Bridging Knowledge Gaps for Protection and Recovery: Habitat Use and Threats of Blanding's Turtles in an Understudied Region of The Great Lakes

By

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GENERAL ABSTRACT:

Ontario is home to 8 species of freshwater turtles, all of which are federally at-risk of extirpation. To conserve declining populations, the government turns to recovery strategies for each species that are listed as threatened, endangered, or extirpated. These recovery strategies require previous field studies to identify critical habitats to be protected and threats that need to be mitigated. Because the majority of this information relies on field studies, there are still many knowledge gaps that need to be investigated, particularly in regions such as eastern Georgian Bay of the Laurentian Great Lakes, where little research has been done. This region contains relatively abundant populations of 6 species of freshwater turtle, including the federally endangered Blanding's turtle (*Emydoidea blandingii*), which acts as an umbrella species for the conservation of other species that share its habitat. This thesis aims to fill knowledge gaps related to the critical habitat that needs to be protected in this region, as well as potential threats to Blanding's turtles that may require mitigation efforts, such as human development or climate change. In the first chapter, we determine the habitats used by 22 Blanding's turtles over the active, nesting, and overwintering seasons among coastal and inland wetlands. We also identify site-specific threats due to preferences for nesting near built-up areas rather than rock barrens. In the second chapter, we determine a significant loss in functional aquatic wetland habitat for Blanding's turtles due to changes in annual water levels and infer associated impacts due to climate change. This was achieved by classifying satellite imagery between 2002 (lower water level) and 2019 (higher water level) and conducting change detection analyses. This research is the first to occur along the eastern coast of Georgian Bay and will advance our understanding of the threats and habitat requirements of freshwater turtles. The findings

will be used to implement recovery strategies aimed at protecting and mitigating threats to imperiled freshwater turtles.

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GENERAL INTRODUCTION

At-risk Freshwater Turtles

We are currently living through the 6th great extinction event with an unprecedented loss of biodiversity worldwide (Pievani 2014). Among the taxa that are in decline, turtles are particularly affected by encroaching anthropogenic activities; nearly 50% of turtles worldwide are considered at risk of extinction (Rhodin et al., 2018). Species that have been listed as threatened, endangered, or extirpated are currently protected under the Endangered Species Act (2007) in Ontario and are protected federally under the Species at Risk Act (2002). Freshwater turtles in Canada are particularly vulnerable, with all 8 species native to Ontario designated as at risk of extirpation federally (COSEWIC 2018; Government of Canada 2018).

Although species listed as threatened, endangered, or extirpated are protected by provincial and federal governments, population declines for many freshwater turtle species still continue to occur (COSEWIC, 2018). To conserve declining species-at-risk (SAR) populations, the federal and provincial governments develop recovery strategies for each population to ensure their long-term survival and recovery (ECCC 2018; OMECP 2019). For freshwater turtle populations, an important component in the development of successful recovery strategies is to understand the habitat requirements and the threats of a population throughout their range. Without such detailed studies, effective management plans cannot be developed to accurately protect and mitigate the critical habitat required for processes such as reproduction, foraging and overwintering (Markle and Chow-Fraser, 2014).

The Blanding's turtle is a semi-aquatic freshwater turtle that is known for extensive movements and that uses a variety of aquatic and terrestrial habitats throughout their active (spring-fall) season (Ernst and Lovich 2009; Edge et al. 2010). Gravid females in particular are known to migrate long distances, often travelling 2km from resident wetlands to access suitable nesting sites, with some cases being up to 6km (Ernst and Lovich 2009; Edge et al. 2010). Unfortunately, their extensive movements, habitat use, and large home ranges expose the populations to encroaching human development, and this has led to habitat loss, degradation, fragmentation, and road mortality (Congdon et al. 1993; Beaudry et al. 2008; Steen & Gibbs 2004). Furthermore, these factors in combination with their life history traits such as low recruitment rate, low annual fecundity, and delayed sexual maturity, have led to a general population decline (Congdon et al., 1993; Gibbons et al., 2000; Marchand and Litvaitis 2004). Currently, the St. Lawrence Great Lakes population of Blanding's turtles is listed as endangered in Canada, and as threatened in Ontario (COSEWIC 2016, COSSARO 2017).

Blanding's turtles are an important species to study, as they are often considered an excellent umbrella species for wetland habitat conservation, due to their extensive habitat use overlapping with the habitat of other species at risk (Herman et al., 2003). This means that by protecting umbrella species such as the Blanding's turtle, we can simultaneously protect many other SAR that share similar habitat features with them (Roberge and Angelstam, 2004). It is also important to study BLTU in under-studied regions to confirm that their threats and habitat requirements align with what current recovery strategies outline in published studies (ECCC 2019; OMECP, 2019). Throughout their range, BLTU have used many wetland types including bogs, fens, marshes, swamps, ponds, streams, and ephemeral wetlands throughout their year (Ross and Anderson 1990; Rowe and Moll 1991; Standing et al. 1999; Joyal et al. 2001; Beaudry et al. 2009; Hartwig and Kiviat 2007);

however, habitats used by BLTU often vary by geographic location due to differences in landscape (Markle and Chow-Fraser 2014). Along with this, threats to each population may also differ with landscape, and it is therefore important to carry out site-specific studies in unstudied regions to fill these knowledge gaps.

Study Site

Our study site is located on the eastern coast of Georgian Bay, Lake Huron. This 80-km^2 Canadian Shield landscape is characterized by an abundance of coniferous-dominated forests amongst nearly 150 coastal and upland wetlands, all of which vary with respect to land ownership and levels of human disturbance. The vast majority of this region is considered low disturbance and is comprised of low-impact private property, nature reserves, and undeveloped crown land, while there are pockets of moderately developed land comprised of cottages, roads, marinas, residential housing, and a First Nations Reserve.

For the Great Lakes -St. Lawrence population of BLTU living in Ontario, past studies have occurred in either Algonquin Park (Edge et al., 2009; Edge et al., 2010) or in highly degraded regions of southern Ontario (Mui et al. 2016; Markle et al., 2017; Markle and Chow-Fraser 2018; Angoh et al. 2020). Eastern Georgian Bay is a region with countless wetlands that are still in a relatively undisturbed state (Cvetkovic and Chow-Fraser 2011), and many of these are considered suitable habitat for BLTU (Markle & Chow-Fraser 2014; Markle & Chow-Fraser 2016). While large community science databases have shown that BLTU populations exist in eastern Georgian Bay (Ontario Nature 2018), very little is known about how they use habitat in this region and what threats they face (Markle & Chow-

Fraser 2014). With increasing demand for cottage development and expansion in the face of a changing climate, there is a dire need to study BLTU populations in this understudied landscape so that effective recovery strategies can be developed for the relatively abundant populations inhabiting this region.

Thesis Objectives

The overall objective of this thesis is to fill knowledge gaps in current recovery strategies for BLTU by identifying their critical habitat requirements as well as threats in eastern Georgian Bay, Lake Huron. The fieldwork, methods, and findings presented in this thesis are intended to guide site-specific conservation efforts so that land managers and governments can work together towards the effective recovery and protection of freshwater turtles in an understudied region of the Great Lakes. In chapter 1, we fill knowledge gaps on the critical habitat to be protected and anthropogenic threats to be mitigated in eastern Georgian Bay by conducting a site-specific study on the habitat use and selection of BLTU and further compare our findings to that of published literature to identify differences in habitat selection across their range. In chapter 2, we fill knowledge gaps on the unassessed threat of climate change and changing water levels on BLTU habitat by investigating changes in coastal wetlands over a 17-year period in our study site. To do so, we classified BLTU habitat with high accuracy using satellite imagery during 2002 (lower water level) and 2019 (higher water level) and used change-detection analyses to determine compositional changes in functional aquatic habitat between the two periods.

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Site-Specific Studies to Identify Site-Specific Threats: Differences in Habitat Use and Selection of the Blanding's Turtle Throughout Their Geographic Range

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Abstract

The threatened Blanding's turtle (*Emydoidea blandingii*) is known for using many habitat types, which can vary greatly throughout their geographic range. This makes it necessary for field studies to be conducted in understudied regions such as eastern Georgian Bay of the Laurentian Great Lakes, where there are still relatively abundant populations. Here, we document habitat use and selection by a population residing in the Georgian Bay archipelago, where there are both natural undisturbed habitats and pockets of built-up areas with moderate housing/cottage development. We used a combination of radio tracking and GPS loggers over 3 years (2019, 2021, and 2022) to study 11 male and 11 female Blanding's turtles; we also used 2019 Pleiades satellite imagery to classify (overall accuracy of 94.8%) land cover and land use features into eight habitat classes that include marsh, peatland, shallow water, lake, built-up, forest, thicket swamp, and rock barren. Both sexes used palustrine wetlands (peatlands, thicket swamp; marsh, shallow water) and coastal wetlands (shallow water, lake) throughout the active season and were observed using shallow water, thicket swamps, and deep open water (lake) to move between resources patches. During the nesting season, females preferred built-up classes over rock barrens when both were available in their home ranges. This coastal population used coastlines, docks, and deep open water more frequently during the active season than has been reported in the literature, and this reinforces the need to establish mitigation measures to protect females near docks, marinas and roadsides during nesting travels in this region. Their use of built-up areas for nesting is consistent with the majority of published studies, as is their use of shallow water, and all wetland types used as overwintering habitat.

Introduction

Implementation of an effective framework for the protection and recovery of species at risk (SAR) requires an understanding of their habitat requirements as well as the threats that they face. By investigating how a species uses their habitat, we can identify the habitat to be protected, such as habitat required by a species to carry out their critical life processes (reproduction and overwintering) and by investigating threats, we can identify areas to be mitigated and incorporate this information into recovery strategies. Although focusing research to identify and protect critical habitat has been considered an easier option to sustain future populations (Rasmussen & Litzgus 2010), it is equally important to focus on understanding threats to be mitigated, since habitat use and threats to populations may not be entirely independent of each other.

Understanding the interaction between habitat use and threats can be especially important for species such as the Blanding's turtle. The Blanding's turtle is a semi-aquatic freshwater turtle species that is known for using a variety of wetland and upland habitats throughout the year (Ernst and Lovich 2009); however, their habitat use may not be confined solely to habitats that are currently protected. This is especially applicable for female Blanding's turtles, which are known to use a variety of habitats while making long-distance movements to access suitable nesting sites, often travelling 2km from resident wetlands, with some cases up to 6km (Standing et al. 1999; Edge et al. 2010).

Unfortunately, their extensive movements, habitat use, and large home ranges expose populations to encroaching human development, which has led to habitat loss, degradation, fragmentation, and road mortality throughout their range (Congdon et al. 1993; Beaudry et al. 2008; Steen & Gibbs 2004). Furthermore, these factors in combination with BLTU life history traits such as low recruitment rate, low annual fecundity, and delayed sexual maturity, have led to a general population decline (Congdon et al., 1993; Gibbons et al., 2000; Marchand and Litvaitis 2004). Currently, the St. Lawrence Great Lakes population of BLTU is listed as endangered in Canada, and as threatened in Ontario (COSEWIC 2016, COSSARO 2017), and effective protections and recovery efforts must be put in place to ensure populations are not disproportionately impacted by landscape changes due to human development.

Understanding patterns in habitat use and preference by BLTU may yield information to identify both critical habitat and threats to specific populations. Habitat selection occurs when a species uses a habitat disproportionately to the availability of that habitat (Johnson 1980), and it can be a useful way to interpret patterns in habitat use by a species (Alldredge and Griswold, 2006). Habitat preference on the other hand, is a relative term to be used, such as when one habitat is used more in comparison to another habitat when both are equally available (Johnson 1980; Aebischer et al., 1993). Understanding both selection and habitat preferences can be important, as they provide complementary information to understand which habitats require priority protections or mitigations.

Johnson (1980) recommends that studies investigate selection at multiple scales to effectively develop management strategies needed to conserve and recover species. Second-order selection refers to selection of an individual's home range from within the population range, while the third-order selection reflects selection of specific locations within the individual's home range (Johnson 1980). In addition to investigating habitat selection at multiple spatial scales, we must also consider differences between sexes and behavioural seasons when studying the Blanding’s turtle (Rasmussen et al., 2010; Edge et al., 2010; Markle and Chow-Fraser 2014; Angloh et al., 2018). As ectotherms, turtles must regulate their metabolism during their active season (spring-fall) season by using many habitats, basking on rocks in the spring, cooling themselves by immersion in water, and overwintering by remaining in water near the sediment surface (Congdon 1989; Huey 1991; Beaudry et al. 2009). There are also stark differences in habitat use between males and females during the active season (spring-fall), especially when females become gravid (Markle and Chow-Fraser 2014). It is therefore important to separately study habitat selection by females during the nesting season and to identify habitat corresponding to highest nesting success.

Past studies on habitat selection by the Great Lakes-St. Lawrence population in Canada have occurred either in relatively low-disturbance protected areas in Algonquin Park (Edge et al., 2009; Edge et al., 2010) or in highly degraded regions of southern Ontario (Mui et al. 2016; Markle et al., 2018; Markle and Chow-Fraser 2018; Angoh et al. 2020; COSEWIC 2016). Only one study has focused on the understudied shores of Georgian Bay within Lake Huron, but that study occurred in the southeast on a completely protected island (Markle & Chow-Fraser 2014). There are numerous coastal wetland complexes along the eastern shore of Georgian Bay that are still in a relatively undisturbed state (Cvetkovic and Chow-Fraser 2011), and many of these are considered suitable habitat for Blanding's turtles (Markle & Chow-Fraser 2016). While large community science databases have shown that Blanding's turtle populations exist in eastern Georgian Bay (Ontario Nature 2018), very little is known about how they use habitat in this region and what threats they face. With increasing demand for cottage development and expansion (Walton and Villeneuve 1999; Niemi et al. 2007), it is important that studies of habitat use and selection are conducted in this region to identify critical habitat and to assess threats to this subpopulation. Furthermore, landscapes with a mosaic of disturbed and undisturbed habitats are important to study, as they may provide a more accurate representation of the interaction between habitat use patterns and threats in Georgian Bay which can support efforts in recovery planning.

A summary of critical habitats used by the Blanding's turtle for nesting (**Table 1.1**) and overwintering (**Table 1.2**) reveals clear differences across the geographic range that underscore the importance of developing site-specific strategies to protect critical habitat and to mitigate threats. Previous studies conducted on a protected area in southeastern Georgian Bay found Blanding's turtles using lichen-filled rock barrens for nesting and bogs for overwintering (Markle and Chow-Fraser 2014; Markle and Chow-Fraser 2017), but we cannot assume this will be applicable to our study site without field verification. This is especially important to investigate because Blanding's turtles exhibit site fidelity to nesting and overwintering habitats (Standing et al., 1999; Newton and Herman, 2009). Furthermore, the critical habitat identified under the Species At Risk Act (2002) for Blanding's turtles has only been partially identified, and more studies are needed to determine what is considered suitable critical habitat to be protected (ECCC, 2018). For example, use of active sandpits and roadsides are currently thought of as an ecological trap for nesting and thus are not considered suitable critical habitat to be protected (ECCC, 2018). In landscapes dominated by the Canadian shield, however, natural nesting substrates for Blanding's turtles may be limited, and it is important to determine if turtles have a preference for nesting sites in natural or modified landscapes.

The focus of this study is to investigate the habitat use and selection patterns of a subpopulation of Blanding's turtles residing in the eastern coast of Georgian Bay. Most of the region experiences low human disturbance that includes low-density seasonal residences on private land, nature reserves, and undeveloped crown land. There are, however, some pockets of moderately developed land with cottages, roads, marinas, residential housing, and a First Nations Reserve. Our study aims to achieve three objectives: 1) to document and identify critical nesting and overwintering habitats used by turtles in this study site and to compare them to published data across the species' geographic range, 2) to investigate habitat selection and preferences of male and female turtles across the active season at the second and third order scale, and 3) to identify site-specific threats by investigating habitat selection and preferences of gravid females exposed to human development. We hypothesize that when given the option, females would indicate a relative preference for using built-up habitats rather than for rock barren habitats during the nesting season, and that both males and females would indicate a preference for peatlands (bogs and fens) over other habitats during the active season. This study will fill important data gaps for BLTU in general and provide data to develop site-specific recovery strategies for turtles residing in this understudied region.

