been lost since the beginning of the 20th century. Most wetlands are lost due to anthropogenic activities such as pollution, land clearing, and hydrological modifications including dams and stream channelization (Kennedy & Mayer, 2002). Canada is home to a quarter of the world's wetlands which constitute 13% of its land area. These wetlands remain threatened by human impacts. Tragically, 68% of the natural wetlands in southern Ontario have been converted to accommodate agriculture and urbanization (Birch et al., 2022; ECCC, 2016; NCC, 2020).

Wetlands are often fed by rivers. The St. Lawrence River, which flows from Lake Ontario to the Gulf of St. Lawrence, feeds many wetlands, some of which are located within islands. I studied Brooker's Pond, a permanent marsh located in the center of Grenadier Island in

Thousand Islands National Park (Figure 1; Parks Canada Agency, 2018). Brooker's Pond and other similar wetlands provide habitat for many at-risk species, including Blanding's Turtles. The Blanding's Turtle (*Emydoidea blandingii*) is a long-lived freshwater turtle that can take up to 25 years to reach maturity. There are two populations of *E. blandingii* in Canada: the Great Lakes/St. Lawrence population and the Nova Scotia population. Both populations are listed as endangered under the Species at Risk Act (ECCC, 2018). Here, a population is defined according to COSEWIC terminology as the total number of mature individuals of the taxon or of the designatable unit (2019). Canadian populations of the Blanding's Turtle constitute 20% of its global range (ECCC, 2021). Brooker's Pond is inhabited by Blanding's Turtles and the conservation, management and restoration of their habitat is deemed of high importance in the recovery strategy for the species (ECCC, 2018). Further, there has been a decline in available wetland habitat for *E. blandingii* within Thousand Islands National Park since 1987 (Lecompte, 2019; MacDougall & Windle, 2019; Zorn, 2012).

Information on habitat selection and microhabitat preferences is of paramount importance for critical habitat delineation, management, and recovery of species at risk (Millar & Blouin-Demers, 2011; Quirt, 2006; Rossell et al., 2006). Microhabitat characteristics preferred by *E. blandingii* in wetlands include abundant submergent, emergent, and floating aquatic vegetation (Millar & Blouin-Demers, 2011), as well as sites suitable for basking, such as fallen logs or large rocks (ECCC, 2018). An abundance of aquatic vegetation within wetlands provides opportunities for foraging and protection from predation for Blanding's Turtles (ECCC, 2018; Hartwig & Kiviat, 2010). Basking sites are important for thermoregulation because, as ectotherms, Blanding's Turtles rely on their environment to regulate their body temperature (Millar et al., 2012). It is also essential that wetlands are in proximity to forest, as forest provides

habitat for nesting and corridors for movement between wetlands, both important aspects of seasonal activity. Upland forest is an important habitat feature for this species and can serve as a predictor of the presence of Blanding's Turtles in an area (Attum et al., 2008; ECCC, 2018). Permanent wetlands are also used as overwintering sites (ECCC, 2018).

While wetland protection and management are important in conserving species, habitat may not be suitable indefinitely. Brooker's Pond is not immune to habitat changes that may be out of the control of conservation managers. Even small changes can affect the species who live there, especially those at-risk, like the Blanding's Turtle. Monitoring habitat changes using remote sensing can inform conservation initiatives. The goal of my study was to evaluate how Brooker's Pond and its habitat features changed through time using historical aerial imagery.

2.0 MATERIALS AND METHODS

2.1 Study Site.—Brooker's Pond is located in the center of Grenadier Island in Thousand Islands National Park, Ontario, Canada (Figure 1). This site is of interest because Blanding's Turtles have been confirmed on the island and studied. In 2009, the estimated population size was 115 individuals (Millar, 2009). This site is unique because it is nested within an island in the St. Lawrence River. Thousand Islands National Park owns 28.4 ha of the northern portion of Grenadier Island, which includes Brooker's Pond (Parks Canada Agency, 2018). I conducted two days of ground-truthing in July 2021 to investigate vegetation composition and to map sites of interest.

2.2 Aerial Imagery.—I collected images from various archives, including Thousand Islands National Park (TINP), the National Air Photo Library (NAPL), and the United States Geological Survey (USGS). My goal was to obtain images from roughly every five years since 1924, the date of the first available images for Grenadier Island. I achieved this from 1953 to the

present. Despite significant efforts, I did not find any imagery for the period between 1925 and 1952, so a significant gap in the data remains. Images were taken at different times of the year, and at varying resolution and scale. As technology evolved over time, the imagery resolution improved significantly. Consequently, I used high resolution imagery from the Digital Raster Acquisition Project for the East (DRAPE) for the period from 2009 to 2019.

2.3 Variables of Interest.—To better understand the changes in habitat characteristics and describe how the site evolved, I evaluated the area of the wetland through time. In addition, there were three main habitat characteristics of importance to Blanding's Turtles that I was able to quantify from aerial imagery. The first variable was the proportion of upland forest within the terrestrial buffer surrounding the wetland. I obtained the terrestrial buffer measurement from the recovery strategy for the Blanding's Turtle, defined as 'suitable terrestrial habitat extending 240 m landward' of the wetland (ECCC, 2018). I determined the proportion of upland forest by dividing the area in square meters of forest by the total area of the buffer zone. The second variable was aquatic vegetation. I evaluated this indirectly by determining the proportion of open water in the wetland relative to its area. Finally, the third variable was available basking sites. Since rocks were not easily distinguishable in the air photos and satellite imagery, I only quantified fallen logs as basking sites. One log counted as one basking site.

