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By ROBERT J. CHRISTENSEN, H.BSc.

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TITLE: **The movement patterns and home ranges of Blanding's turtles (*Emydoidea blandingii*) in two protected areas in Ontario Canada**

AUTHOR: **Robert J. Christensen, H.BSc. (McMaster University)**

SUPERVISOR: **Dr. Patricia Chow-Fraser**

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ABSTRACT

The distribution of Blanding's turtles in North America is centered on the Great Lakes region, where the impacts from high levels of development have reduced and isolated populations. They are particularly sensitive to habitat loss and fragmentation because of their broad habitat requirements, migratory behaviour, and relatively large seasonal movements and home ranges. Consequently, Blanding's turtles have been designated a species at-risk throughout the majority of their geographic range. In 2011 we conducted a radio-tracking program to compare the home ranges and movement patterns of Blanding's turtles in two eco-regions of Ontario that have contrasting habitat and landscape characteristics: Georgian Bay Islands National Park and Rondeau Provincial Park. We also used GPS loggers to supplement data collection by radio-tracking and to evaluate the effectiveness of GPS loggers in tracking the movements of a semi-aquatic species. We found differences in home range between our two study populations that may be linked to landscape features and seasonal differences in movement within the population in Georgian Bay Islands National Park. We also determined that GPS loggers, when used in combination with radio-tracking, can effectively track the movements of Blanding's turtles with a higher temporal and spatial resolution than by radio-tracking alone. This study highlights the importance of developing management strategies that are tailored to the spatial requirements of distinct populations, and the need for conservation measures that protect aquatic and terrestrial habitat surrounding the main activity centres of Blanding's turtles.

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INTRODUCTION

Biodiversity is rapidly decreasing on a global scale, primarily as a result of habitat loss and degradation. As human encroachment continues there is an urgency to take a proactive approach to protect yet undisturbed habitat, and develop conservation strategies that prioritize the protection for species that are most sensitive to human disturbance, and are at the highest risk of further population declines. Amphibians, and more recently, reptiles have taken centre stage in the global concern over habitat loss because of the alarming rate of species declines and the overwhelming number of species that have been listed as at-risk (Gibbons et al., 2000). Many of these at-risk species are semi-aquatics that represent a unique problem in conservation because they require both aquatic and terrestrial habitat to complete their lifecycles.

Turtles are reptiles of the order Chelonii (or Testudine) that consist of 330 identified living species, and are represented in every continent with the exception of Antarctica (van Dikj et al., 2011). Only seven species are marine turtles, and the remainder are either freshwater or terrestrial species. Altogether, 149 (45.2%) of the 330 identified species are listed as threatened on the IUCN Redlist. Canada is home to 12 native taxa (including subspecies) of freshwater turtles and tortoises, 1 introduced freshwater species, and 2 sea turtle species (van Dikj et al., 2011). In Ontario, Canada there are 8 native species, 7 of which are considered at-risk at provincial and federal levels (Government of Canada, 2009; Ontario Ministry of Natural Resources, 2012).

Rapid population declines of the majority of turtle species have been discovered in the Great Lakes region in Ontario due to destruction of habitat, rapid development of

urban areas, and increased rates of road mortality (Ashley & Robinson, 1996; DeCatanzaro & Chow-Fraser 2010; Haxton, 2000). Recent research has revealed that turtles and other reptiles with larger home ranges and longer annual migrations may experience higher rates of population declines in developed areas because they are more likely to encounter modified habitats, which in turn increase their risk of mortality (Aresco, 2005; Attum et al., 2008; Gibbs & Shriver, 2002; Refsnider & Linck, 2012). Blanding's turtles were chosen for this research project because of their complex habitat requirements, relatively large home ranges, long annual nesting migrations, and their status as a threatened species (Government of Canada, 2009; Ontario Ministry of Natural Resources, 2012).

Blanding's turtles are a mid-sized semi-aquatic species that can have a shell length as long as 27 cm, and can weigh as much as 3 kg (Congdon & Keinath, 2006; COSEWIC, 2005). They can be distinguished from other species by their bright yellow throat, and smooth dome shaped shell. In North America Blanding's turtles are mainly distributed around the Great Lakes region, but also extends as far west as Nebraska (COSEWIC, 2005). There are also several disjunct populations in Canada and the United States including a population in the Lower Hudson River Valley in New York, a population that extends through Eastern Massachusetts and Southeastern New Hampshire, and a third in Southern Maine, and a population in Nova Scotia (COSEWIC, 2005). Blanding's turtles usually exist in small fairly isolated populations throughout their range; however, there is a large population in Nebraska that has more than 130,000 individuals (Lang, 2004).