Methods

Study Site

Our study was carried out in eastern Georgian Bay of Lake Huron during 2019, 2021, and 2022. The study site is an 80-km^2 area comprised of both natural and relatively undisturbed land within the Georgian Bay Archipelago, as well as built-up areas with moderate housing, cottage, and road development. This coastal region is characterized by a

Canadian Shield landscape with a heavy abundance of gneiss rock barrens and coniferous forests. There are over 150 wetlands and wetland complexes in this site, both coastal and palustrine, and while few are fragmented by the development of roads, majority have been conserved with minimal human footprint for over 100 years. Most ground-reference data were collected between 2019 and 2022; additional habitat information was extracted by visually examining 2018 images (16-cm resolution) from the South Central Ontario Orthophotography Project (SCOOP) using ArcGIS Pro (ESRI). Descriptions for the eight habitat classes in this study (marsh, peatland, shallow water, lake, built-up, forest, thicket swamp, and rock barren) come from the Canadian National Wetlands Classification System (Warner and Rubec 1997) and Anderson et al. (1976).

To accurately classify the 8 habitat classes, we used high-resolution satellite imagery acquired on June 27th, 2019 (0.5-m resolution Pleiades imagery; 2-scenes) to ensure the phenology of live vegetation and turtle habitat would appropriately represent available and used habitat during the active season. After image data were preprocessed with ENVI (Harris Geospatial), radiometric and atmospheric corrections were applied to each scene, and then both were orthorectified, stitched together, and pansharpened. Image data were projected to Universal Transverse Mercator projection datum (NAD83, UTM Zone 17); to minimize processing time, we used the nearest neighbour method to resample to a resolution of 1 m. We stacked together 5 layers of the satellite imagery, which consisted of 4 pansharpened multispectral layers (blue, green, red (R), and near infrared (NIR)) and the Normalized Difference Vegetation Index (NDVI) layer, calculated with NIR and R. NDVI is a great discriminator of green vegetation (Rouse et al. 1974) and helps to differentiate between open water and dry land, and in delineating wetland boundaries (Ozesmi and Bauer, 2002; Mui et al. 2015).

Object-based image analysis (OBIA) has been used successfully in studies on Blanding's turtle habitat because it is great at capturing the spatial heterogeneity of wetland classes (Fournier et al. 2007; Barker and King 2012; Markle and Chow-Fraser 2016 ; Mui et al. 2015) and is a suitable alternative method to pixel-based classification (Grenier et al., 2007; Midwood and Chow-Fraser 2010). Image segmentation is the first step in which pixels are grouped together into image objects based on their spectral properties. The Large Scale Mean Shift (LSMS) segmentation algorithm was then used in Orfeo Toolbox 8.0.0 to segment the image. We used a spatial radius of 5, range radius of 3, and minimum region size of 50 to ensure all habitat types would be segmented across the image.

The second step is classification. We used a minimum of 100 ground-reference points to train each of the six habitat classes (Marsh, Lake, Rock, Peatland, Shallow Water, Forest) in the segmented image. This was accomplished with the Support Vector Machine (SVM) algorithm in the TrainVectorClassifier tool of Orfeo Toolbox 8.0.0. The ground-reference data were supplemented with habitat information extracted visually from the 2018 SCOOP images in under-sampled portions of our study area to train the classification. We assessed the accuracy of our habitat classification by using a minimum of 45 independently selected samples from the ground reference data and aerial imagery following the methods of Mui et al. (2019), and we ensured that objects used for training and accuracy assessment did not overlap. Finally, we used the ComputeConfusionMatrix tool in Orfeo Toolbox 8.0.0 to calculate the accuracy statistics.

Because thicket swamps and built-up habitat types were most often confused with rock and forest habitat types, they were removed from supervised classification and were instead manually delineated to reduce misclassification. We mapped built-up habitats (roads, cottages, docks, lawns, sand pits) by selecting segmented images of buildings, cottages, and docks, and using a 5-m buffer of roads in the Ontario Roads Network Shapefile. Since it is difficult to differentiate between thicket swamps and forests in summer imagery, we manually delineated these using the 2018 SCOOP images, which had been acquired during spring leaf-off conditions.

Radio-tracking

In total, we monitored the movements of 22 adult BLTU (11 males, 11 females) across 3 different years (2019, 2021, and 2022). Unfortunately, due to the COVID19 pandemic, no fieldwork was permitted between March 2020 and March 2021. We radio tracked 6 turtles (5M, 1F) between April 25th-October 4th 2021, and 19 turtles (8M, 11F) between May 9th – October 5th, 2022. Two male turtles were also radio tracked between July 26th 2019, and March 2020.

We captured the BLTU with either baited hoop nets or caught them opportunistically and determined their sex based on secondary morphological characteristics (Hamernick 2000; Innes et al. 2008). AI-2F radio transmitters (Holohil Systems Ltd., Carp,ON, Canada, 19 g) were fixed to each individual's shell with epoxy putty, and in 2022, an additional 8 BLTU were fitted with GPS loggers (AxyTrek, 5 females and 3 males). We attached these loggers to obtain additional locations between tracking events and to help us identify fine-scale movements during the pre-nesting and nesting seasons. We ensured that the total weight of any attachments on a turtle's shell was less than 5% of the body mass, and we notched the scutes to ensure they could be identified from these markings alone (Cagle 1939).

In 2021 and 2022, we aimed to track each individual 1-4 times per week throughout the active season (May-August), and once in September and October. We used a 3-element Yagi antenna (Wildlife Materials International, Murphysboro, IL) and Lotek Biotracker Receiver (Lotek Wireless, Newmarket, ON, Canada) to find turtles. We used a GPS (Handheld Garmin, 5-m accuracy) to obtain geographic coordinates of each individual location, and if we could not visually find the turtle, we would find their location by triangulating their signal and then take a GPS point. We caught turtles with GPS loggers several times throughout the pre-nesting and nesting season to download data (accuracy to within 10 m). We imported locational data from turtles and superimposed them into the GIS containing the classified 2019 satellite image to make inferences about habitat classes used.

We investigated the use of two critical habitats: nesting and overwintering habitats in this study. We identified nesting sites in 2022 using a combination of GPS loggers and nesting surveys. The nesting season started on June 1st, 2022, when the first female commenced her overland migration, and continued until the last female was no longer gravid (June 28th). When females were nesting, we started surveying at 7:00PM to identify potential nesting sites, and after they had nested, we would start the survey at 10:00PM to minimize disturbance. After a female nested, data from the GPS logger would be downloaded, and we then visited the logged locations to look for their nests. We also identified overwintering habitat in part of the study site that only contained natural habitat (i.e. no built-up land). During the three winter surveys (February in 2020, 2022, and 2023), we used radio tracking to locate tagged turtles under the ice and in this way tracked them to ~5 m of their location in the wetland. During the beginning of the active season, we returned to these tagged locations to confirm the corresponding habitat class that was used.

Habitat Selection and Delineation Methods

The methods used to determine the boundaries of available and used habitat at multiple spatial scales have varied in different studies (Row and Blouin-Demers 2006; Rasmussen and Litzgus 2010; Markle and Chow-Fraser 2014) and may pose a challenge when deciding which approach to use. A common method used to delineate home ranges and population ranges is the minimum convex polygon (MCP) method (Mohr 1947). This method creates a minimum bounding shape around all radio locations and has been used to estimate the ranges of reptiles in many studies (Litzgus et al. 2004; Row and Blouin-Demers 2006; Rasmussen and Litzgus 2010; Millar and Blouin-Demers 2011; Markle and Chow-Fraser 2014). Although the MCP method is simple, it can include large areas of unused habitats and may change with addition of new data points, and is therefore sensitive to sampling effort (Harris et al. 1990; White and Garrott 1990; Burgman and Fox, 2003).

Other methods, such as kernel density estimators, may be more biologically relevant for estimating home ranges, but the choice of a smoothing factor can heavily influence the estimated home range size, leading to potential bias (Row and Blouin-Demers 2006; Rasmussen and Litzgus 2010; Markle and Chow-Fraser). In our study, we opted to use the MCP method as it provided better results than the method used by Row and Blouin-Demers

(2006) which created disjunct turtle home ranges that excluded some habitats used as travel corridors in our study site. This was also an issue that Rasmussen and Litzgus (2010) had, and they also opted to use the MCP method instead.

To determine the available habitat at the second order scale, we created a MCP around the relocation of every individual in the study site to delieate the population range boundary, and then buffered this by the average daily distance travelled by the population (60m). We used Angoh et al.'s methods (2021) to further simulate the available habitat to each BLTU by randomly distributing 20 home ranges with the same size and shape for each individual home range within the buffered MCP, and then used the tabulate area tool in ArcGIS Pro 3.0.0 (ESRI 2022) to calculate the simulated available habitat for each turtle.

To define the used habitat at the second-order scale and available habitat at the third-order scale, we created an MCP surrounding all individual relocations to create home ranges for each individual.

For used habitat at the third-order scale, the habitat that a turtle is found in at each relocation may not be an accurate representation of the habitat that they are using due to data collection from fieldwork and GPS loggers occurring in intervals. We were concerned that this may misrepresent the actual habitat types that they may be using, and so we delineated the "used" habitat at the third-order scale by creating buffers around each relocation using the average daily distance travelled by the population (60m). We summed the total area of all habitats within each buffer and divided each habitat by the total area to calculate the proportion of each habitat that was used. To ensure that there was only one relocation per day per turtle, we randomly selected one GPS relocation point if multiple relocations per day were obtained.

Statistical Analyses:

We determined habitat selection using the 'adehabitatHR' package (Calenge 2006) in R 2022.07.1 (R Core Team 2022). We used compositional analyses (Aebischer et al. 1993) and Manly Selection Ratios (Manly et al. 2002) to assess habitat selection of turtles across the active seasons in 2021 and 2022. While both methods can reveal patterns of selection, there are some key differences. Compositional analysis compares between proportional use of available and used habitats and can be used to identify relative preferences between habitat types (Aebischer et al. 1993); on the other hand, the Manly selection ratio is a selectivity measure that estimates the relative probability of a habitat being used disproportionately compared to its availability, and can be used to understand the strength and direction of selection (Manly et al. 2002; Calenge and Dufour 2006). Manly Selection ratios and their corresponding confidence intervals (CI) can be used to indicate selection of habitat that is disproportionately lower than what is expected based on availability (±CI between 0 and 1), selection that is disproportionately higher than what is expected based on availability (±CI greater than 1), and selection that is used in proportion to habitat availability (±CI do not exceed or proceed 1; Calenge and Dufour 2006; Angoh et al. 2021). During the 2022 nesting season, we also conducted analyses separately for gravid females whose home ranges included built-up habitats to investigate their preference for using nesting sites along roadsides or in crevices of rock barrens where moss/lichen have accumulated.

Results

Habitat classes

The study site consisted of a mosaic of eight habitat types which included forests, rock barrens, peatlands (bogs and fens), lake (deep open water >2m deep), marsh, shallow open water (beaver impoundments and littoral coastlines <2m deep), thicket swamps, and built-up areas (roads and human development) (**Figure 1.1**; **Table 1.3**). We obtained excellent overall accuracy of 94.8% and kappa statistic of 0.89 for the classification of the 2019 Pleaides satellite images using Support Vector Machine. The most dominant habitat class was forest, which covered 1574.1 ha and accounted for 57.8% of the total study area, while the second most dominant habitat class was lake, which covered 551.4 ha and accounted for 20.2% of the study area. The remaining 20% consisted of shallow water (6.1%), rock barren (5.4%), and three wetland types (marsh (4.3%), peatland (3.2%) and thicket swamps (1.82%). The built-up area covered only 35.1 ha and made up only 1.3% of the study area (photos of each habitat class is shown in **Figure 1.2**).

Daily Distance Travelled and Home Range

Over the course of the 3 active seasons, we re-located the 22 Blanding's turtles 907 times. Although the mean of the 11 male home ranges was 87.19 ha (ranging from 1.55 - 563.33 ha) and that of 10 females was only 35.48 ha (ranging from 8.08 - 103.2 ha), there was no significant difference between sexes due to the large individual variation among males (Wilcoxon test; p=0.48) (**Table 1.4**). The mean daily distance travelled (DDT) was 50.80 and 64.93 m/d respectively for males and females, with an overall average DDT for the population of 57.90 m/d (**Table 1.5**).

General movements and habitat use

Both sexes used a variety of palustrine wetlands and wetland complexes (shallow water, peatland, marsh) and coastal habitats (marsh, shallow water) during the active season; they also used shallow water primarily along coastal shorelines or in beaver ponds as travel corridors between wetland classes. Another habitat class used as travel corridor was thicket swamp, especially in the region with minimal disturbance. Both males and females used these to travel between the coastline and palustrine wetlands; in particular, three females used these to travel to their staging areas during the nesting season.

Three males and 1 female (#'s 04M, 07M, 13M, and 23F) crossed two separate embayment's over deep open water (lake) in 2021 and 2022. In June 2021, #04M who had been using a coastal wetland on a peninsula, swam across the embayment and entered a beaver impoundment on the mainland 2km away. He disappeared for 2 months and was found crossing a road in early September, having traversed several large wetland complexes during the summer for a minimum total distance of 7.97km. In June and July of 2022, deep water crossings were observed by #07M and #13M, who crossed a deep-water channel from an island and entered a beaver impoundment on the mainland. While #07M eventually was confirmed swimming back across the channel in water depths <20m at the end of the summer, #13M remained in the beaver impoundment until mid-October, and likely overwintered there.

Critical Habitat: overwintering and nesting

Blanding's turtles overwintered in peatlands, marshes, thicket swamps, and shallow open water habitats. During the 2020 winter survey, #02M was found overwintering in a shallow water beaver impoundment, while #01M overwintered in a large peatland complex. During the 2022 survey, 2 (#05M, #06F) overwintered in shallow water, 3 (#08M, #09F, #10M) overwintered in marshes, and 2 (#03M, #07M) overwintered in separate thicket swamps. In 2023, 2 individuals (#13M, #21F) overwintered in shallow water, 3 (#19F, #20F, #22F) overwintered in peatlands, and 2 (#16F, #18F) overwintered in marshes.

Due to difficulties finding female turtles in 2021, observations associated with nesting migrations of females were only available for the 2022 season (June 1^{st} – June 28^{th}). In the more developed region of our study area, three turtles (#19F, #21F, and #23F) were observed making nesting movements along roadsides for multiple days, and two females (#18F, #20F) spent majority of their nesting season near marinas where they had been observed attempting to nest in loose substrate within the parking lots of the marina parking. It should be noted that four turtles (#09F, #14F, #18F, #20F) were observed hiding within or in high proximity (<5m) to docks before and after nesting travels. While only two of these individuals (#18F, #20F) were observed frequenting docks at marinas, to our dismay, we found the injured carcass of one untagged gravid female floating along the shore of a boat ramp near a marina. And she had likely been crushed by a boat trailer just hours earlier.

We confirmed that females used both roadsides and rock barrens for nesting. Using logged locations of a gravid female (#14F), we confirmed that she laid her eggs in a lichen-filled rock outcrop in the relatively undisturbed region of our study area. The nest had been depredated and eggshells characteristic of a Blanding's turtle had been scattered along the ground. In the more disturbed region of our study area, #23F successfully nested in loose substrate along the road in early June; she disappeared shortly thereafter and could not be found again until late August, where she was located in a peatland complex on the opposite side of a boating channel 3.13 km away. First Nation's community members placed a protector over the nest of #23F, and in September, two hatchlings emerged from the nest and were released back to the nearest wetland. It's notable that at least 16 female turtles of different species (including three gravid tagged females) attempted to nest along this same road near a specific building; these attempted nest sites were all within ~150m-radius circular buffer. We learned from members of the First Nations community that female turtles had been observed nesting there for many years, and that only 20 years earlier, before the building was erected, there had been a sand pit in that location that contained suitable nesting substrate.