2.4 Data Collection.—I collected data using ArcGIS Pro (Esri, 2021). First, I georeferenced each image onto its own base map in zone 18 of the Universal Transverse Mercator (UTM) system, each with a minimum of five control points. Then, I digitized each of the variables of interest. I used a polygon feature class for each of the variables except basking sites, where I used a point feature class. I drew all polygon variables by hand using the streaming

and trace tools. I drew buffer zones by hand using line notes and the measure tool, because the buffer drawn with the ArcGIS buffer tool was not satisfactory.

2.5 Statistical Analyses.—I performed all statistical analyses using RStudio, R version 4.1.1 (RStudio Team, 2021). The year the imagery was taken was the continuous independent variable. Habitat characteristics and wetland area were the response variables. I evaluated changes in both wetland area and the proportion of forest within the terrestrial buffer over time using a third-degree polynomial regression model because the relationships were not linear, and data transformation failed to linearize the relationship. I evaluated changes in the proportion of open water over time using a second-degree polynomial regression model, again because the relationship was not linear and data transformation failed to linearize the relationship.

In all three cases, I used a forward stepwise model selection process, beginning with a simple linear model, to determine which model maximized the goodness of fit and minimized complexity. Then, I used ANOVAs to compare model fits using the null hypothesis that there was no difference in goodness of fit between models. I ensured that the residuals of all models met the assumptions of normality and equal variances by examining residual plots and conducting associated tests (Shapiro-Wilk, Breusch-Pagan, Durbin-Watson, etc.). Finally, I applied a Bonferroni correction for multiple comparisons, and I thus accepted the significance of tests at a level of $\alpha = 0.02$. There were not enough data points on the number of available basking sites to fit a regression.

3.0 RESULTS

Overall, I observed noteworthy changes in the habitat characteristics of Brooker's Pond through time. Wetland area changed significantly over the last century, with 83% of the variance described by the year (third degree polynomial regression, $F_{3,12} = 24.74$, $P < 0.0001$). From 1953 to 1978, the wetland area increased steadily (Figure 2). In 1988, the wetland peaked in area. Between 2003 and 2009, wetland area decreased significantly. In the last decade, wetland area remained stable, at an average of 76 ha.

Further, the proportion of upland forest within the terrestrial buffer surrounding Brooker's Pond changed significantly through time, with 87% of the variance described by the year (third degree polynomial regression, $F_{3,12} = 33.76$, $P < 0.0001$). From 1920 to 1959, the proportion of forest surrounding the wetland remained stable (Figure 3). Thereafter, forest cover increased markedly from 1954 to 1969. From the late 1970s until present, the proportion of upland forest cover remained stable, constituting an average of 92% of the terrestrial buffer area.

In contrast, there was no trend in the proportion of open water, and therefore abundance of aquatic vegetation within the wetland, through time (Figure 4), with only 24% of the variance described by the year (second degree polynomial regression, $F_{2,13} = 3.36$, $P = 0.07$).

Finally, data on the number of available basking sites in the wetland through time were limited to recent years due to low imagery resolution for the oldest images. Records every five years since 1998 were insufficient to conduct formal statistical analyses. Based on the available data, there is no obvious indication that the number of basking sites decreased in recent years (Figure 5).

4.0 DISCUSSION

I conducted a remote sensing analysis of habitat change for Blanding's Turtles on Grenadier Island, Thousand Islands National Park, Canada. Understanding how a habitat changes is of paramount importance to conservation of species at risk, because habitat loss is one of the largest threats to their persistence. Brooker's Pond has indeed changed through time. Most notable were the distinct changes in the wetland's area and surrounding forest cover. In contrast, there was no trend in the proportion of open water through time and data on basking sites were too limited to formally evaluate trends. Moreover, causes of change are not directly discernable from aerial imagery, so hypotheses describing potential effects of external variables must be used to explain the observed changes.

4.1 Wetland Area and Surrounding Forest Cover.—The most striking changes observed in Brooker's Pond over time were in its area and the proportion of surrounding forest cover. Grenadier Island was historically used for farming, and the imagery from 1924 reflects this. Eventually, the Thousand Islands shifted toward a tourism-centered economy (Lunman, 2008; Parks Canada Agency, 2004). From 1954 to 1978, the wetland area increased, which coincided with the construction of the Saint Lawrence Seaway. The creation of this seaway involved the construction of the Iroquois Dam and the Moses-Saunders Power Dam, both located downstream from Grenadier Island (Figure 6). Both dams opened in 1958 and work together to control the outflow of water from Lake Ontario (Great Lakes St. Lawrence Seaway Development Corporation, 2022).