Throughout the species' range they are typically found in aquatic habitats including lakes, rivers streams, bogs, fens, marshes, swamps and vernal pools

Blanding's turtles have a strongly k-selected life history traits: they are slow to reach sexual maturity (> 14 years), have a low annual reproductive rate, a long lifespan (> 75 years) and are reported to maintain their reproductive abilities as long as 77 years (Congdon et al., 1993). Hatchlings have low annual survivorship (26 %), while adults in a single population have been found to have survivorship as high as 96% (Congdon et al., 1993; Gibbs & Shriver, 2002; Grgurovic & Sievert, 2005). Their slow rate of reproduction leaves Blanding's turtles particularly vulnerable to changes in their environment, and even a small increase in rate of mortality for adults can have a considerable impact on population stability (Congdon et al., 1993).

Blanding's turtles have a complex set of habitat requirements as they use several types of aquatic and terrestrial habitat within their home range during each active season (Congdon et al., 2008; Edge et al., 2010; Joyal et al., 2001; Millar & Blouin-Demers, 2011). These include a residence wetland where they spend the majority of the active season, ephemeral wetland habitat during the spring and prior to the nesting period, terrestrial habitat for movement among activity centres and for nesting, and a suitable location for hibernation which can last as long as six months in any particular year. Their vulnerability to human encroachment is a consequence of these requirements; a loss of any one of these critical habitat locations can interfere with or prevent Blanding's turtles from completing their life cycles, which results in destabilization of the population. Until appropriate land protection is provided, and effective mitigation efforts are taken,

populations of Blanding's turtles throughout the species range will continue to experience sharp declines.

Conservation planning needs to be based on a developed understanding of a species' primary ecological requirements, including the spatial relationship a species has with its environment. Individual populations may express unique spatial and temporal patterns of movement depending on environmental factors such as climate, landscape characteristics, and availability of suitable habitat. Studies of the movement of individuals can be used to extrapolate the unique spatial requirements and habitat preferences of populations. Individual movement is dependent on an animal's requirements of survival and reproduction; animals move to acquire resources, to avoid sources of mortality, to avoid competition, and for social interaction and mating opportunities (Fahrig, 2007). The differences among populations make implementation of effective conservation strategies across a species range a considerable challenge.

Analysis of animal movement and accurate estimation of an animal's spatial requirements necessitates the collection of a considerable number of individual locations. Animal tracking studies are primarily conducted using visual observations of individuals over time, mark-recapture and radio-tracking (Harris et al., 1990). The effectiveness of these methods will vary depending on the studies' primary research goals. For instance, a mark-recapture study allows researchers to observe animal movements among active trap locations within a study site, but does not enable accurate inferences about an animal's path of movement. Radio-tracking allows researchers to follow animals as they move throughout their home ranges and to map travel corridors, but even high intensity tracking

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regimes can still fail to observe the use of temporary habitat. In the last decade the use of GPS-devices for animal tracking has become more common, and has been primarily used for larger terrestrial animals including bears, wolves and many ungulates species (Johnson et al., 2002; Rodgers et. al., 1996; Sand et al., 2005; Schwartz & Arthur, 1999). Recently, miniaturized devices have become available and have enabled the tracking of smaller terrestrial animals including small mammals, birds and reptiles (Cagnacci, 2010; Kotzerka et al., 2009; Recio et al., 2011); however, their high upfront purchase price has made them cost-prohibitive for many studies.

Measures of an animal's home range, for which the most highly cited definition is: 'that area traversed by the individual in its normal activities of food gathering, mating and caring for young' - Burt (1943, p. 351), are commonly used to delimit the area and habitat used by an animal. Many methods for estimating home range size have been developed since they were first used to identify the spatial requirements of animals; minimum convex polygon (MCP) has been the most commonly used method, and variations of density estimation techniques such as kernel smoothing have become more prevalent (Kie et al., 2010). Each method has its advantages and disadvantages depending on factors such as the animal of study, the types of habitat used by the animal, and the amount of data collected. For example, grid summation likely underestimates home range size because movement corridors are excluded (Piepgras & Lang, 2000), and the adaptive kernel method requires at least 30 individual locations for estimates to be robust (Seaman et al., 1999). MCP has been recommended for studies of herpetofauna because of the

inconsistencies associated with using kernel estimators (Row et al., 2006), and it is well suited for comparison with other studies.