Third Order Habitat Selection

During the 2022 nesting season, gravid females with home ranges that included built-up areas exhibited non-random habitat use at the third-order scale (i.e. within home range; Wilks lambda test, $n = 6$, $\lambda = 8.39e\text{-}03$, $p = 2.67e\text{-}05$). Based on Manly's Selection ratios, they selected shallow open water habitats in greater proportion than they were available (Confidence Interval (CI) > 1.0; **Figure 1.3**), but selected forest and peatlands in lower proportion than they were available (CI < 1.0). Compositional analyses indicated that females preferred shallow water over rock barrens or forests ($P < 0.05$) and that built-up areas were preferred over rock barrens or forests ($P < 0.05$) (**Figure 1.4**). Peatland and marsh were not disproportionately used significantly more or less compared to any habitat types.

Across the active season, both male and female Blanding's turtles exhibited non-random habitat selection at the third order scale as well (Weighted mean lambda randomization test, 1000 permutations; $\lambda = 0.1125$ and $P = 0.00700$ for males, and $\lambda = 0.034$, $P = 0.037$ for females). Manly Selection ratios (**Figure 1.5**) indicated that males selected all habitat classes according to their availability other than for thicket swamps, which were selected in lower proportion than they were available. Accordingly, compositional analyses indicated that all habitat types were preferred over thicket swamps, and that shallow water was preferred over forest, marsh, and rock (**Figure 1.6**). Manly Selection ratios indicated that females selected for shallow water habitats in greater proportion than they were available; however, they selected for thicket swamps, forest, and rock in lower proportion than they were available (**Figure 1.5**). Compositional analyses indicated that shallow water was preferred over forest, marsh, peatland, and rock, and that marsh was preferred over forest (**Figure 1.6**).

Second Order Habitat Selection

Both males ($n = 10$, $\lambda = 5.946111e{-}03$, $P = 8.203095e{-}09$) and females ($n = 11$, $\lambda = 3.44e{-}02$, $P = 4.87e{-}6$) exhibited a non-random habitat selection at the second order scale (landscape scale; Wilks lambda test) (data not shown). Based on results of the compositional analyses, females preferred shallow water over all other habitat types ($P <0.05$) except for peatlands, while males preferred shallow water over all habitat types ($P <0.05$) except for rock and peatland. Males preferred all other habitat classes more than they did for lake and built-up areas ($P <0.05$), and while females had similar results, their selection for built-up areas was only significantly lower when compared to marsh, peatland

and shallow water (P <0.05). Both sexes also preferred to use marsh, shallow water and peatlands over thicket swamps (P <0.05).

Discussion

Our study site is a large, mostly undisturbed and forested region on the Canadian Shield, containing hundreds of wetlands and wetland complexes consisting of shallow open water, marshes, peatlands, thicket swamps, as well as deeper open water. We expected such intact habitat to provide excellent habitat for Blanding's turtles. Given the Shield landscape, however, we suspected that nesting habitat may be limiting since Blanding's turtles tend to use sandy beaches or agricultural land and/or seek out loose and well-drained substrates that are often found in built-up areas such as driveways, parking lots and roadsides (Standing, Herman & Morrison, 1999; Congdon et al., 2000; Hughes and Brooks 2006; Dowling et al. 2010). In previous studies of Blanding's and other freshwater turtles in eastern Georgian Bay, however, investigators found females nesting in soil deposits in shallow depressions on rock barrens (Markle et al. 2021) or loose moss/lichen that accumulate in crevices and depressions of rocks (Markle and Chow-Fraser 2014). Shallowness of these substrates did not always produce suitable soil temperature and moisture dynamics for successful recruitment (Markle et al. 2021), and it may be easier for females to find suitable nesting sites along roadsides compared to lichen-filled depressions on rock barrens.

Similar to the Blanding's populations in Maine, females appeared to use both built-up areas as well as rock outcroppings, however they did not use agricultural fields such as old vineyards and pastures (Joyal et al. 2001; Beaudry et al. 2010). We hypothesized that when given the option, females would indicate a preference for using built-up habitats in comparison to rock barren habitats during the nesting season, and this was supported by results of the compositional analyses. In Manly selection ratios, however, the females did not appear to select built-up habitat in a significantly higher proportion than expected based on availability, since the lower confidence interval did not exceed 1.0. Only 7 of the 11 females had an individual home range that included built-up habitat areas during the 2022 nesting season, and only 6 of these females had sufficient relocations to create stable home ranges for tests of selection. Although this small sample size meets the minimum recommended by Aebischer et al. (1993) for compositional analyses, a larger sample of gravid females might have yielded statistically significant results through Manly selection, as the lower confidence interval was very close to 1.

Although artificial habitats such as roadsides have the potential to act as an ecological trap to Blanding's turtles that nest there (Refsnider and Linck 2012), artificial nesting sites can increase recruitment for freshwater turtles if they are built and managed properly (Beaudry et al. 2010). Based on informal discussions with members of the indigenous community, we know that not more than 20 years ago, a sand pile had been located in the vicinity where three females attempted to nest during 2022; community members also recalled seeing other species of turtle nest in this area in previous years. Since Blanding's turtles are known to exhibit nest-site fidelity in Georgian Bay (Markle and Chow-Fraser 2014), we recommend pursuing plans to design artificial nesting sites in this location to allow females to nest safely, for eggs in the nests to develop optimally free of nest predation, and for the hatchlings to be released safely into nearby wetlands.

Based on previous research in Georgian Bay (Markle and Chow-Fraser 2014), we also hypothesized that Blanding's turtles in our study would prefer to use peatlands (bogs and fens) during the active season over other wetland types at the third-order scale; however, our results did not support this hypothesis based on compositional analyses and Manly Selection results. We did not find any statistically significant preferences or disproportionate use for peatlands for either sex during any season. Instead, the turtles in our study exhibited preferences for shallow water habitats such as beaver ponds and shallow open-water coastlines over other wetland types. While females indicated a significant preference for using shallow water over most habitats including marsh and peatland at the third-order, males did not show a significant preference for shallow water wetlands over peatlands. The reason for this could be because males in this population used a larger variety of habitat types than did females, and their home ranges were more variable than those of females (**Table 4**). While four males in our study spent the majority of the active season in a single beaver impoundment and had home range sizes < 15 ha, three other males with extremely large home ranges (>100 ha) crossed a large embayment and travelled through a variety of wetlands and wetland complexes (including peatlands) during 2021 and 2022. This variation may also explain why the Manly Selection ratios indicated no habitat classes other than thicket swamp were used disproportionately to their availability for males. Males were highly individualistic with respect to habitat use, which likely contributed to less selection of specific habitat classes in comparison to females.

Use of shallow, open water such as ponds (Ross and Anderson 1990; Rubin et al. 2001), pools (Joyal et al. 2001), and beaver impoundments (Millar and Blouin-Demers

2011; Markle and Chow-Fraser 2014) have been commonly reported in studies of Blanding's turtles across their geographic range. While all males and females used beaver impoundments at some point in this study, females tended to use shallow water along the coastline more often than males. Blanding's turtles have been documented using coastal wetlands in many regions surrounding the Great Lakes (Markle and Chow-Fraser 2014; Markle and Chow-Fraser 2018; Dupuis-Desormeaux et al. 2021); however, use of the littoral zone in the Great Lakes has not been well documented. In our case, this was an important habitat since 8 of the 9 females were found swimming along the coastline as they travelled to their nesting sites during 2022, while only 3 males spent majority of the active season moving along the coastline. Both males and females were found hiding in flooded meadow vegetation (inundated sweet gale), and may have used these for cover, foraging, and finding mates.

Markle and Chow-Fraser (2014) hypothesized that in Georgian bay, successful genetic exchange among metapopulations depend on certain males travelling long-distances to coastal wetlands to find mates. Such behaviour may explain why we observed 3 males spend the majority of the season along coastlines, and further travelling across the deep portion of an embayment and channel (up to 20 m deep) during this study. We could not test this hypothesis in our study since we did not actually observe any mating by these individuals. On a similar note, one of the females nested and then made a similarly long journey across a deep channel after nesting, which may be another method for gene dispersal among metapopulations. We suspect that she originated from the other side of the channel, mated, nested, and then returned to her resident wetland, travelling a minimum of 3.13 km over a season. If this behaviour is widespread, then injuries due to boat collisions may be an additional threat to this metapopulation.

Impacts of recreational boating are recognized as a threat to mostly aquatic freshwater turtle species (Bulté et al. 2010; Bennet and Litzgus 2014; Smith et al. 2018), but little is known about this being a potential threat to Blanding's turtles, a semi-aquatic species. Nevertheless, Bennet and Litzgus (2014) noted that propeller strikes on recreational waterways have injured Blanding's turtles; in addition to injuries due to propeller strikes, boating can indirectly threaten populations when females are run over by cars and boat trailers on the road to the marina or in parking lots where they attempt to nest, or as we noted in this study, on the boat launch.

In this study, thicket swamps were selected disproportionately less than expected based on their availability during the active seasons. Interestingly, thickets provide important habitat for both overwintering and as travel corridors in this site. Since turtles are travelling through thicket swamps, they may spend much less time in this habitat class compared to those where they are foraging, mating, or aestivating. The probability of locating them in thicket swamp may be low because of the reduced amount of time spent in this habitat type. We attached a GPS logger on one female and determined that she travelled ~350 m through a thicket swamp over a 5-h period to access a coastal wetland. We speculate that use of conventional radio tracking may severely underestimate such movement and inadvertently reduced the importance of this habitat class as they are only used temporarily. The thicket swamp may be similar to vernal pools in providing temporary hydration, food, shelter and cover for Blanding's as they make their long overland migrations (Markle and Chow-Fraser 2014). Although not all females had thicket swamps in their home ranges during the nesting season, we noted extensive use of thicket swamps for upland nesting travels by females in the minimally disturbed region of the study area. These habitats remain wet throughout the year, with an abundance of shrub and other vegetation cover that are likely more protective during travel than terrestrial habitats such as rock barrens that have open canopy and limited cover.

Although Markle and Chow-Fraser (2017) found that turtles overwintered exclusively in bogs in eastern Georgian Bay, our Blanding's turtles in this study used four wetland habitat classes including marshes, peatlands, swamps, and shallow water (**Table 1.2**). This is rather unique compared to most other studies, where turtles seemed to have used at most 2 habitat classes. We have not found Blanding's turtles to overwinter in streams and channels although this habitat type appears to have only been used by populations in Wisconsin and Nova Scotia (Ross and Anderson 1990; Newton and Herman 2009). This speaks to the exceptional quality of habitat for Blanding's turtles in this region, where there are hundreds of wetlands and wetland complexes in a relatively low disturbance region of eastern Georgian Bay. We did not have sufficient resources to determine if this population exhibited overwintering site fidelity. It is likely that due to the abundance of high-quality overwintering habitat in eastern Georgian Bay, the Blanding's turtles in our study have many options and do not need to return to the same overwintering spot each year. We were, however, able to confirm communal overwintering, with three individuals overwintering within 10 m of each other during February 2022, and two individuals overwintering in the same location in February 2023.

Review of the literature confirmed similarities in critical habitat use for populations of Blanding's turtles across their geographic range. It is clear, however, that no two

Blanding's turtle subpopulations use habitat in the exact same way. To properly assess habitat requirements and threats of a population to develop effective recovery plans, site-specific habitat studies with appropriate surveying equipment must be carried out each time. We have clearly demonstrated that Blanding's populations have variable behaviours that make it inappropriate to generalize across their geographic range. Until we know the cues used by Blanding's turtles to choose microhabitats, we will need to carry out field studies to identify the critical habitats for each population.

Based on our extensive field surveys, we confirm that the critical habitat for our population of Blanding's turtle include 1) Inland and coastal wetlands that are used for overwintering and during the active season 2) Thicket swamps, beaver impoundments, as well as the littoral zone for travelling between habitats and 3) Rock barrens, as well as loose substrate in active parking lots and roadsides that are used for nesting. Further studies need to be carried out to address specific threats including 1) mortality of adults and hatchlings due to collision with cars, boat trailers and boats in the built-up areas (roadsides, marina, boat launch, docks, parking lots) and 2) boat injuries associated with long-distance travels over recreational boating channels.

The landscape in this study is largely intact except for a two-lane road that serves a community of several hundred residences and cottages, a marina and parking lots. Though the amount of built-up land accounts for only 1.3% of the study area, the human activities associated with this modified land use have a disproportionately large effect on the welfare of this Blanding's population because of the tendency of gravid females to nest along the road, in the parking lot and near the dock. This is the first habitat selection study to occur along the eastern coast of Georgian Bay, and we have found sufficient differences in habitat use between this population and documented populations that we can say without hesitation that more research must be conducted along the coast of Georgian Bay to identify site-specific threats. Without this, we cannot ensure the long-term protection and recovery of Blanding's turtles along this important and geologically unique Great Lakes region.

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Table 1.1: Nesting habitat classes used by Blanding's turtles throughout their geographic range as reported in most published studies. Built-up includes lawns, active roadsides, trails, as well as sand and gravel pits.

				Habitat class				
Region	**Country**	**Location**	**Study**	**Beaches**	**Agricultural Field**	**Built-up**	**Grasslands**	**Rock Barren**
Great Lakes region	Canada	Algonquin Park, Ontario	Edge et al. 2010			X		
		Eastern Georgian Bay	**This study**			**X**		**X**
		Southeastern Georgian Bay	Markle & Chow-Fraser 2014					X
		Brant County, Ontario	Mui et al. 2016		X			
	U.S.	Wisconsin	Ross & Anderson 1990		X	X	X	
		Minnesota	Refsnider & Linck 2012		X	X	X	
North-eastern region	Canada	Nova Scotia	Standing et al. 1999	X		X		
	U.S.	York County, Maine	Beaudry et al. 2010		X	X		X

Table 1.2. Overwintering habitat classes used by Blanding's turtles throughout their geographic range as reported in published studies.

Region	Country	Location	Study	Habitat class: Marshes	Peatlands	Shallow water	Swamps	Streams/ channels
Great Lakes Region	Canada	Algonquin Park, Ontario	Edge et al. 2009		X	X		
		Ottawa, Ontario	Seburn 2010	X			X	
		Eastern Georgian Bay	**This study**	**X**	**X**	**X**	**X**	
		Southeastern Georgian Bay	Markle & Chow-Fraser 2017		X			
		West of Lake Simcoe	Markle & Chow-Fraser 2017				X	
		North shore, Lake Erie	Markle & Chow-Fraser 2017	X		X		
	U.S.	Wisconsin	Ross & Anderson 1990			X		X
		Minnesota	Refsnider & Linck 2012	X		X		
North-eastern Region	Canada	Nova Scotia	Newton & Herman 2009			X		X
	U.S.	Maine	Joyal et al. 2001			X	X	

Table 1.3. Description and total area (as of 2019) of eight habitat classes for Blanding's turtles in this study. Classes were identified and ground-truthed between 2019-2022.

Habitat Class	Description	Area (Ha)
Rock	Rock outcrops that are characteristic of the Canadian Shield.	147.24
Marsh	Either coastal or inland wetlands in which water levels fluctuate seasonally or annually. Dominated by emergent vegetation such as sedges, rushes and tall grasses.	115.96
Peatland	Either Bog or Fen. Dominated by *Sphagnum* mosses and accumulated peat. Main source of water is through precipitation and snowmelt. May contain pitcher plants (*Sarracenia purpurea*) and coniferous trees such as black spruce (*Picea mariana*).	86.08
Forest (Upland)	Terrestrial habitat not associated with water. Predominantly windswept jack pine & white pine forests on exposed bedrock, with lichens, juniper & other low-lying shrubs under the canopy. Some areas with accumulation of soil.	1574.08
Thicket Swamp	Wet forests seasonally inundated, developed in bedrock depressions and abutting beaver dams. Abundant tall shrubs such as alder (*Alnus spp.)* and *Sphagnum* mosses. Stagnant water underlain by thick organic layer.	49.80
Shallow Open Water	Basins, pools, beaver ponds, or shallow littoral areas of Georgian Bay. Shallow water (<2 m) that connect bogs, fens, marshes, and embayments. Vegetation predominantly floating-leaved plants such as water lillies (*Nymphea odorata)* and water shield (*Brasenia schreberi*). May also include flooded trees/shrubs that had been established during period of sustained low water levels more than a decade earlier.	166.04
Lake	Deeper (>2 m) open water in an embayment that is connected to Georgian Bay, with no visible emergent or floating vegetation present.	551.37
Built-up	Cottages, docks, marina, roads, parking lots, and other developed buildings within the study area.	35.05
Entire study area	Not applicable	2725.62

Table 1.4. Home range size, calculated with Minimum Convex Polygons, corresponding to data collected for female (F) and male (M) Blanding's turtles that were tracked in study area for full year. Individuals were tracked in 2019 from July 26th to October 4th, in 2021 from April 25th to October 5th, and in 2022 from May 9th to October 2nd.