Construction of these dams caused water levels to rise upstream in the St. Lawrence River. This increase in water level historically flooded the area between the two dams, creating 'Lake St. Lawrence', which led to the loss of many coastal towns (International Joint

Commission, 2019). Grenadier Island is located upstream of the Iroquois Dam (Figure 6) and downstream from Lake Ontario. This section of the river may have also experienced a rise in water levels, leading to flooding of Grenadier Island and thus an expansion of Brooker's Pond. Creation of these dams, specifically the Iroquois Dam, is the most plausible explanation for the observed increase in the area of Brooker's Pond due to the correspondence of timing. However, it is only one of many factors that influence the water levels of the St. Lawrence River. Other factors include inflow and outflow of the St. Lawrence River and Lake Ontario, snow melt, and precipitation (International Joint Commission, 2019).

Previous studies report a decrease in the amount of available habitat for the Blanding's Turtle within Thousand Islands National Park from 1987 to 2007 (Lecompte, 2019; MacDonald & Windle, 2019; Zorn, 2012). I did not evaluate the entire habitat area for this species within the park, but based on the increasing area of the wetland during this time, Brooker's Pond was not part of the area that contributed to the observed net decline in habitat for the Blanding's Turtle.

Parks Canada acquired Brooker's Pond as part of Thousand Islands National Park in 1999 (Parks Canada Agency, 2018). Since then, the wetland decreased in area, but has remained stable in recent years. These changes are also likely attributable to water level fluctuation in the St. Lawrence River. This is inconsistent with a study conducted by MacDougall and Windle (2019), which determined using satellite imagery that the area of available habitat for Blanding's Turtles within the park increased from 2013 to 2017. Clearly, Brooker's Pond did not directly contribute to this observed increase. There is presumably no net effect on the overall suitable habitat area in the park due to the consistent area of the wetland during this time.

Similarly, forest cover surrounding the wetland changed significantly. Before 1959, forest covered constituted 30% of the buffer area surrounding the wetland. The steady increase in

forest cover since then could be due to the shift away from agriculture. The imagery shows a gradual decrease in the amount of farmland surrounding Brooker's Pond. Conversely, perhaps the creation of the Saint Lawrence Seaway and its associated dams and flooding rendered this land unsuitable for agriculture.

From 1985 until the present, forest cover within the terrestrial buffer surrounding the wetland remained constant. The only areas not covered by forest are a few residential properties on the periphery of the buffer. The amount of usable terrestrial habitat for Blanding's Turtles surrounding Brooker's Pond remained optimal for decades. This trend may continue since the area is well-protected and not easily accessible to the public (Parks Canada Agency, 2018).

4.2 Proportion of Open Water.—The lack of a trend in the proportion of open water in Brooker's Pond through time could be due to several factors. First, I detected and digitized vegetation mats using my best judgment. The historical images are of varying resolution, leading to potential inconsistencies that only add to those from human error while digitizing. In combination, this could have impacted my ability to discern vegetation and open water.

Second, the abundance of vegetation, and thus the proportion of open water, changes seasonally. For example, emergent vegetation will be much thicker in mid-summer than in early spring. The images available to me were not taken during the same season every year. Trends could have been better detected if the time of year for the imagery had been consistent, such as examining the proportion of open water in August over time, when most plant communities flourish.

Further, an important aspect of wetland vegetation that I was unable to evaluate was the presence of invasive vegetation, namely *Phragmites australis* that has been documented elsewhere in Thousand Islands National Park. Ground-truthing in July 2021 revealed that

P. australis is present in small stands in the marsh. I mapped these stands, though they were unrecognizable amongst other vegetation, especially cattail, in recent imagery. Future studies of the area should collect high-resolution imagery to monitor the changes in invasive vegetation in the wetland annually. When present, *P. australis* drastically reduces the amount of usable habitat in a wetland for the Blanding's Turtle. Turtles actively avoid this plant because they cannot move through such thick stands, and it does not provide any beneficial foraging or basking opportunities (Markle & Chow-Fraser, 2018).

4.3 Basking Site Availability.—Due to lower imagery resolution in older images, fallen logs were the only discernible basking sites. Certainly, these are not the only basking sites used by Blanding's Turtles. Other sites suitable for basking include large rocks (ECCC, 2018), beaver and muskrat lodges (Ernst et al., 1972), and tussock sedges (Pappas & Brecke, 1992), all of which are present in Brooker's Pond, but not visible on aerial imagery. Field-based analysis in addition to remote sensing would provide a more accurate estimate of basking site availability for future projects. Ultimately, the available data show that the number of basking sites seem to have increased in the recent years.

4.4 Main Limitation of this Study.—There is a gap in the available aerial imagery between 1924 and 1952 (Supplementary Table 1). It would be fascinating to see how Brooker's Pond evolved since 1924, from when it was only a small cattail marsh surrounded by farmland until before the Saint Lawrence Seaway was built. In a study conducted at Lake St. François, further downstream from Grenadier Island, Jean and Bouchard (1991) discovered a 7% net loss of wetland habitat from 1946 to 1983. The wetlands they evaluated fit into one of three temporal patterns: wetlands reduced by human activities, wetlands that remained stable, and wetlands that changed in structure but not area. To see where Brooker's Pond may fit into this classification

system in earlier years would be interesting. Nevertheless, the available data from the last 70 years remains particularly informative.