In this study we first examine the differences in the movement and home ranges of Blanding's turtles in two-study locations in Ontario that have contrasting habitat characteristics: Georgian Bay Islands National Park and Rondeau Provincial Park. We also more closely examine the seasonal movements of male and female Blanding's turtles within Georgian Bay Islands National Park to gain a better understanding of seasonal and inter-annual differences in movement, and how sex-specific reproductive strategies influence their spatial requirements. In addition to providing detailed descriptions of Blanding's turtle movement and home ranges that will help to guide the management of these and other populations, we also reveal important information about how features of the landscape may be key determinants of their home range size and movement patterns. The second chapter of this thesis is provides an assessment of the usefulness of GPS tracking devices for studying the movements of freshwater turtles, and guidance for the incorporation of this technology into tracking studies of this and other semi-aquatic species.

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CHAPTER 1   DIFFERENCES IN HOME RANGES AND MOVEMENT PATTERNS OF
                BLANDING'S TURTLES IN TWO DISTINCT ECO-REGIONS OF ONTARIO WITH
                CONTRASTING LANDSCAPE FEATURES

ABSTRACT

        The distribution of Blanding's turtles in North America is centered on the Great

Lakes region, where the impacts from high levels of development have reduced and

isolated populations. They are particularly sensitive to habitat loss and fragmentation

because of their broad habitat requirements, migratory behaviour, and relatively large

seasonal movements and home ranges. Consequently, Blanding's turtles have been

designated a species at-risk throughout the majority of their geographic range. To create

effective management strategies for their survival and recovery, the spatial requirements

of distinct populations must be well understood. In 2011 we conducted a radio-tracking

program to compare the home ranges and movement patterns of Blanding's turtles in two

eco-regions of Ontario that have contrasting habitat and landscape characteristics:

Georgian Bay Islands National Park (GB) and Rondeau Provincial Park (RD). We found

that male Blanding's turtles in RD have significantly larger home ranges than do males in

GB, but found no significant differences between populations for the females. In addition,

within the GB study site there were significant seasonal (pre-nesting, nesting and post-

nesting) differences in movement patterns between males and females as well as inter-

annual differences in home ranges of females. Our findings suggest that the spatial

requirements and movement patterns of Blanding's turtles are linked to the availability,

configuration and connectivity of aquatic habitat. Additionally, important sex-specific

spatial and habitat requirements exist within each population and vary on a seasonal basis.

This study highlights the importance of developing management strategies that are tailored to the spatial requirements of distinct populations, and the protection of aquatic and terrestrial habitat surrounding the main centers of activity for Blanding's turtles.

The distribution of Blanding's turtles is concentrated in the Great Lakes Basin in Canada and the United States where the impacts from human development have reduced and isolated populations (COSEWIC, 2005). Blanding's turtles are particularly sensitive to anthropogenic stressors because they have long annual migrations, large home ranges, and require a variety of wetland and terrestrial habitats (Beaudry et al., 2009; Congdon at al., 2008). These traits lead them to encounter modified landscapes such as roads and agricultural areas, which in turn may increase their risk of mortality (Aresco, 2005; Gibbs & Shriver, 2002; Refsnider & Linck, 2012). They also have delayed sexual maturity (>14 years), high rates of mortality as hatchlings, and a slow rate of juvenile recruitment into the breeding population. As a strongly k- selected species they require high annual survivorship of adults to maintain population stability (Congdon et al., 1993). Continuing population declines have led to their designation as an at-risk species throughout Canada and majority of the United States (COSEWIC, 2005; Government of Canada, 2009; van Dikj et al., 2011).

Blanding's turtles are a semi-aquatic species that resides mainly in wetland habitat including bogs, fens, swamps, marshes. They remain within a single residence wetland for the majority of the year, and are reported to show high site fidelity to these wetlands throughout their lives (Congdon et al., 2011). They do, however, require an assortment of aquatic and terrestrial habitat types within their home range during each active season (Congdon et al., 2008; Edge et al., 2010; Joyal et al., 2001; Millar & Blouin-Demers, 2011). These include ephemeral wetlands in the spring and early summer, upland

terrestrial habitat for nesting, and a suitable upland matrix that enables their movement

among habitat locations (Congdon, et al., 2008; Joyal et al., 2001; Refsnider et al., 2012).