Turtle ID	Sex	Year	Home Range Size (ha)
3	M	2021	14.88
4	M	2021	563.30
5	M	2021	2.29
5	M	2022	1.55
7	M	2021	38.03
7	M	2022	167.62
8	M	2021	8.46
8	M	2022	13.48
10	M	2022	6.68
11	M	2022	23.36
13	M	2022	119.41
			$\text{Mean}_{2021,2022}$ = 87.19
			Mean_{2022} = 55.35
6	F	2022	16.24
9	F	2022	36.48
14	F	2022	58.56
15	F	2022	23.64
16	F	2022	22.45
18	F	2022	23.19
19	F	2022	28.20
20	F	2022	103.20
21	F	2022	34.73
22	F	2022	8.08
			$\text{Mean}_{2021,2022}$ = 35.48

Table 1.5. Daily Distance Travelled (DDT) calculated for male (M) and female (F) Blanding's turtles living in the study site during 2021 and 2022. Fieldwork was conducted from April 25th to October 5th in 2021 and from May 9th to October 2nd in 2022.

Turtle ID	Sex	Mean DDT (m)	(±SE)
3	M	32.82	14.83
4	M	54.01	21.17
5	M	9.47	1.84
7	M	95.21	21.59
8	M	53.55	10.60
10	M	11.40	4.42
11	M	85.63	32.09
13	M	91.59	26.07
17	M	9.19	3.02
		Mean = 50.8	
6	F	40.12	16.01
9	F	82.30	22.62
14	F	80.85	15.68
15	F	63.98	16.39
16	F	56.39	32.16
18	F	68.50	22.07
19	F	81.12	34.61
20	F	111.32	47.49
21	F	32.97	22.49
22	F	34.53	10.65
23	F	62.17	37.87
		Mean = 64.93	

Mean for Males and Females = 57.90

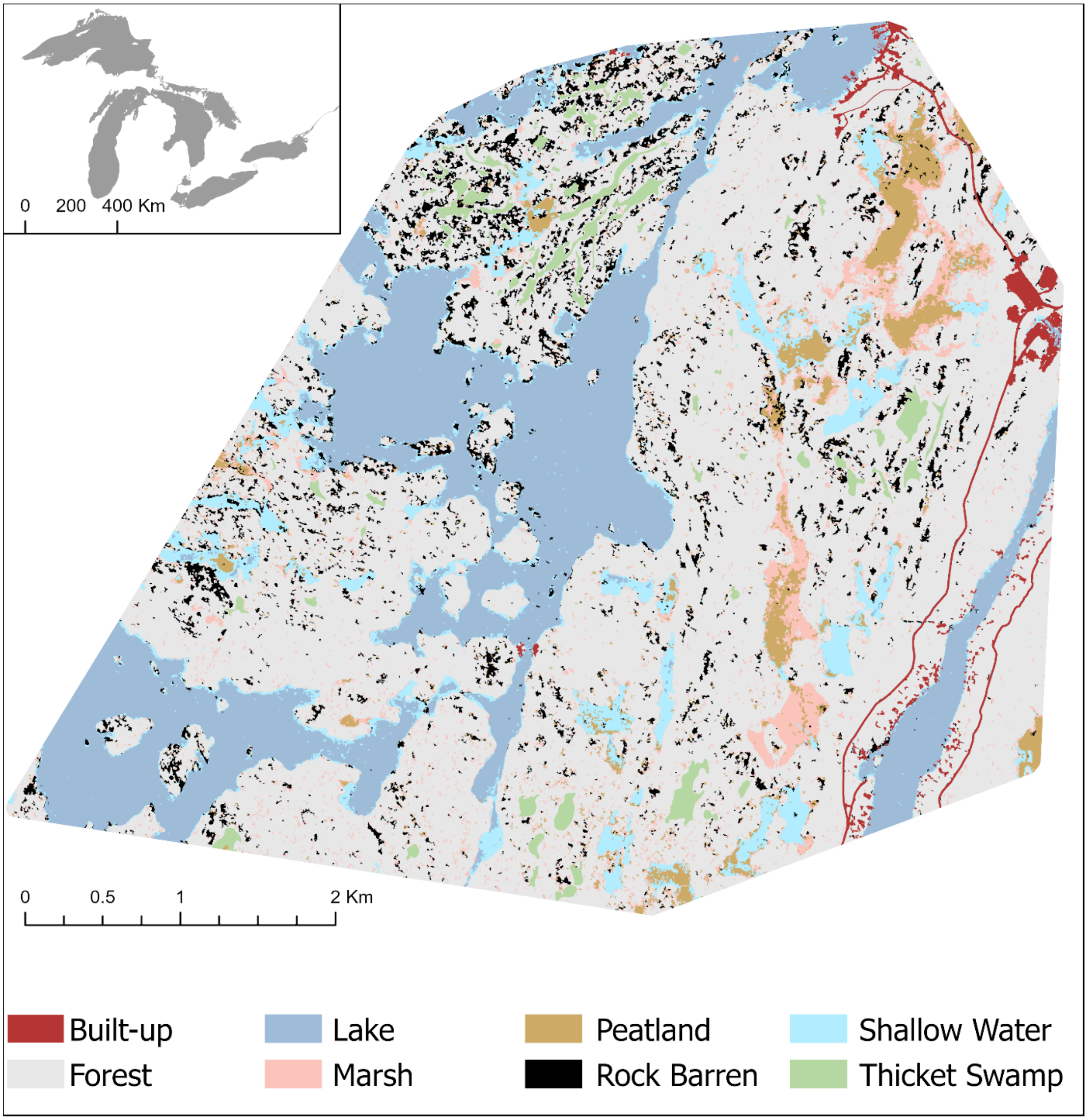

Figure 1.1: Location of population home range in eastern Georgian Bay of Lake Huron. Study site boundary was delineated using minimum convex polygon method with 60m buffer.

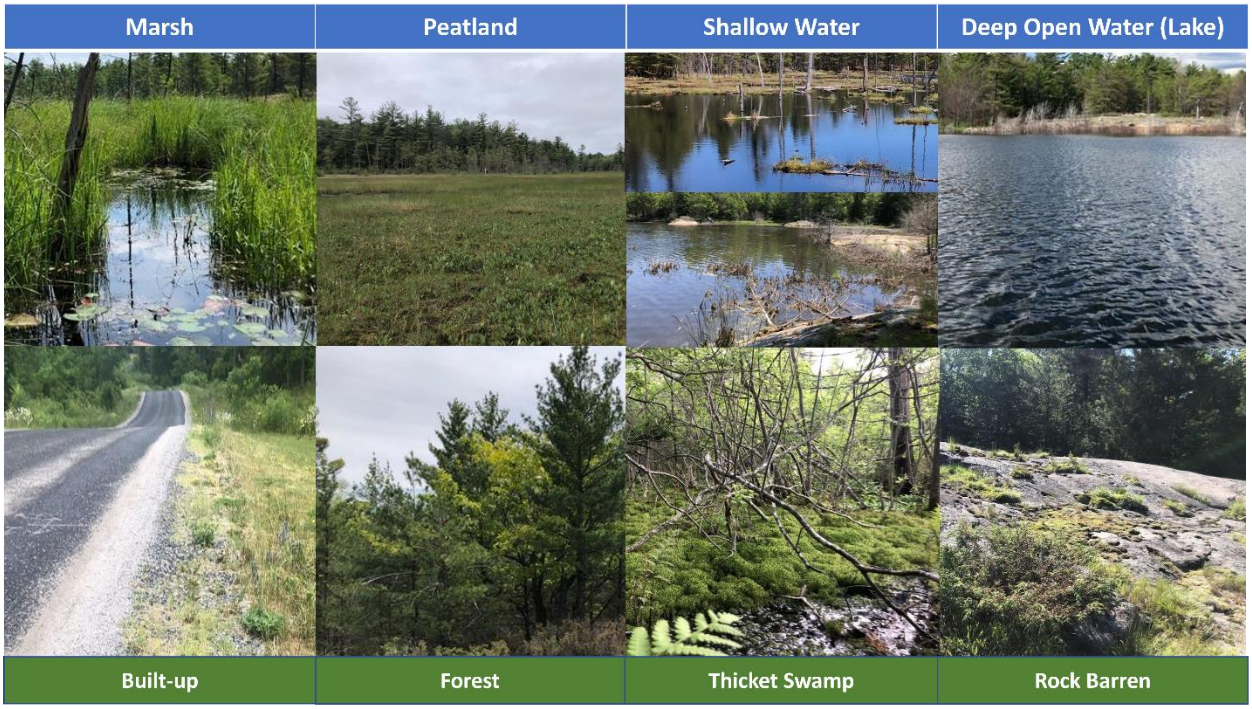

Figure 1.2: Ground-level photographs of the eight habitat classes.

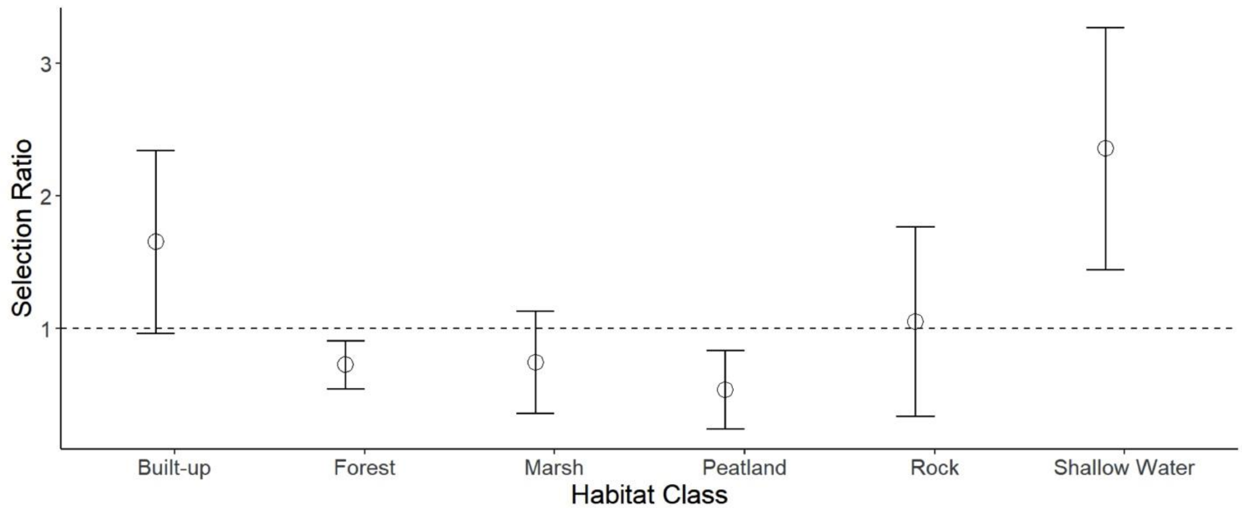

Figure 1.3: Manley's Selection ratio (± 95% confidence intervals) of habitat selection by female Blanding's turtles (n=6) at the third-order scale. Built-up areas in turtle home ranges have been included in calculations of habitat selection.

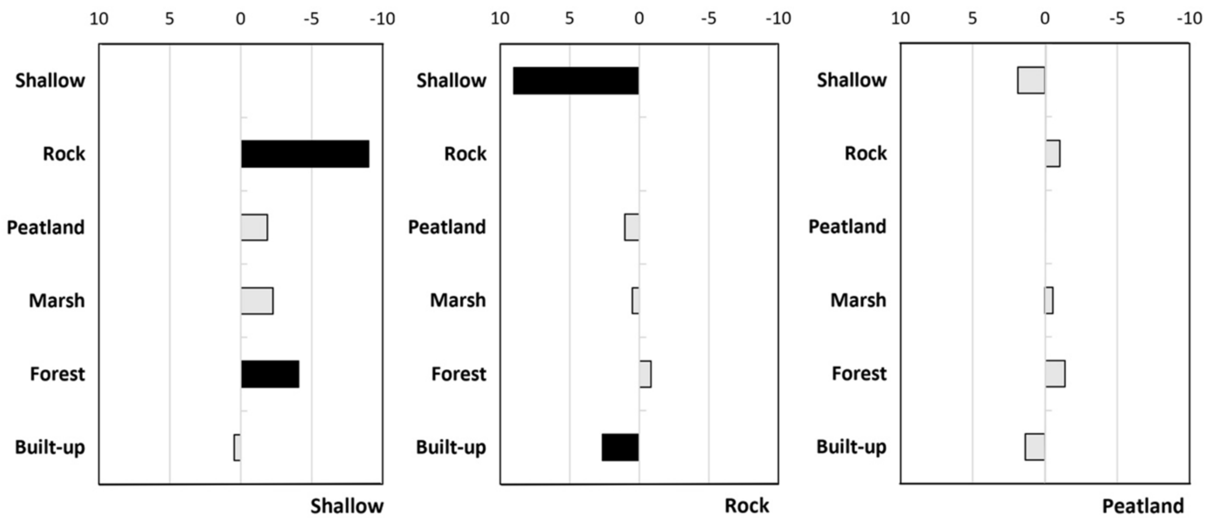

Figure 1.4: Results of compositional analyses for all adult female Blanding's turtles that have built-up areas in their home range during the nesting season (third order scale, N=6). X-axis is the t-statistic corresponding to two-tailed t-tests comparing the habitat class named at the bottom right corner of each panel with the habitat classes listed on the y-axis. A positive t-value indicates selection for the habitat class named on the y-axis, whereas a negative t-value indicates selection for the habitat class named at the bottom right corner. Black bars indicate that the selections are statistically significant ($p < 0.05$) whereas gray bars indicate no significant selection between habitat classes.