4.5 Implications for Conservation.—Human hydrological modifications, namely dams and irrigation systems, can greatly impact wetlands. Such alterations can change flood frequencies, affecting water levels and circulation in wetlands, which likely occurred in Brooker's Pond because of the Iroquois dam. These impacts extend beyond surface level. They can increase susceptibility to invasive species, deprive wetlands of nutrient inputs and change nutrient cycling, affecting plant community composition (Kennedey & Mayer, 2002). Dams can even drastically alter river temperatures (Maheu et al., 2016). The Moses-Saunders Power Dam has long been discharging mercury and other harmful metals into the St. Lawrence River, negatively impacting fish populations both upstream and downstream of the dam (Goulet et al., 2008; Lalonde et al., 1999). These lines of evidence demonstrate the need for wetland monitoring in the St. Lawrence and other rivers, as human activities can lead to long-term ecosystem changes that may alter the distribution and abundance of species.

The protection of Blanding's Turtle habitat also inevitably leads to the protection of other species that share these habitats. Vertebrates can often act as 'umbrella species', indirectly conserving other wildlife that live within their habitat when it is protected (Demers et al., 2018; Fraser, 1999). Changes in habitat extend far beyond the impacts on a single species; they can alter entire ecosystems. Further research on this population of Blanding's Turtles should maintain photographic records to investigate future changes.

Finally, Wintle et al. (2018) provide evidence that even small, isolated patches of habitat play a crucial role in maintaining biodiversity at the global scale. For this reason, delineating critical habitat for species at risk is essential for their protection. The recovery strategy for the

Blanding's Turtle identifies critical habitat based on two criteria: habitat occupancy and habitat suitability (ECCC, 2018). Protected areas such as Brooker's Pond of Thousand Islands National Park, however, are especially vulnerable to anthropogenic impacts, so managers must ensure that this habitat remains suitable over time. Remote sensing techniques and aerial imagery can be used to monitor the extent of changes in land cover and condition (Townsend et al., 2009), as demonstrated by my study. This approach provides widespread spatial coverage which complements and extends field-based monitoring. For example, these approaches can be incredibly useful when it comes to tracking Canada's progress in meeting its goal to protect 25% of its land and waters by 2025 (Government of Canada, 2022).

5.0 CONCLUSION

Brooker's Pond has changed throughout the last century and will continue to do so. Historical changes appear to be driven by human activities. My study illustrates the value of remote sensing as a tool for evaluating changes of critical habitat areas and ensuring they remain suitable for species at risk over time. Considering historical trends, habitat for the Blanding's Turtle within Thousand Islands National Park has been deemed 'Of Least Concern', which is good news for the Great Lakes/St. Lawrence population (MacDougall & Windle, 2019). However, this will not be the case forever. Habitat change remains the most prevalent threat to Canadian biodiversity as we enter the sixth mass extinction (Ceballos et al., 2015; Gardner et al., 2007; Kraus & Hebb, 2020; Wilson et al., 2016). Protected areas are particularly vulnerable to human disturbances and these threats will only be exacerbated by incessant changes in climate and depletion of natural resources. The variety of life on Earth underpins the health of our planet, and it is declining at unprecedented rates. Monitoring ecological processes and landcover change is crucial to protecting what is left of our natural areas and preserving biodiversity.

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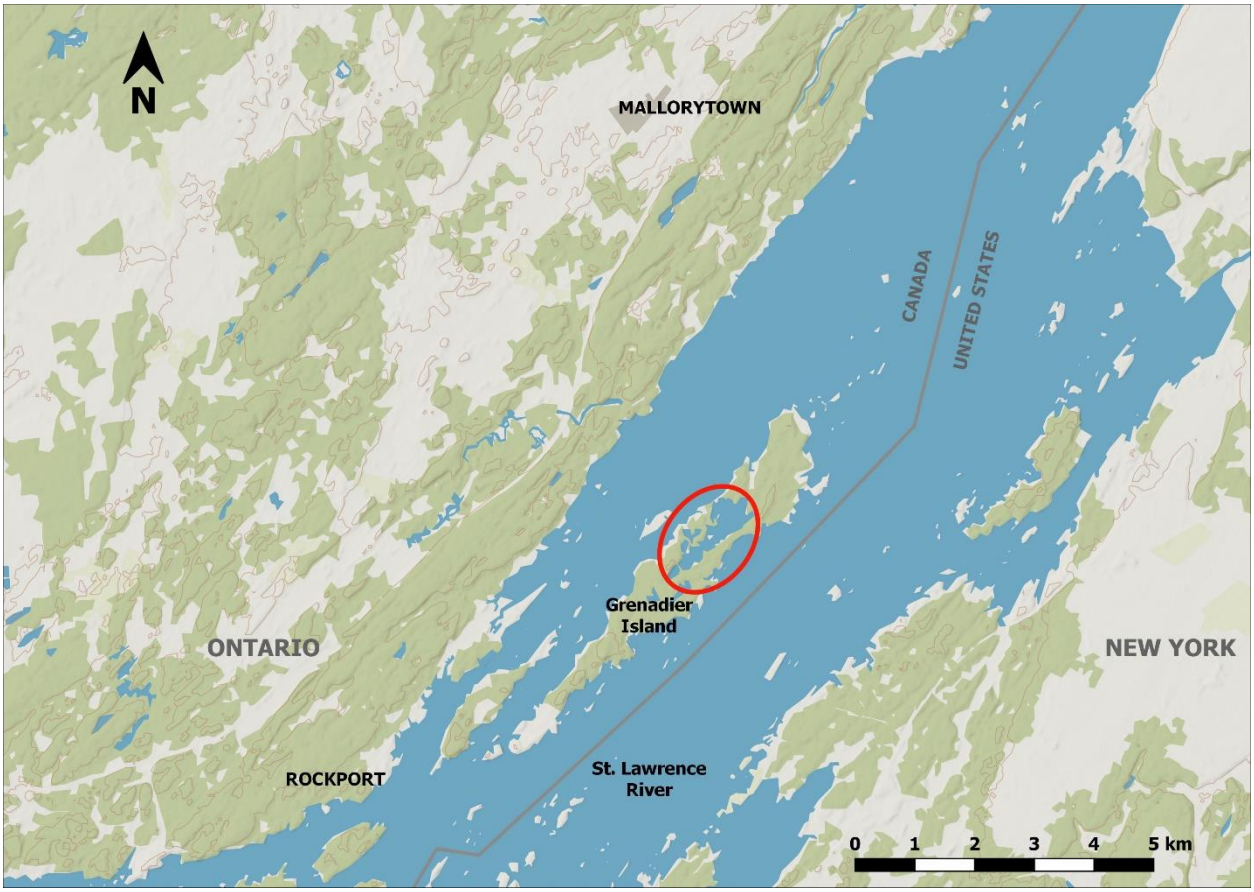