Even though the observed decline in Blanding's turtle populations has mainly been

attributed to destruction of their primary wetland habitats, many recent studies suggest

that impacts on population size from loss of movement corridors and upland habitat

surrounding residence wetlands within their home ranges have been underestimated

(Attum et al., 2008; Congdon et al., 2011; Gibbons, 2003; Refsnider & Linck, 2012).

Past studies have reported differences in the home range size and movements of

Blanding's turtles from individual populations throughout their species range. This

variation among populations is not well understood, making it difficult to anticipate what

terrestrial and aquatic habitat Blanding's turtles from distinct populations are utilizing.

These differences may be related to habitat quality and population density, as has been

noted for other reptile species. In Maryland, Box turtle's associated with larger home

ranges were found in higher population densities and more diverse habitats (Stickle,

1989). Kapfer et al., (2010) found that home range of Bullsnakes increased with the

amount of avoided habitat. Although differences in home range among study populations

of Blanding's turtles have been linked to environmental characteristics, no published

studies have empirically examined the specific factors associated with home range size

and movement patterns. For example, in a Nova Scotia population, longer movements of

Blanding's turtles were proposed to be associated with less productive habitat (Power,

1989). In Minnesota, larger home range size was proposed to be related to amount of

aquatic habitat and higher aquatic connectivity (Hamernick, 2000). Other environmental

factors that may affect home range size and movement patterns include habitat availability, spatial arrangement of habitat, habitat productivity, resource density, landscape composition, and level of human development (Congdon et al., 2008; Grgurovic & Sievert, 2005; Refsnider & Linck, 2012; Roe et. al., 2009; Ross & Anderson, 1990; Rowe & Moll, 1991). In addition to variation among populations, recent studies have reported seasonal differences in movement of males and females, including greater activity of males in the spring and greater activity of females during the nesting season (Beaudry et al., 2009; Edge, et al., 2010; Millar & Blouin-Demers, 2011) These findings are consistent with the predictions of the reproductive strategies hypothesis (Morreale et al., 1984); however, it is not known how these reproductive pressures influence the spatial requirements of populations from distinct eco-regions that have different environmental features.

The primary objective of this study is to investigate differences in movements of two distinct Blanding's populations that have contrasting landscape and environmental features, in order to identify over-arching factors that govern home range size and movement patterns. The two study sites are Beausoleil Island in Georgian Bay Island National Park (GB), Lake Huron, and Rondeau Provincial Park (RD), Lake Erie. Studying the movements of Blanding's turtles in two protected areas enables us to observe population-level differences in sites where the direct impacts of human activities is minimal and our ability to track the animals is not restricted by private property. Although both study sites are within parks, they differ with respect to surrounding land uses; GB is surrounded by land developed for cottages whereas RD is surrounded by land

used for cottage development and agriculture. GB is also naturally fragmented, situated on Precambrian Shield that includes a network of poor fens, bogs, swamps and vernal pools distributed among rocky outcrops, whereas RD has an expansive and contiguous network of productive marshes. We predict that in the highly productive and relatively large wetlands of RD, Blanding's turtles would only need a small area to satisfy their resource and reproductive requirements, and therefore have significantly smaller home ranges than do turtles in GB.

Our second objective is to investigate the inter-annual differences in spatial and temporal movements of male and female Blanding's turtles in Beausoleil Island. Based on published trends, we anticipate that there will be significant differences between males and females with respect to annual home ranges and seasonal movement patterns. Our final objective is to combine our results with those in published studies and conduct a meta-analysis to identify habitat features and environmental conditions that may affect home range and movement patterns of this species. Findings from this study will advance our understanding of the spatial requirements of the Blanding's turtle and enable better protection of critical aquatic and terrestrial habitat for this at-risk species.

METHODS

The radio-tracking program in GB took place between April 2011 and August 2012, while that in RD took place between April and July of 2011. Georgian Bay Islands National Park (GBINP) is a protected area that consists of 59 islands, and is part of the world's largest freshwater archipelago of 30,000 islands in the eastern arm of Lake Huron.