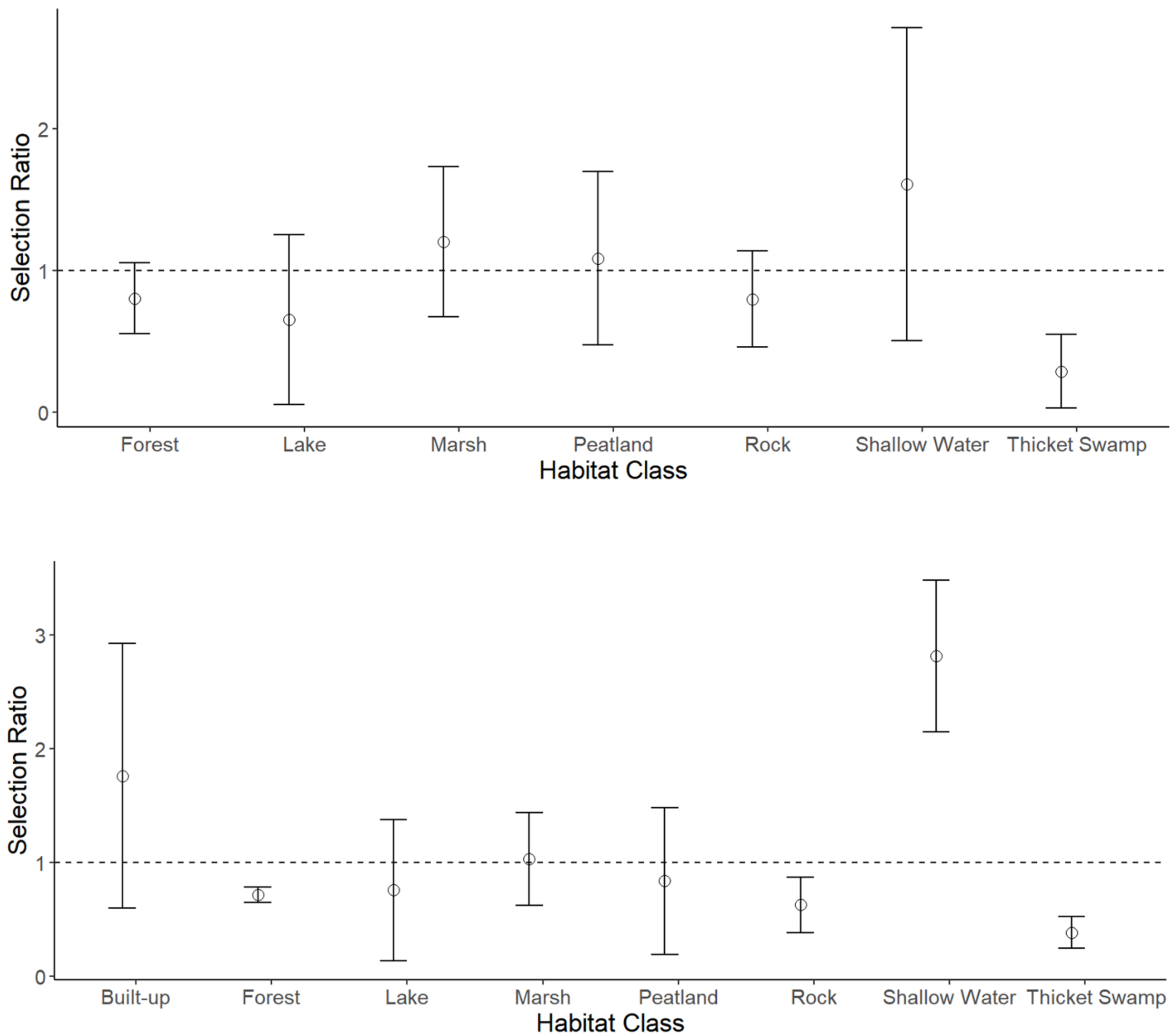

Figure 1.5: Manley's Selection Ratio (± 95% confidence intervals) of habitat selection by a) male (top, n = 10) and b)female (bottom, n =9) Blanding's turtles at the third-order home-range scale.

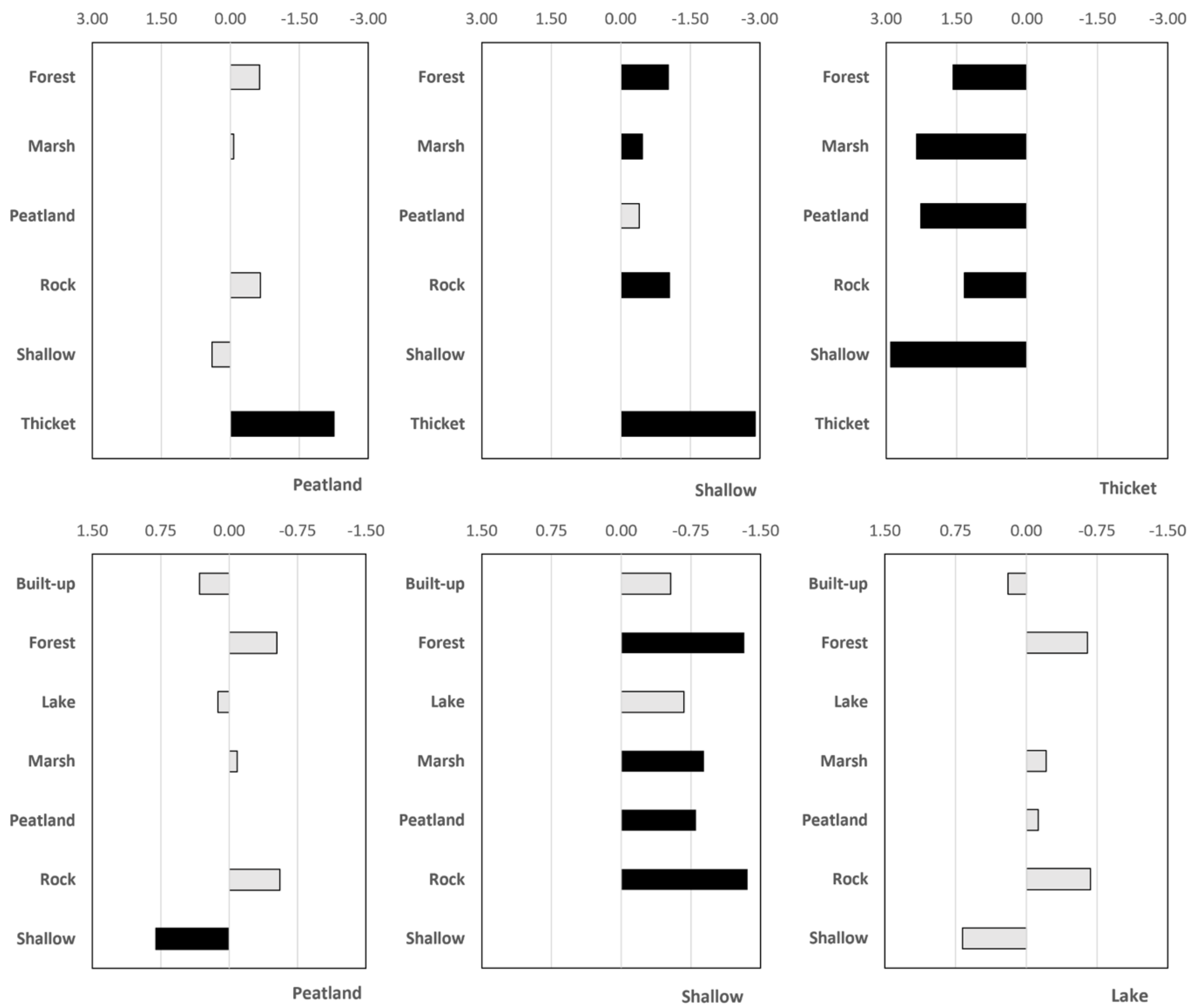

Figure 1.6: Results of compositional analyses for male (n=10, three top panels) and female (n= 9, three bottom panels) Blanding's turtles at the third order home-range scale. Randomisation tests (1000 permutations) were used to determine significant differences in habitat usage between habitat types (black bars indicate statistically significant selection; $p < 0.05$). X-axis represents the mean difference between the used and available log-ratios for each habitat type, and the habitat categories are listed on the y-axis. A positive log-ratio indicates selection for the corresponding habitat category along the y-axis, and a negative log-ratio indicates selection for the habitat category labelled on the bottom right of each panel. Gray bars indicate no significant selection was observed between habitat classes.

Inferred Impacts of Climate Change on Blanding's Turtle Wetland Habitat In A Relatively Undisturbed Landscape Of Eastern Georgian Bay

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Key words: Blanding's turtle; Wetlands; Remote Sensing; OBIA; Object based image analysis; change detection

Abstract:

The relatively undisturbed wetlands in the coastal region of eastern Georgian Bay have been subjected to extreme water-level fluctuations during the first two decades of the 21st century and are expected to trend towards lower-than-average water levels in the future due to climate change. Between 1999 and 2019, water levels fluctuated by over a meter and changed the proportion of aquatic and terrestrial habitats in this region, possibly affecting the many at-risk reptiles that use these wetland complexes. In this study, we used open-source remote-sensing software to classify six habitat types (rock, forest, marsh, peatland, shallow water, deep open water) using 2002 and 2019 high-resolution satellite images with high accuracy (85-94%). We then used a change detection analysis to quantify change in these habitats among wetlands that are sensitive to water-level fluctuations of Georgian Bay (Group A; i.e. lacustrine wetlands) and those that are not (Group B; palustrine wetland complexes). The amount of functional aquatic Blanding's turtle habitat in Group A wetlands was significantly lower (by 20.7%) in 2002 (lower water level year; 176.12m asl) compared with the amount in 2019 (higher water level year; 177.14m asl; $N=82$, $V = 387$, $p < 0.0001$, one-tailed Wilcoxon signed-rank test). By comparison, the amount of Group B habitat did not change significantly between time periods. This difference in habitat availability is an unassessed risk to imperiled reptiles such as the Blanding's turtles that depend on both aquatic and terrestrial habitat to carry out their life processes, and may have implications for future water level predictions in the face of a changing climate. Decreases in functional aquatic habitat during periods of low water levels may limit connectivity between coastal wetlands in the Georgian Bay archipelago and result in periods of inbreeding and reduced genetic diversity among metapopulations.

Introduction:

All 8 species of freshwater turtles in Ontario have been listed federally as being at risk of extinction (Government of Canada, 2018). To recover these declining populations, effective management and implementation of conservation actions require an understanding of critical habitat required by a species for survival, as well as threats to the species and their habitat. For the federally endangered Blanding's turtle (COSEWIC, 2016), understanding their threats and critical habitat are particularly important, as this species is known to use a variety of habitats throughout the year (Ernst and Lovich 2009; Edge et al., 2010; Markle and Chow-Fraser, 2014;). Since their extensive habitat requirements overlaps that of many other at-risk species, Blanding's turtles have been considered an umbrella species (Herman et al., 2003), and by conserving their habitat, we can simultaneously conserve the habitats of many other species (Lambeck, 1997). Most studies on freshwater turtles have focused on threats related to human disturbance such as habitat loss, alteration, degradation, and road mortality (COSEWIC 2016; ECCC 2018; OMECP 2019); few, however, have investigated threats to Blanding's turtles as a result of other human-induced processes such as climate change. This has resulted in the overall threat impact being considered "unknown" for the St. Lawrence Great Lakes population (COSEWIC 2016).

Climate change is expected to alter the hydrological cycle at a global scale, leading to more extreme and variable precipitation patterns, higher frequency of drought, and increases in sea level (Karl & Trenberth, 2003; Trenberth et al., 2003). In the Great Lakes region, climate change is expected to lead to increased rates of precipitation and evaporation, earlier spring melt, and warmer winters with reduced ice cover (Hanrahan et al., 2010; Notaro et al., 2015). These factors in combination with water-level regulations and potential water diversion schemes will have a profound impact on water-level fluctuations in the Great Lakes (Quinn, 2002). Although there are disagreements on exactly how climate change will change the hydrological cycle in this area, most studies predict an overall decline in water levels of all five Great Lakes and greater extremes than previously observed (Mortsch & Quinn, 1996; Magnuson et al., 1997; Angel & Kunkel, 2010; Lofgren and Rouhana 2016). For example, over the past two decades, water levels of Georgian Bay increased by over a meter from record low water levels in the early 2000s to record high levels in 2021 (Montocchio and Chow-Fraser 2021; see **Figure 2.1**). Such changes are expected to have a disproportionate effect on lacustrine wetlands such as coastal marshes compared to palustrine (isolated) wetlands (bogs, beaver impoundments, wetland complexes) in the coastal zone, and may have important implications for wildlife that reside there.

Over 13,200 hectares of wetland complexes can be found along the coast of Georgian Bay, many of which are in relatively pristine condition because of minimal human development (Cvetkovic and Chow-Fraser, 2011). These wetlands provide habitat for six species of at-risk freshwater turtles, including the Blanding's turtle (Litzgus and Brooks 1998; deCatanzaro & Chow-Fraser, 2010; Markle and Chow-Fraser, 2014). Lehman and Chow-Fraser (2023; Chapter 1) showed that wetland features along the Georgian Bay coast are frequently used by Blanding's turtles during the active and nesting seasons, particularly shallow water (<2m depth) in littoral areas, which are used to access resource patches needed for protection, thermoregulation, staging and dispersal.

There is limited understanding of how climate change will influence the quantity of wetland habitat in the Great Lakes region, but the scarce information suggests that there will be reduced coastal wetland habitat available for Blanding's turtles in Lake Erie and Huron (COSEWIC 2016). Given the relatively abundant and diverse array of at-risk turtles that currently exist along the shores of Georgian Bay, including the 30,000+ islands of the Georgian Bay archipelago, there is some urgency to investigate how wetland habitat have already changed in response to the most recent episode of water-level extremes since this information is needed for land managers to formulate recommendations for future water-level management.

A cost effective approach to calculate habitat changes is to use Remote sensing (RS) combined with geographic information systems (GIS) to classify relevant habitat classes with high-resolution satellite images (Midwood & Chow-Fraser, 2010; Rupasinghe and Chow-Fraser 2021), and then conduct a change detection analysis to quantify changes between periods (Bartlett & Klemas, 1980; Silva et al., 2008;; Midwood & Chow-Fraser, 2012). This approach has been previously used to investigate temporal changes in coastal wetlands (Leahy et al., 2005; Baker et al., 2007) and fish habitat in coastal marshes of Georgian Bay during sustained low water levels (Midwood & Chow-Fraser 2012). Remotely sensed imagery has also been used to map Blanding's turtle habitat in many regions of Ontario (Barker & King, 2012; Mui et al. 2017; Markle et al, 2016), but no study has yet mapped BLTU habitat and determined changes in regions of eastern Georgian Bay that have close to reference conditions.

The overall goal in this study is to quantify proportional changes in BLTU wetland habitat in an undisturbed region of eastern Georgian Bay between 2002 and 2019, when water levels were among the lowest and highest, respectively. We classified high-resolution satellite imagery of the study site acquired in 2002 and 2019 and then conducted a change detection analysis between these time periods. This is the first study to investigate changes in freshwater turtle habitat under minimal human impact, and any changes measured in this landscape could be used to interpret the potential impacts of climate change on a reference site.

Methods:

Study site

Our study site is located on the eastern coast of Georgian Bay, Lake Huron. This 36.83 km^2 region contains hundreds of wetlands, both coastal and palustrine, that are home to a diverse community of 6 species at risk freshwater turtles, including the Blanding's turtle. While most natural areas have undergone some level of disturbance or human alteration, we consider this study site to be relatively undisturbed, as only 1.3% of the area has been moderately developed or altered over the past century (Lehman & chow-Fraser 2023; Chapter 1). Furthermore, majority of land in this study site (over 6000 acres) is owned by a private club that has kept it as a fish and wildlife sanctuary since the early 1900s.

Imagery preprocessing

To accurately represent the phenology of live vegetation in turtle habitat during the active summer season, as well as to classify habitat at two different water levels, we used image data acquired from IKONOS (lower water level; 3 scenes; July 3, 2002) and Pleiades-1B (higher water level; 2 scenes; June 27, 2019) sensors over the study site (**Table 2.1**).

Image data captured from both IKONOS (1.0m pansharpened) and Pleiades (0.5m pansharpened) sensors have high spatial resolution, and each scene from the respective sensor was captured free of cloud cover. The use of two different sensors was not ideal, but we had no choice because the IKONOS satellite was decommissioned in 2015, and Pleiades-1B was launched in 2012. This is a common problem in RS research (Mui et al. 2015), particularly when there is a time gap of almost two decades between satellite acquisitions. We pre-processed the images using ENVI 5.6.0 (Harris Geospatial), applying radiometric and atmospheric corrections to each scene. We stitched together these scenes and georeferenced them using a 1st-order polynomial transformation with a root mean squared error of less than 2 pixels. The image data were projected to Universal Transverse Mercator projection datum (NAD83, UTM Zone 17), and we used the nearest neighbor method to resample the image data to minimize processing time. To account for possible differences in spatial resolution between the two sensors, we pansharpened the image data from both sensors and resampled the Pleiades-1B data from 0.50m resolution to 1m resolution to match that of IKONOS.

To increase the relevance of our results to Blanding's turtles residing in this region, we restricted the habitat mapping to the population range we surveyed in Lehman and Chow-Fraser (2023; Chapter 1). We used the minimum convex polygon method (Mohr 1947) to delineate the land around all known Blanding's turtle relocations and observations between 2019 and 2022. The polygon was further buffered by 500 m to include all wetlands that may be connected based on each occurrence, and we considered all land cover within this range to be available habitat to the Blanding's turtle population. We applied a 500-m buffer rather than the 2-km buffer recommended by the provincial and federal government (ECCC, 2018; MECP, 2019) because we wanted to restrict our analysis to areas that we were certain Blanding's turtles used and because using the 2-km buffer would produce an image that would require unacceptably long processing times. We also manually excluded the few developed areas within our study site from the classification process by using a 5-m buffer around the Ontario Roads Network shapefile (OMNRF, 2018) and manual delineation.