Figure 1. Study site of the Blanding's Turtle population on Grenadier Island. Brooker's Pond is circled in the center of the island. Map was created using QGIS (QGIS Development Team, 2022).

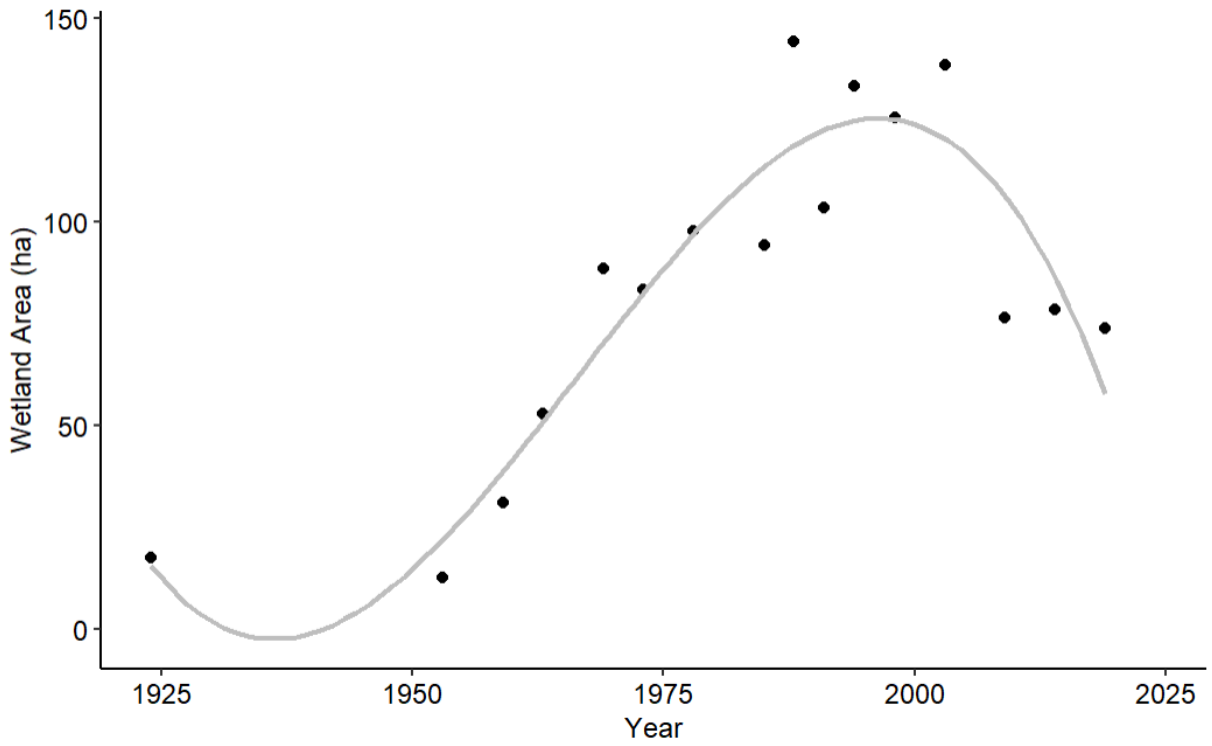

Figure 2. Changes in the area of Brooker's Pond from 1924 to 2019. Area estimates were determined in square meters using streaming, trace, and measurement tools in ArcGIS Pro (n = 16) and then converted to hectares (Esri Inc, 2021). The trendline displayed is that of a third-degree polynomial regression and was calculated in RStudio using the stat_smooth function from the ggplot2 package (RStudio Team, 2021; Wickham, 2016).

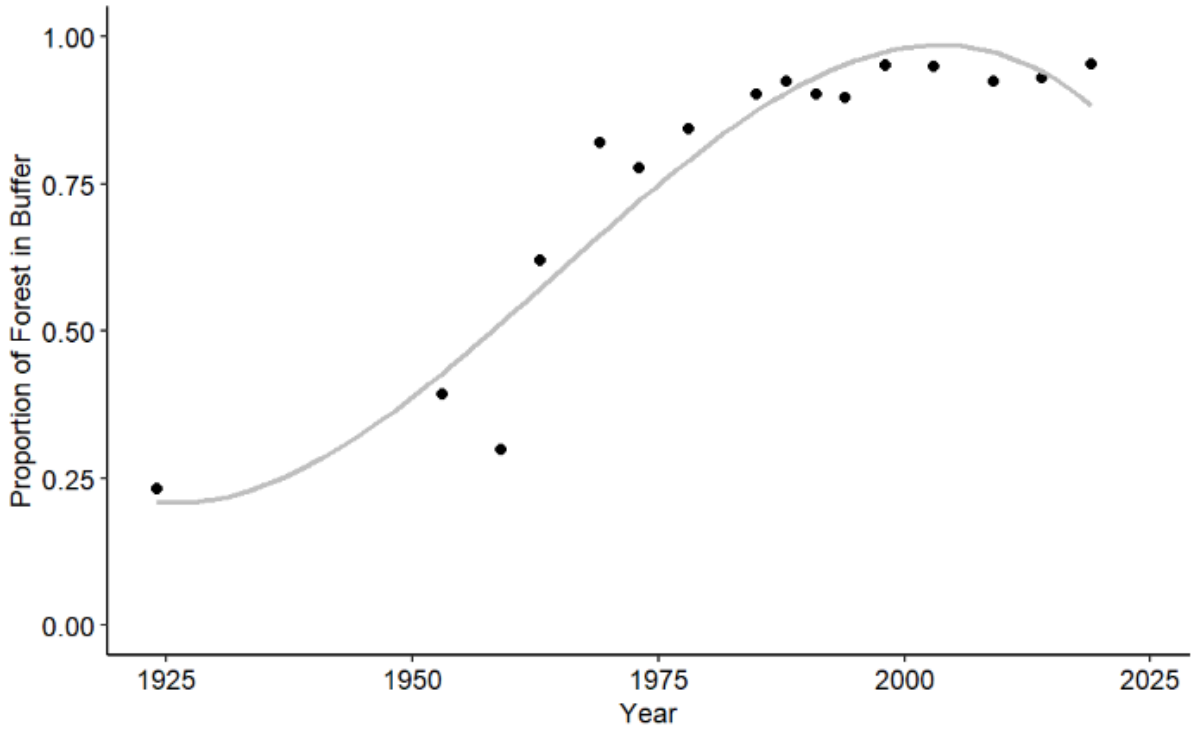

Figure 3. Changes in the proportion of forest cover within the terrestrial buffer surrounding Brooker's Pond from 1924 to 2019. Buffer zones were drawn 240 meters landward from the wetland (n = 16). Forest area was determined in square meters using streaming, trace, and measurement tools in ArcGIS Pro (Esri Inc, 2021). Proportions were determined by dividing the forest area by the total buffer area. The trendline displayed is that of a third-degree polynomial regression and was calculated in RStudio using the stat_smooth function from the ggplot2 package (RStudio Team, 2021; Wickham, 2016).