Data layers

We used a 5-layer stack of image data for image classification, comprising of 4 pansharpened multispectral layers (blue (B), green (G), red (R), and near infrared (NIR)) and a Normalized Difference Vegetation Index (NDVI) layer, calculated with NIR and R bands. The NDVI is a well-established method for discriminating living green vegetation from other classes (Rouse et al. 1974) and is useful for distinguishing between open water and dry land as well as in delineating wetland boundaries (Ozesmi and Bauer, 2002; Mui et al. 2015). We did not use additional data layers such as elevation or texture (Mui et al. 2015; De Luca et al. 2019) because inclusion of extra data layers would have been impractical to process for such a large study site (i.e. 1-m resolution image data). There were no accurate elevation data with similar resolution that would have facilitated segmentation of objects differing in height, such as between upland vs wetland habitats (Mitsch and Gosselink, 2000). Additionally, since our study area was relatively undeveloped, we decided not to use a texture layer, as they have previously been beneficial for differentiating wetlands from built-up areas in remotely sensed imagery (Mui et al. 2015).

Image Classification Software

We employed OrfeoToolbox (OTB), an open-source software library for remote sensing, to classify Blanding's turtle habitat in our study site. Developed by CNES in France (www.orfeo-toolbox.org, Cresson et al., 2018), OTB offers a range of powerful remote sensing tools ranging from image preprocessing and classification to accuracy assessment. Specifically, we used the OTB 8.1.1 plugin for QGIS software 3.22 Biatowieza (www.qgis.org; QGIS Project, 2022) for our image classification (see workflow in **Figure 2.2**). Previous studies have used object-based image analysis (OBIA) to map Blanding's turtle habitat (Barker & King, 2012; Mui et al., 2015; Markle & Chow-Fraser 2016), however they often use proprietary software such as ArcGIS Pro (ESRI) and eCognition (Definiens, Munich, Germany). We chose to use OTB and QGIS because they are both open-source software, making our methods and results accessible to everyone.

Image segmentation

Image segmentation is a critical component of OBIA, as it is the first step in which pixels are grouped together into image objects based on their spectral properties (Baatz et al., 2008). We used the LargeScaleMeanShift (LSMS) segmentation algorithm in OTB to segment the image using each of the 5 data layers (R, G, B, NIR, & NDVI). This algorithm was created by Fukunaga and Hostetler (1975) and is a non-parametric and iterative clustering method that is great for segmenting large high-resolution images by using a tile-wise process (De Luca et al., 2019). In OTB, the output creates a vector that is free of artifacts, and each polygon in the output corresponds to a segmented image based on the variance and mean of each input data layer (De Luca et al., 2019; OTB Development Team

2022). We chose this method over other segmentation algorithms, as LSMS was specifically designed for large-sized image data with high spatial resolution, enabling optimal use of both the processors and memory (Michel et al., 2016; De Luca et al., 2019).

The LSMS segmentation algorithm in OTB makes use of a variety of parameters to control the size and shape of segmented image objects created (OTB Development Team 2022). Since there was no indication of the ideal parameters to use for our habitats of interest, we experimented with various combinations and determined that a vector representative of all desired habitat classes could be obtained if we used a spatial radius of 5, range radius of 3, and minimum region size of 50 while keeping default values for all other parameters.

Sample selection and ground-truthing

Our final classification made use of the Canadian wetland classification system (Warner and Rubec, 1999), as well as other general habitat classes observed in previous studies with freshwater turtle habitat (Edge et al., 2010; Markle & Chow-Fraser 2014). Specifically, we classified our study area into 6 habitat types that are characteristic of the Georgian bay archipelago: rock outcroppings, marshes, peatlands, forests, deep open water (open water >2m deep), and shallow water (open water <2m deep) (**Table 2.2**). Some classes, such as peatlands and shallow water were broad categories consisting of multiple classes grouped together in this study. Bog and fen complexes were common in this study site and were difficult to differentiate, so they were therefore classified as a more general group, “peatlands”. Similarly, shallow water consisted of two specific habitats, being the littoral zone along Georgian Bay coastlines, as well as inland ponds, pools, and beaver impoundments. These two habitats were grouped together, as they both consisted of shallow open water <2m deep that Blanding's could use.

We selected training sample objects for classification through in-field ground-truthing conducted from 2019 to 2022, supplemented with habitat information extracted visually from 2018 spring orthoimagery (SCOOP,16cm resolution; Ontario Ministry of Natural Resources and Forestry) in under-sampled portions of our study area. A minimum of 100 ground-reference points for each of the six habitat classes was used as training sample objects for classification. Although reference data were arbitrarily selected since the majority were collected during fieldwork, we ensured that training samples for the six habitat classes were evenly distributed throughout the images. However, it should be noted that there might be differences in land cover classification between the 2002 and 2019-2022 imagery. To account for these potential differences, we compared training samples visually between segmented images from both years and slightly adjusted the training samples for the 2002 image when necessary to represent the correct land class.

Classification and accuracy assessment

Using these training data, we classified our study site in both years with the Support Vector Machine (SVM) algorithm using the TrainVectorClassifier tool in OTB. SVM is a non-parametric supervised classification algorithm (Cortes & Vapnik 1995; Vapnik 1998) with relatively new applications for image classification and remote sensing (Moutrakis & Ogole 2011). Often efficient and relatively accurate, SVM has been used in multiple studies for remote sensing of various land classes (Pal & Mather 2005; Sanchez-Hernandez et al., 2007; Moutrakis & Ogole 2011; Adam et al., 2014; Hawryło et al., 2018). Because previous studies have suggested that default parameters for classification in OTB often generate the best results (Immtzer et al. 2016; Trisasongko et al. 2017), a similar approach to De Luca et al. (2019) was used for SVM classification in OTB, with a linear kernel-type as well as a model-type with a C value of 1.

Following similar methods of Mui et al. (2015), we assessed the accuracy of our habitat classification by using a minimum of 45 independently selected samples from the ground reference data and aerial imagery, and we ensured that objects used for training and accuracy assessment did not overlap. We used the ComputeConfusionMatrix tool in OTB to generate an error matrix to calculate statistics such as overall accuracy, the kappa statistic, and producer's and user's accuracy.

In remote sensing, the overall accuracy is a metric that tells us the total percentage of correctly classified pixels across all landcover classes (Congalton, 1991) and the Kappa statistic that tells us the level of agreement between the actual and predicted classification results (Cohen, 1960). 100% overall accuracy means that all pixels for all landcover classes have been correctly classified, whereas a Kappa of 1 is perfect agreement between the actual and predicted classification. It is also important to report producer's (1 – error of omission) and user's (1 - error of commission) accuracies for each individual land cover class, which offer insights into the occurrence of false negatives and false positives (Congalton, 1991). Specifically, producer's accuracy refers to the proportion of actual positive samples correctly identified as positive by the classifier for a given land cover class, while user's accuracy represents the proportion of predicted positive samples correctly identified by the classifier for a specific land cover class (Congalton, 1991). Considering all of these statistics together provides a more comprehensive assessment of the classification results, and further helps to identify which classes have the highest and lowest accuracies so that error may be accounted for when conducting a change detection.

Wetland Habitat and Change Detection

Determining changes in wetland habitat can be challenging due to the lack of a clear definition of what constitutes as a wetland and how their boundary is delineated. To address this issue, we used the McMaster Coastal Wetland Inventory (MCWI; Midwood et al., 2012) to define the wetland boundaries in our study area and created a modified shapefile to be used as a mask in our change-detection analyses. The MCWI is an accurate record of all major wetland complexes along the coast of Georgian Bay that are greater than 2 hectares and that were manually delineated with IKONOS imagery from 2002 to 2010 with a standardized protocol (Midwood et al. 2012). As only wetlands greater than 2 ha were recorded within the study area, we used 2018 SCOOP orthoimagery and satellite imagery to manually delineate any visible wetlands smaller than 2 ha that had not been included in the MCWI; however, forested wetlands such as thicket swamps that were not clearly visible were omitted because their boundaries could not be accurately delineated. We then used the modified shapefile as a mask and computed a change detection matrix across all wetlands in the study site for both years using the land cover change tool in the Semi-Automatic Classification plugin (SCP) for QGIS (Table 4). SCP is a free and open-source plugin for QGIS that offers a set of tools for classifying and processing remotely sensed imagery and classified data through an easily accessible interface (Congedo 2021).

While all wetlands in this study are within 2km of the shoreline and are therefore considered to be coastal under the Ontario Wetland Evaluation System (OMNR 1993), not all wetlands may be influenced by changes in water levels. We anticipated that habitat types in the boundaries of palustrine wetlands such as peatlands, beaver-impoundments, and complexes would not likely be affected by water-level fluctuations of Georgian Bay because of where they are situated in the landscape, whereas those that are lacustrine would be affected by water-level fluctuations (Warner and Rubec, 1997). Therefore, we wanted to analyze changes in habitat classes separately for wetlands that would be affected by Georgian Bay water levels (Group A) and those that would not (Group B) (**Figure 2.3**). We visually confirmed wetlands in each group using ground-reference data collected from the field, satellite and orthoimagery, and other information such as their topographic position and evidence of hydrological connection to Georgian Bay.

To assess changes in wetland habitat between the two years, we calculated the proportional area of each habitat type within the boundaries of each group A and B wetland. Proportional area was determined by summing the total area (m^2) of each habitat type within a wetland and dividing it by the total area of the wetland (m^2). Besides examining changes in individual habitat types within wetland boundaries, we also calculated the amount of “functional aquatic habitat” for Blanding’s turtles by combining the area occupied by marsh, shallow water, peatland, and deep open water habitat classes within each wetland. This composite class represents the potential area of aquatic features that make up BLTU habitat requirements, such as those used for mating, foraging, thermoregulation, staging, dispersal, and overwintering.

Results:

The error matrix statistics for each of the six habitat classes in the study site were calculated (**Table 2.3**), and the overall classification accuracy across the entire study site was high (>85%) for both years (**Figure 2.4**). The accuracy for the 2019 image data of 94.8% (0.90 Kappa) was higher than that of 85.6% for 2002 (0.83 Kappa). Producer's and User's accuracies were both high (>80%) for most habitat types during both years, and deep open water had the highest accuracies, followed by rock, and shallow water. Marsh had the lowest Producer's and User's accuracies for both years (ranging from 65.7 to 80.8%). Interestingly, while Producer's accuracies for forest habitats were very high in both 2002 and 2019 (91.5% and 96.4% respectively), corresponding User's accuracies seemed to be lower (73.2% and 69.9% respectively). This indicates that commission errors were higher for forest than omission errors. Marsh and forest had the highest confusion across both images, as classification results often contained small patches of misclassified marshes in the shadows of forests across the study site (**Figure 2.4**).

Change Detection

Our classified map contains a total of 144 lacustrine and palustrine wetlands, comprised of coastal marshes, beaver impoundments, peatlands, and upland wetland complexes (**Figure 2.4**). A change detection matrix (**Table 2.4**) across all wetlands indicated there were areal increases in shallow water, deep open water and marsh habitats from 2002 to 2019, whereas forest, peatland, and rock habitats decreased. Rock experienced the largest decrease in area, with a reduction of 12.67 ha (60.72%) across all wetlands. The area of shallow water, marsh, and deep open water habitats increased by

12.93 ha (9.79%), 6.71 ha (9.78%), and 3.06 ha (9.14%) respectively, while the area of peatlands decreased by 9.52 ha (7.90%). Forest experienced the smallest change in area of all habitats, decreasing by only 0.51 ha (0.88%) from 2002 to 2019.

Of the 144 wetlands in the study site, 82 were classified into Group A (lacustrine; affected by water levels) and 62 into Group B (palustrine; not affected by water levels) (**Figure 2.3**). For group A wetlands, mean proportional area of deep open water, forest, and shallow water increased between years while marsh, peatland, and rock decreased (**Figure 2.6**). For Group A wetlands, the proportion of rock decreased on average by 29.3% while marsh decreased by 2.6%. By contrast, shallow water increased by 19.7%, deep open water by 9.6%, and forest by 6.8%. It should be noted that peatlands exhibited a notable decrease in mean proportional area as well (4.1%), decreasing proportionally from a value of 0.042 in 2002 to 0.002 in 2019. For group B wetlands, there were no noticeable changes between years. Deep open water exhibited the largest change with a 1.2% decrease between years. Peatlands increased by 0.96%, forest by 0.76%, and marsh by 0.20%, while shallow water decreased by 0.47% and rock by 0.24%.

The proportion of functional aquatic habitat for Blanding's turtles in Group A wetlands was significantly lower in 2002 compared with that in 2019 ($N=82$, $V = 387$, $p < 0.0001$, one-tailed Wilcoxon test) (**Figure 2.6**). This difference was on average 20.7% lower among wetlands in 2002 (lower water level; median = 0.487, mean = 0.505, SE = 0.036) compared with those in 2019 (higher water level; median = 0.769, mean = 0.712, SE = 0.025). For Group B wetlands, however, we found no significant changes in the proportion of functional aquatic habitat among wetlands between years.

Discussion:

This is one of the first studies to use remote sensing to analyze changes in freshwater turtle habitat over time under relatively undisturbed conditions. Classification results demonstrated an overall accuracy of over 85% for both 2002 IKONOS and 2019 Pleiades scenes using OrfeoToolbox 8.0.0, indicating that an open-source approach can be effective for classifying freshwater turtle habitats with high accuracy. These results are similar to those of Mui et al. (2015), who achieved overall accuracies ranging from 81%-90% for wetlands across 3 different study sites.

Our classification scheme occasionally misclassified shadows in forested areas as patches of marshes, but this was not a problem for other habitat classes. This is likely why the producer's accuracies of forest were high (91.5% and 96.4%), but the user's accuracies were not (73.2% and 69.9%). Furthermore, this confusion of forest with marsh also likely explains why marsh had the lowest accuracies compared to other habitat classes. Another explanation for this may be because marshes included a variety of emergent vegetation that had spectral characteristics that were often confused with other habitat types. The emergent vegetation present in our study included cattails (*Typha spp*.), bulrushes (*Scirpus spp*.), sedges (*Carex spp*.), and other grasses, which had similar spectral properties to peatlands (sphagnum mosses and grasses), rock barrens (juniper and lichen), and forests (trees and shrubs). It would be difficult to resolve such confusion without high-resolution digital elevation data, which were unavailable for this study.

One trade-off with using proprietary remote sensing software over an open-source approach is that more specialized tools and algorithms may be available for users to improve classification. For example, the multi-resolution segmentation algorithm in eCognition (Munich, Germany) can be used to segment images at multiple scales and levels, allowing for certain features to be classified at a coarse scale (such as wetlands), and smaller features to be classified within those features (such as habitat types). Mui et al, (2015) used this approach and were able to receive high producer's and user's accuracies for marsh classes, ranging between 81%-94%. OrfeoToolbox does not currently have any algorithms that includes this functionality, and therefore, we had to carry out our classification at a single fine scale across the entire study site. While this could lead to higher error when examining changes in upland habitat such as forests, we do not believe this would have a large impact on our results, since we focused on changes in wetlands.

Results of the change detection analysis indicated that the functional aquatic habitat in Group A wetlands during 2002, when mean water level was only 176.12 m above sea level (asl), was 21% lower than that in 2019, when mean water level was 177.14 m asl. These are similar results to Fracz and Chow-Fraser (2013), as they found an average loss of 24% in fish habitat among lacustrine wetlands in Georgian Bay when water levels dropped from 177.5 m asl to ~176 m asl. They also estimated that over 50% of all coastal wetlands were at risk of becoming hydrologically disconnected from Georgian Bay if water levels drop to 174 m asl. While this clearly has implications for a decrease in the aquatic connectivity of fish habitat, declines in water levels this extreme may also have implications for the connectivity of functional aquatic habitat for Blanding's turtle and should be investigated further.