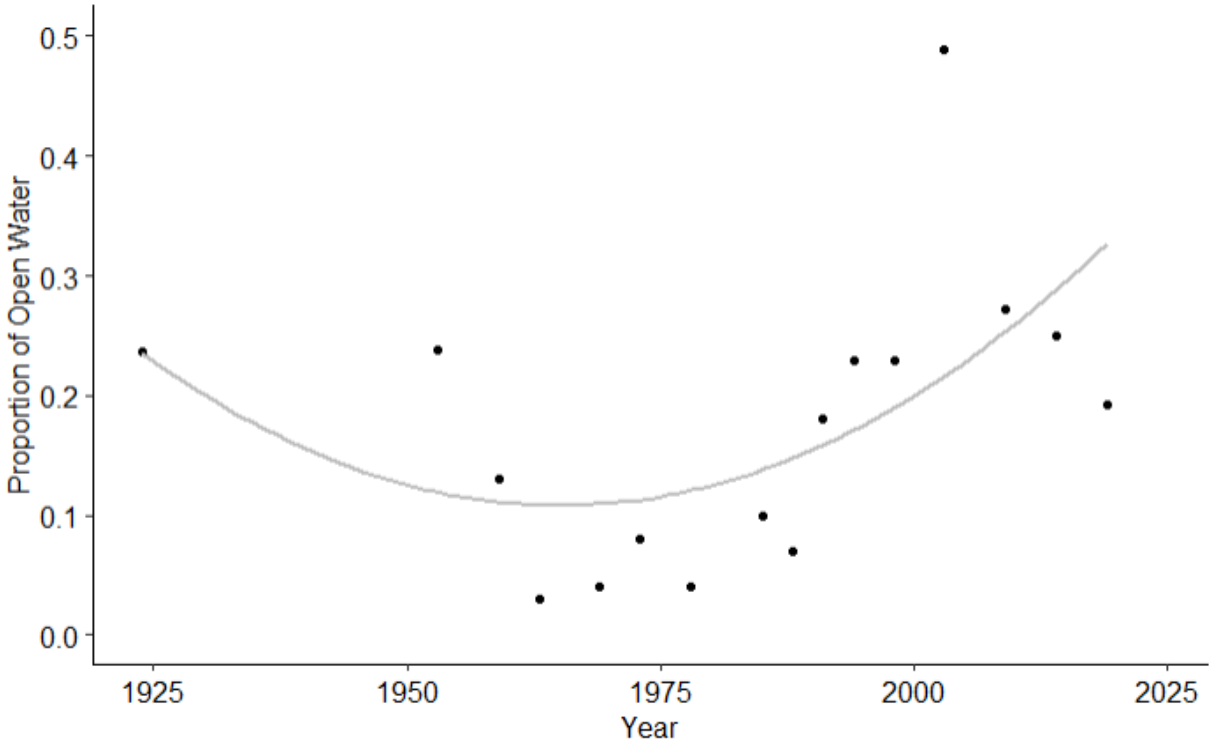

Figure 4. Changes in the proportion of open water within Brooker's Pond from 1924 to 2019. Area estimates were determined in square meters using streaming, trace and measurement tools in ArcGIS Pro (Esri Inc, 2021). Proportion of open water was determined by dividing the area of open water by the total area of the wetland (n = 16). The trendline displayed is that of a second-degree polynomial regression and was calculated in RStudio using the stat_smooth function from the ggplot2 package (RStudio Team, 2021; Wickham, 2016).

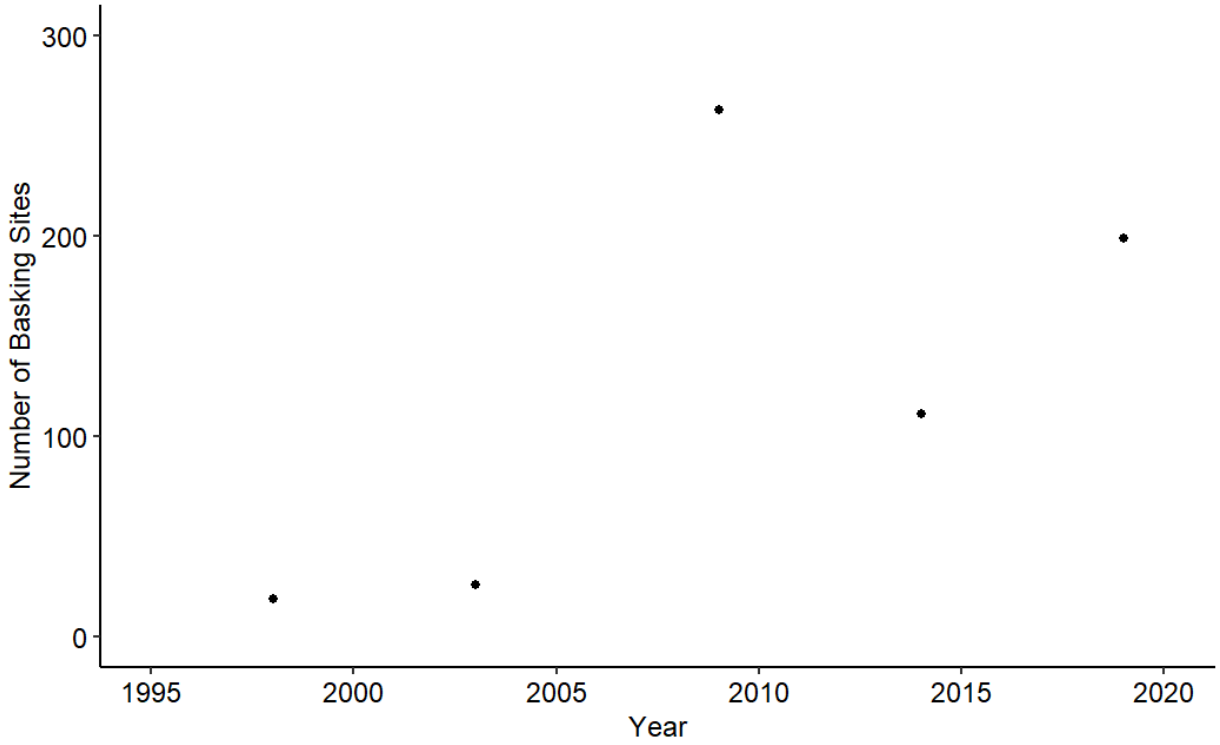

Figure 5. Changes in the number of available basking sites in Brooker's Pond from 1998 to 2019. Estimates were determined using the point feature class and tool in ArcGIS Pro and the total number of basking sites were recorded (Esri Inc, 2021). There were not enough data points to fit a regression. Graph was created using RStudio with the ggplot2 package (RStudio Team, 2021; Wickham, 2016).

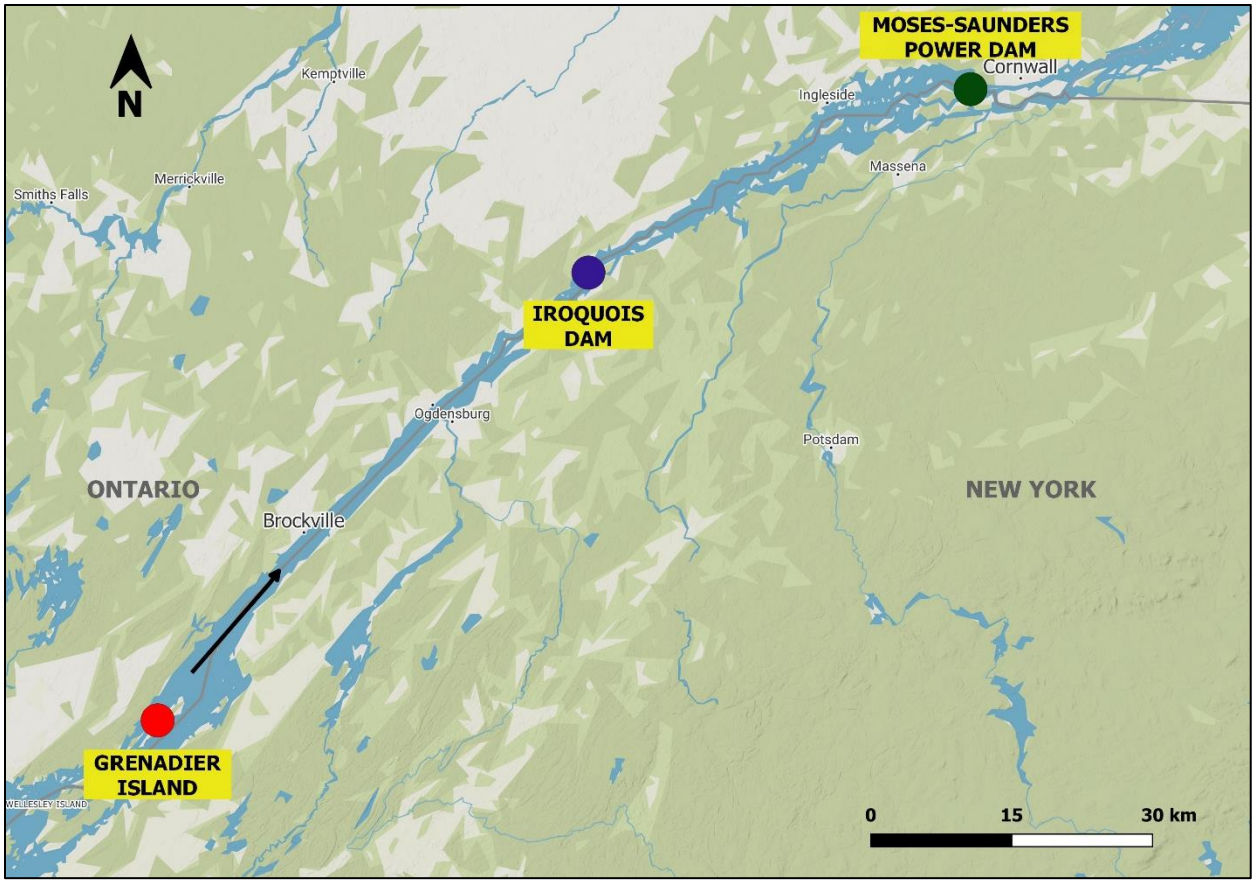

Figure 6. Location of Grenadier Island relative to the two dams created downstream as part of the Saint Lawrence Seaway. Grenadier Island is marked in red; the Iroquois Dam is marked in dark blue and the Moses-Saunders Power Dam of Cornwall is marked in green. The area between these two dams is known as Lake St. Lawrence. The black arrow illustrates the direction of water flow. Lake Ontario is located further upstream of Grenadier Island, the outflow of which is dictated by the dams depicted above. Map was created using QGIS (QGIS Development Team, 2022).

7.0 APPENDIX—SUPPLEMENTARY MATERIAL

Supplementary Table 1. Raw data summary.

Year	Wetland Size (ha)	Proportion of Open Water	Proportion of Forest Cover	Number of Basking Sites
1924	17.54	0.24	0.23	
1953	12.39	0.24	0.39	
1959	30.98	0.13	0.30	
1963	52.92	0.03	0.62	
1969	88.59	0.04	0.82	
1973	83.31	0.08	0.78	
1978	97.83	0.04	0.84	
1985	94.40	0.10	0.90	
1988	144.35	0.07	0.92	
1991	103.60	0.18	0.90	
1994	133.40	0.23	0.90	
1998	125.70	0.23	0.95	19
2003	138.68	0.49	0.95	26
2009	76.55	0.27	0.92	263
2014	78.40	0.25	0.93	111
2019	73.71	0.19	0.95	199