Our definition of functional aquatic habitats for Blanding's turtles included areas occupied by marshes, peatlands, shallow water habitats, and deep open water. In group A wetlands, this area provides habitat for Blanding's turtles to access other resource patches for staging and dispersal, as well as for thermoregulation and cover (Lehman and Chow-Fraser 2023; Chapter 1). These wetlands are likely also used by BLTU for foraging and mating, and future studies should be conducted to confirm this. We have observed an abundance of fish in these coastal wetland habitats during field surveys, and these are likely an important food source for the turtles (Lehman and Chow-Fraser, unpublished data). We have also observed Blanding's turtles using shallow water and deep open water for dispersal and travel along the coast of Georgian Bay (Lehman and Chow-Fraser 2023; Chapter 1) and it is likely that they are also using these as travel corridors in search of mates.

During periods of lower water levels, the decline in functional aquatic habitat for Blanding's turtles – in particular, declines in shallow littoral habitats, deep open water, and the increase of rocky habitats - may limit connectivity between coastal wetlands in the Georgian Bay archipelago. While rocky habitats may offer more basking options, decreased connectivity between one coastal wetland and another may make it harder for Blanding's turtles to access other habitat patches that could be vital for carrying out many lifecycle processes. Since coastal marshes will likely experience more extreme and sustained low-water periods such as those observed during the early 2000s (Canadian Hydrographic Services 2023), loss of functional habitats and connectivity may have implications for dispersal and could result in periods of inbreeding and reduced genetic diversity among metapopulations. Since the Blanding's turtle is an umbrella species (Herman et al., 2003), implications of declining water levels may be applied to other at-risk turtles that have been previously found in Group A wetlands in this region. Multiple observations have been made for the northern map turtle, common snapping turtle, midland painted turtle, eastern musk turtle, and the spotted turtle (Lehman and Chow-Fraser, unpublished data), however there is likely variation in habitat use among each species, and future studies should investigate how a reduction in functional aquatic habitat might impact each on an individual level.

Overall, we found that significant changes occurred to the functional aquatic habitat of Blanding's turtles in coastal wetlands of a largely undisturbed region of eastern Georgian Bay that were likely related to changes in water levels by ~1m. This highlights an unassessed risk to the Blanding's turtle and other herpetofauna that should be further investigated, as climate change may exacerbate these risks. Continued monitoring and research efforts are needed to further understand potential threats of declining water levels to these species in the Georgian Bay archipelago. We recommend that future research efforts focus on (1) studying Blanding's turtles during periods of lower water levels to understand habitat use and selection patterns, (2) investigating the use of coastal wetland habitat by all freshwater turtle species, and determining what habitats are used to carry out various biological requirements, and (3) conducting climate change vulnerability assessments for freshwater turtles across eastern Georgian Bay so that the level of risk can be understood, and potential management strategies can be developed.

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Table 2.1: 2002 and 2019 satellite image data information.

Year	**2002 Imagery**	**2019 Imagery**
Acquisition Date	03 Jul 2002	27 Jun 2019
Sensor	IKONOS	Pleiades 1B
Spatial Resolution (m)	4.0 m multispectral (1.0 pansharpened)	2.0 m multispectral (0.5 pansharpened)
Spectral Resolution (μm)	Blue (0.40 - 0.52) Green (0.52 - 0.60) Red (0.63 - 0.69) Near Infrared (0.76 - 0.90) Panchromatic (0.45 - 0.90)	Blue (0.43 - 0.55) Green (0.49 - 0.62) Red (0.60 - 0.720) Near Infrared (0.75 - 0.95) Panchromatic (0.48 - 0.83)
Radiometric Resolution	11 bits	12 bits
Number of Scenes	3 scenes	2 scenes
Commissioned	Geoeye, Dulles, VA, USA	Airbus Defense and Space, Toulouse, France

Table 2.2. Description of eight habitat classes that were classified in study site during 2002 and 2019. Habitat classes were adapted from both Anderson et al. (1976) and the Canadian wetland classification system (National Wetlands Working Group, 1997).

Habitat Class	Description
Rock	Rock outcrops that are characteristic of the Canadian Shield.
Marsh	Emergent vegetation such as sedges, rushes and tall grasses. Often influenced by seasonal or annual water levels fluctuations.
Peatland	Either Bog or Fen. Dominated by *Sphagnum* mosses and accumulated peat. Main source of water is through precipitation and snowmelt. May contain pitcher plants (*Sarracenia purpurea*) and coniferous trees such as black spruce (*Picea mariana*).
Forest	Terrestrial habitat not associated with water. Predominantly windswept jack pine & white pine forests on exposed bedrock, with lichens, juniper & other low-lying shrubs under the canopy. Some areas with accumulation of soil.
Shallow Water	Shallow water habitats (<2 m) within wetland complexes that connect bogs, fens, marshes, and lake. There are two broad categories: 1) within palustrine wetlands, they consist of basins, pools, and beaver ponds and 2) along the coastal zone, they consist of shallow open water characteristic of the littoral zone along "coastal marshes". Within palustrine wetlands, vegetation predominantly consists of floating-leaved plants such as water lillies (*Nymphea odorata)* and water shield (*Brasenia schreberi*). Along the coast they are predominantly open but may include flooded trees/shrubs during high water levels.
Deep Open water	Also called "Lake". Deeper (>2 m) open water that is connected to Georgian Bay, with no visible emergent or floating vegetation present.

Table 2.3: Habitat class accuracies for 2002 IKONOS and 2019 PLEIADES satellite image data using Support Vector Machine Algorithm in OrfeoToolbox.

Habitat Class	2002 Accuracy (%)		2019 Accuracy (%)	
	Producer's	User's	Producer's	User's
Shallow Water	89.50	85.88	88.42	90.02
Forest	91.50	73.22	96.40	69.90
Peatland	73.90	87.41	87.62	94.30
Deep Open Water	97.13	96.63	98.06	99.85
Rock	90.57	89.09	100.00	93.50
Marsh	67.65	80.80	65.74	66.37
Overall Accuracy	**85.62**		**94.77**	
Kappa	**0.827**		**0.895**	

Table 2.4: Matrix of change detection indicating amount and type of habitat classes that have changed within wetlands between 2002 and 2019 (in hectares). SW = shallow water, DOW = deep open water.

		2019 Classification						
	Area (Ha)	**SW**	**Forest**	**Peatland**	**DOW**	**Rock**	**Marsh**	**Total**
2002 Classification	**SW**	92.58	7.57	10.84	11.38	2.21	7.56	132.15
	Forest	8.18	29.40	6.96	0.14	0.76	12.49	57.92
	Peatland	17.59	6.93	70.36	0.49	1.50	23.57	120.45
	DOW	10.56	0.08	0.04	22.49	0.17	0.11	33.45
	Rock	8.59	2.82	3.09	1.28	2.97	2.12	20.87
	Marsh	7.59	10.60	19.64	0.73	0.59	29.50	68.63
	Total	145.09	57.41	110.93	36.51	8.20	75.34	433.48
	Change (Area)	12.93	-0.51	-9.52	3.06	-12.67	6.71	
	Change (%)	9.79	-0.88	-7.90	9.14	-60.72	9.78	

Table 2.5: List of functional aquatic habitats for Blanding's turtles in study site and their confirmed and unconfirmed use for various activities. Bold 'X' represents an activity that has been confirmed to occur through fieldwork observations, and '?' represents an unknown or unconfirmed activity that requires future fieldwork validation in that habitat type.

	Functional Aquatic Habitat					
	Shallow Water		Marsh		Deep Open Water	Peatland
Wetland Group	Coastal (A)	Inland (B)	Coastal (A)	Inland (B)	Coastal (A)	Inland (B)
Overwintering Season Use	?	**X**	?	**X**	?	**X**
Nesting Season Use	**X**	**X**	**X**	**X**	**X**	**X**
Active season Use	**X**	**X**	**X**	**X**	**X**	**X**
Travel/Dispersal	**X**	**X**	?	?	**X**	?
Refuge/cover	**X**	**X**	**X**	**X**	?	**X**
Thermoregulation	**X**	**X**	**X**	?	?	**X**
Foraging	?	?	?	?	?	?
Mating	?	?	?	?	?	?

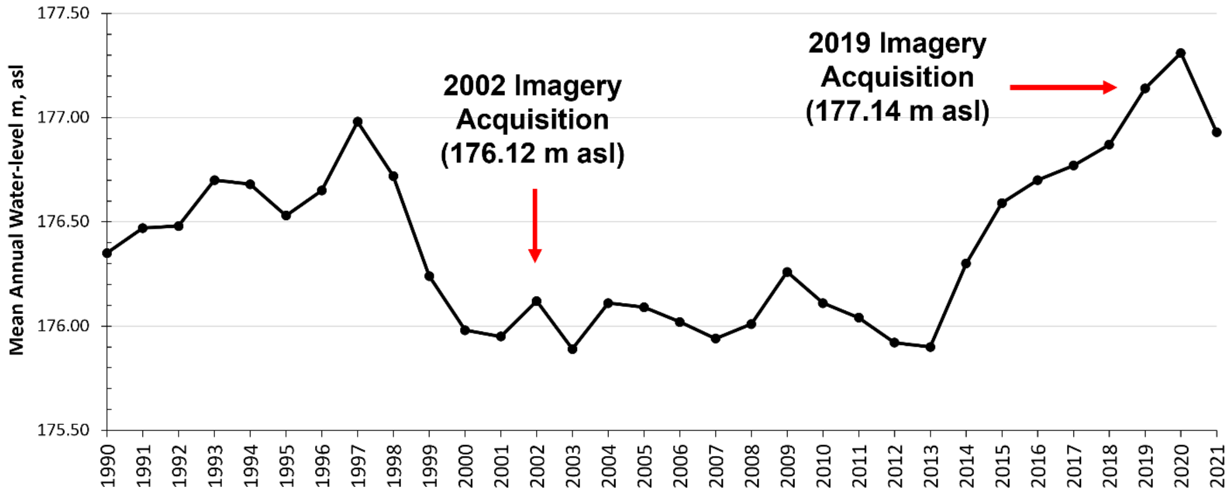

Figure 2.1: Change in mean annual water levels of Lake Huron from 1990 to 2020 (data from Canadian Hydrographic Services, Department of Fisheries and Oceans). 2002 represents the year that IKONOS imagery was acquired (lower water level; 176.12m asl), and 2019 was the year that Pleaides 1B imagery was acquired (higher water level; 177.14 m asl).

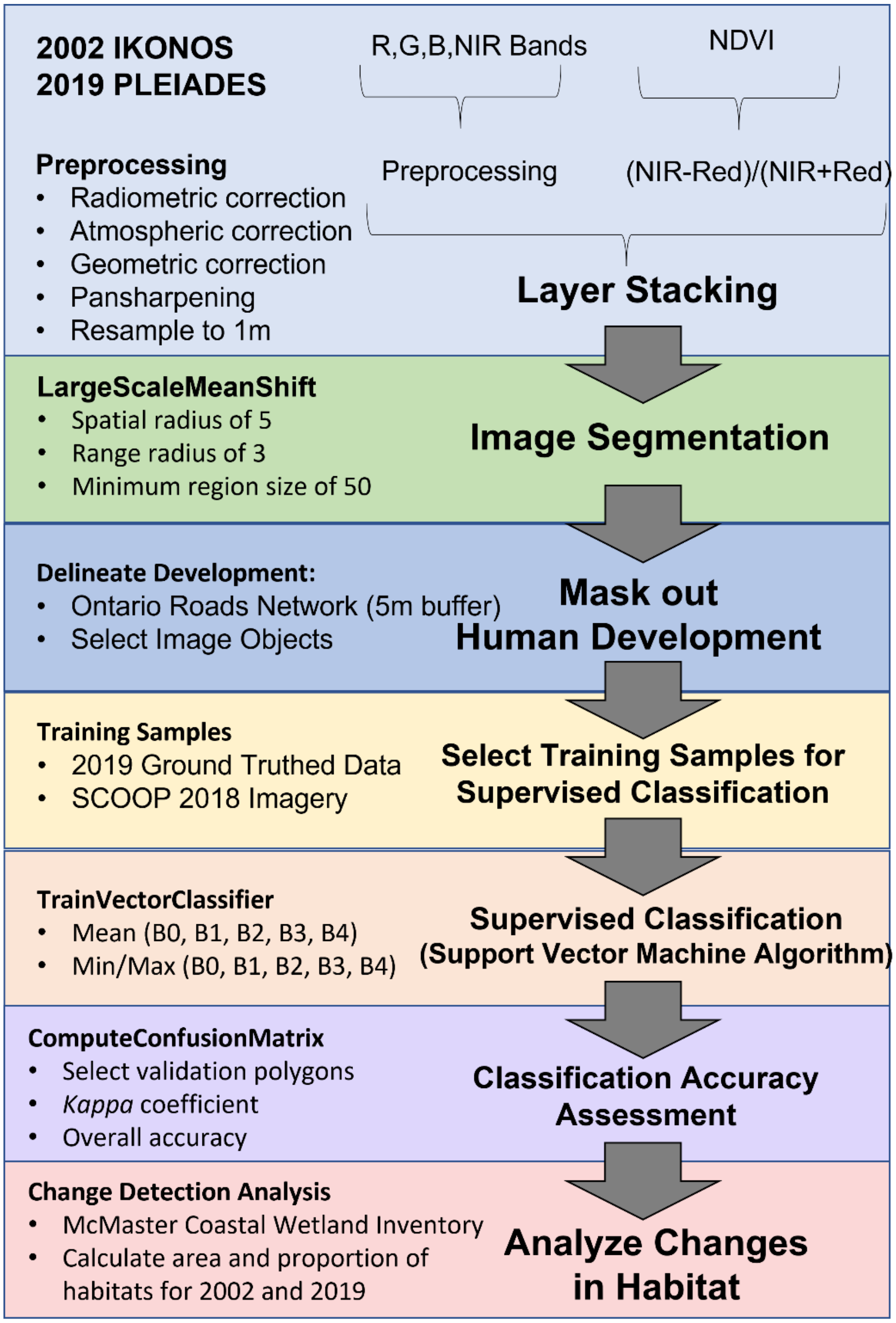

Figure 2.2: The workflow of OBIA in QGIS and OrfeoToolbox 8.0.0 for image classification and analysis.

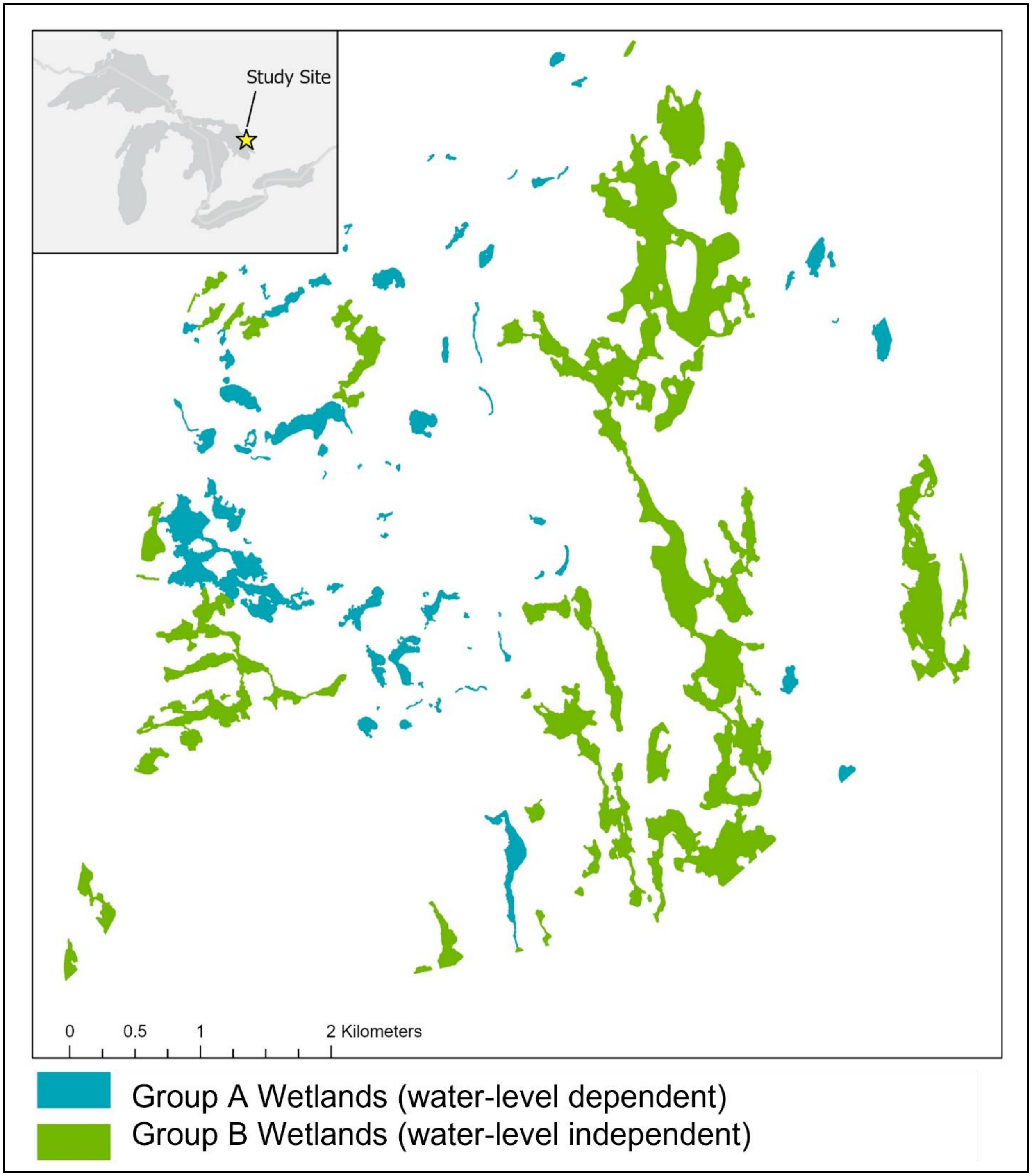

Figure 2.3: Location of wetlands in study site, located in eastern Georgian Bay of Lake Huron. Blue represents 82 lacustrine "group A" wetlands that are hydrologically connected to Lake Huron. Green represents 62 palustrine "group B" wetlands and wetland complexes that are not affected by water levels.

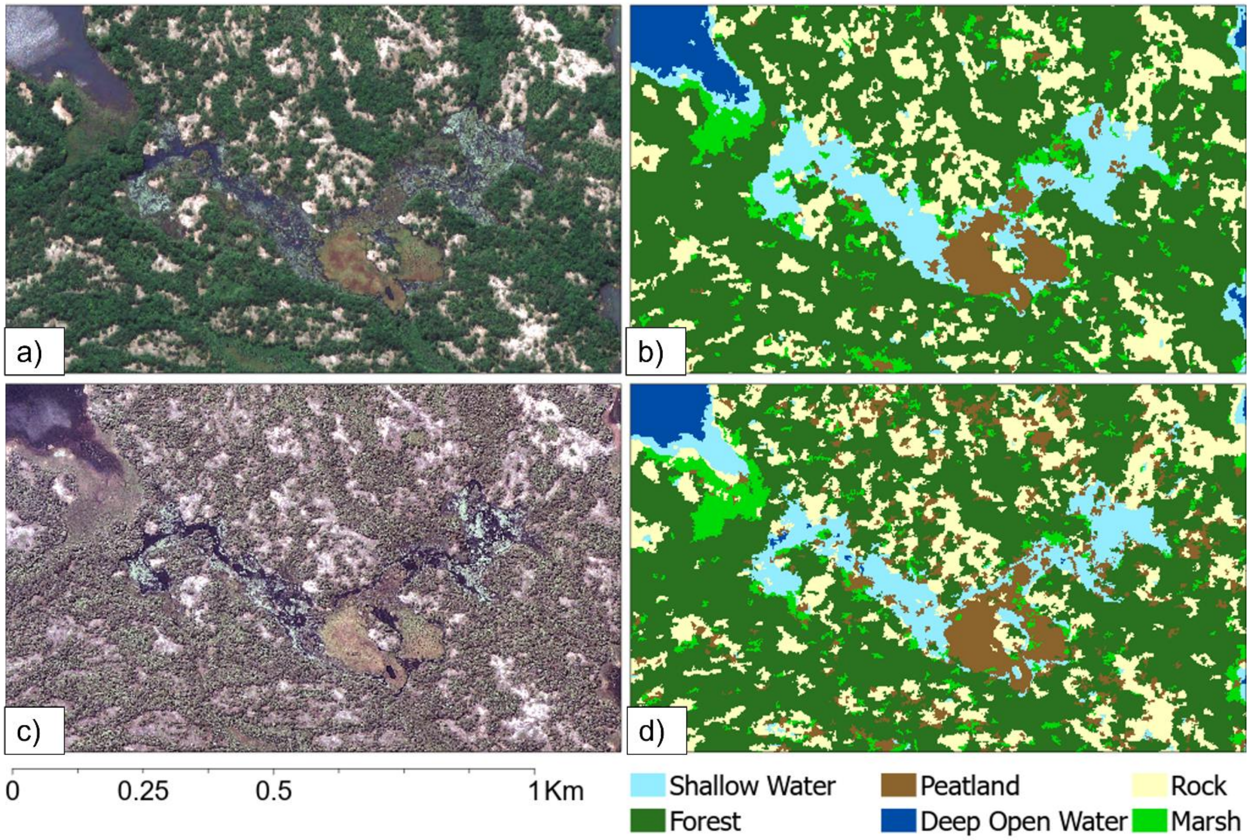

Figure 2.4: Classification results showing RBG satellite images and final classified maps of study site for 2019 Pleaides 1B (a, b), and 2002 IKONOS (c,d) image data.

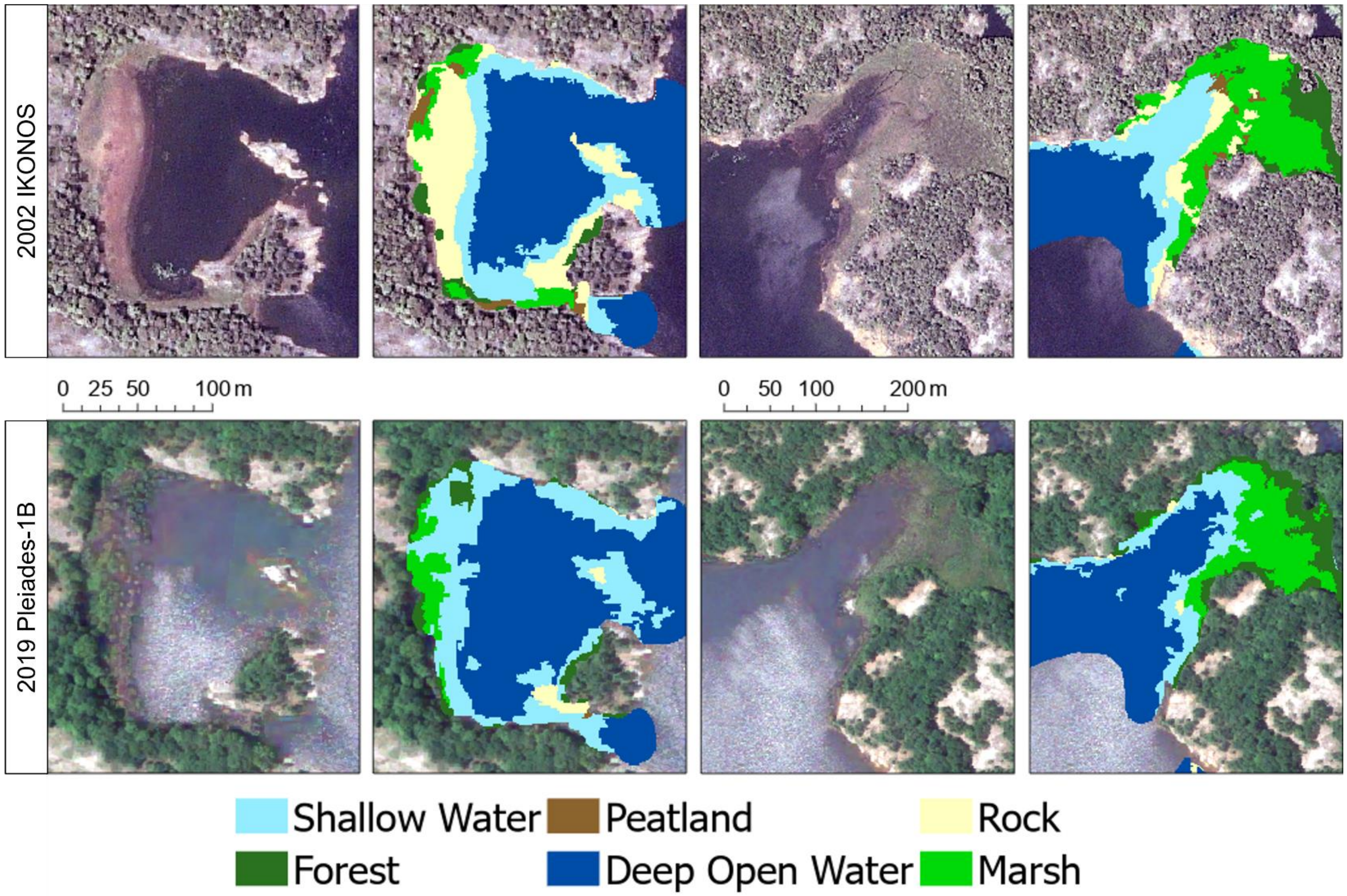

Figure 2.5: Comparison of IKONOS (2002) and PLEIADES (2019) images with coastal marsh habitat used by Blanding's turtles that have been classified using object-based image analysis.

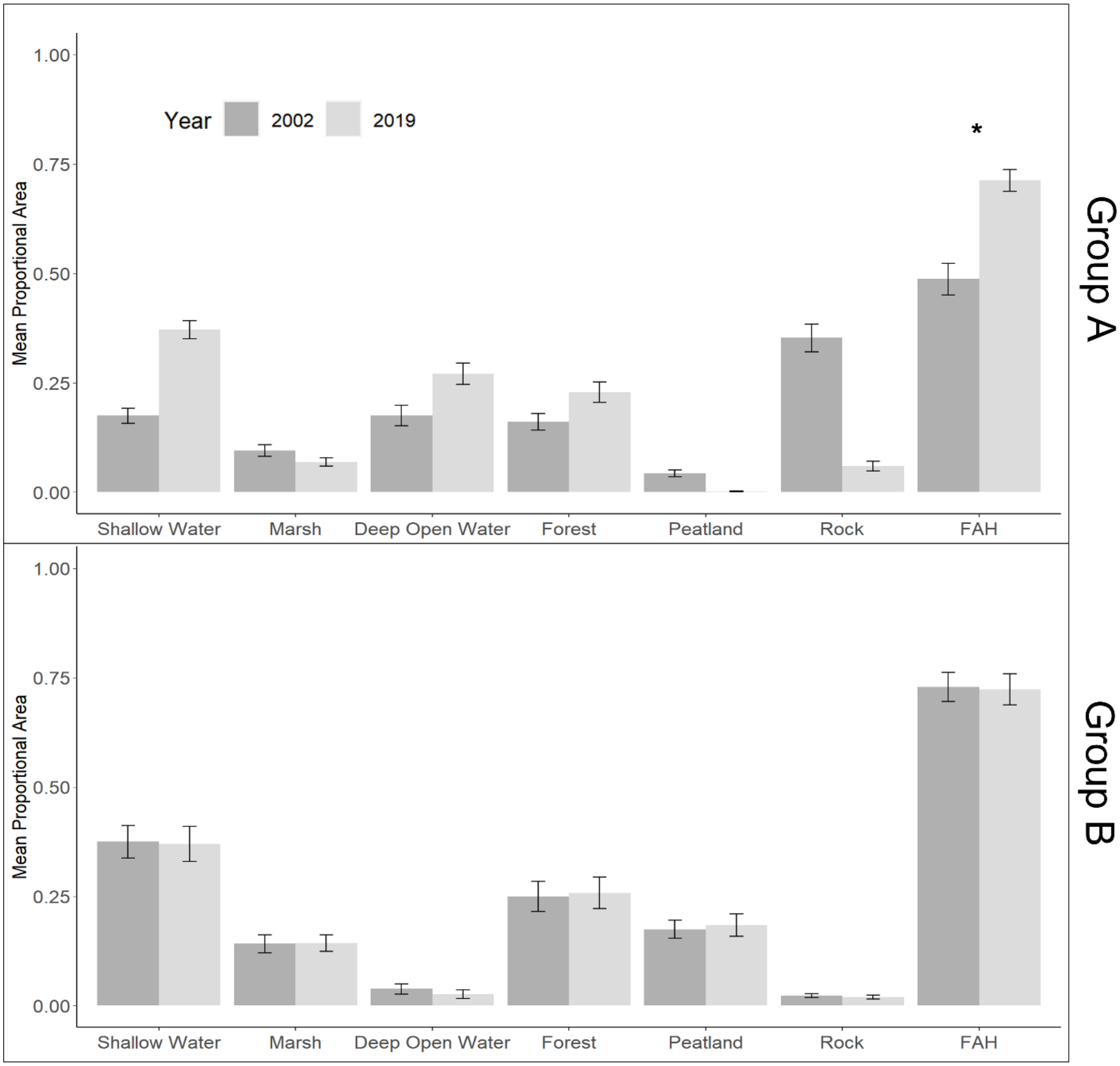

Figure 2.6: Mean proportional area of habitats within wetlands during the years 2002 and 2019. Top represents wetlands that are affected by water levels (Group A, N=82), and bottom represents wetlands that are not affected by water levels (Group B, N=62). Deep open water, shallow open water, Marsh, and peatland habitats were merged to calculate the functional aquatic habitat (FAH) for Blanding's turtles.

GENERAL CONCLUSIONS

To implement effective protection and recovery methods for species at risk, the threats and habitat requirements for each subpopulation need to be known across their entire geographic range. These two chapters have bridged knowledge gaps in our current understanding of the critical habitat use and threats to the Blanding's turtle so that effective conservation plans can be implemented along the understudied shores of eastern Georgian Bay. In chapter 1 we highlighted the importance of protecting and mitigating Blanding's turtle habitat using a site-specific approach, as the critical habitat used by this subpopulation differed from those documented in the literature.

This subpopulation also used the littoral zone extensively during the nesting and active season and some individuals also used deep open water for dispersal, indicating that they use coastal wetland habitat to a greater extent than has been published previously. We also documented anthropogenic threats specific to this site in eastern Georgian Bay because female Blanding's turtles disproportionately nested in roadsides and loose substrate around buildings that only made up of 1.3% of our study area. This may be because the nesting females have an affinity for using built-up habitats in comparison to rock barrens during the nesting season, or perhaps there is a scarcity of nesting habitats in rock barrens.

In chapter 2, we identified that the functional aquatic habitat for the Blanding's turtle in coastal wetlands was 21% lower in during 2002 than in 2019, and we attribute this loss to the greater than 1-m difference in water levels between years. Therefore, the anticipated low water levels accompanying climate change will have serious implications for Blanding's turtle that need to use the littoral zone to access habitat patches. More research should be conducted to determine how water levels affect freshwater turtle habitat in the Great Lakes coastal wetlands, especially in Georgian Bay.

This thesis has illustrated what critical habitat needs to be protected and what threats exist that need to be further investigated to allow mitigation measures to be developed. The critical habitat for Blanding's in this region include 1) inland and coastal wetlands that are used for overwintering and during the active season 2) thicket swamps, beaver impoundments, as well as the littoral zone that are used travelling between habitats and 3) rock barrens, as well as loose substrate in parking lots and roadsides that are used for nesting. Further studies need to be carried out to address specific threats including 1) mortality of adults and hatchlings due to collision with cars, boat trailers and boats in the built-up areas (roadsides, marina, boat launch, docks, parking lots), 2) boat injuries associated with long-distance travels over recreational boating channels and 3) habitat loss due to extreme water-level declines associated with climate change.