Our study site is located on Beausoleil Island (approximately 1100ha), the largest island of GBINP (Table 1; Figure 1a). Vegetation is mainly of mixed boreal and deciduous forest, and on the northern part of the island, which is overlain by the Canadian Shield, there are numerous isolated wetlands including, bogs, swamps and vernal pools. Human development within this habitat is limited to park trails and several camps on the periphery of the island (i.e. there are no paved roads in this portion of the island). By comparison, Rondeau Provincial Park is also a protected area (approximately 3250ha) and is located on northern Lake Erie (Table 1; Figure 1b). The Park is a sand-spit peninsula, surrounded by a sandy beach with an interior consisting of expansive and contiguous wetland habitat that includes deciduous forest swamps and highly productive marshes. Only a few paved roads with controlled access exist within the park boundaries, and development including housing and park facilities are mostly situated around the Park's periphery. The majority of the parks interior wetlands are distant from human activity and disturbance.

Field Techniques

We conducted the comparison of home ranges and migration patterns of our two study sites during the same year; we focused on spring and early summer because that is the time when turtles are expected to have the highest rates of movement (Beaudry et al., 2009; Congdon et al., 2008; Edge et al., 2010; Millar & Blouin-Demers, 2011; Rowe & Moll, 1991). In 2011, twelve adult Blanding's turtles (6 males, 6 females) in GB and seven in RD (4 males, 3 females) were captured by hand, with a dipnet, or in hoop nets baited with canned sardines or cat food (see Table 2 for dates of initial capture). We

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sexed the individuals by identifying male secondary sexual characteristics (Ernst & Lovich, 2009) and marked each turtle for future identification by filing a unique combination of notches into their marginal scutes (Cagle, 1939). We recorded straight carapace length and width, plastron length and width, and shell depth for each turtle. We also weighed each turtle using a scale (Starfrit Digital Scale, acc. ±1g) to ensure that each turtle was large enough to carry the weight of the tracking devices (the combined weight of the radio-transmitters and fittings was required to be <5% of body weight).

We attached radio transmitters (Holohil, Carp, Ontario, Canada, Model AI-2F 19g) to the rear marginal scutes of each turtle using fast-drying epoxy (LePage Speed Set Epoxy) and plumber's epoxy (Oatey Epoxy Putty). These radio transmitters were designed to have a battery life of at least 24 months to ensure that two field seasons of tracking was possible. As recommended in the literature (Innes et al., 2008; Edge, et al., 2010; Millar & Blouin-Demers, 2011), total weight of the devices and fittings did not exceed 5% of total body weight of adults. Once we confirmed that the devices were firmly attached, the turtles were returned to their point of capture.

Turtles were radio-tracked with a Lotek Biotracker Receiver (Lotek Wireless, Newmarket, Ontario, Canada) and a Yagi antenna (Wildlife Materials International, Murphysboro, Illinois, USA). In the variable terrain and wetlands of our study sites, we were able to receive a signal from the radio-transmitters when the turtles were within 1250 m. Once located, the time of day and position were recorded with a handheld GPS unit (Garmin Handheld, <6m accuracy). We also recorded the activity of the animal at the

time of capture, water depth when in aquatic habitat, dominant substrate, dominant vegetation, and took images of each location with a digital camera.

During 2011, turtles in RD were tracked 1-2 times per week between the initial date of capture (Table 2) and 18 July 2011, at the onset of the post-nesting season when turtles moved back to their residence wetlands in preparation for hibernation. That same year, turtles in GB were tracked 1 to 2 times per week from April until September, and in 2012, from April until August. Due to differences in sampling effort for the two sites, we only used data collected between 12 April and 18 July in 2011 to compare home ranges. This subset included data of 12 individuals (6 males, 6 females) that were tracked in GB and 7 (4 males, 3 females) in RD, but excluded all movements associated with nesting migrations.

Home Range and Movement Calculations

We used the minimum convex polygon (MCP) method to calculate home ranges and seasonal ranges. This method is the most widely used for estimations of animal home range (Powell, 2000; White & Garrot, 1990), and is considered appropriate for herpetofauna (Row & Blouin-Demers, 2006). Although MCP is a nonstatistical approach to estimating home range, this technique can still be sensitive to autocorrelated data (Swihart & Slade, 1985). To ensure the independence of each of our data points when estimating home range size, we included only one data point for any sets of points that had been collected within a 13-hour period.

In GB, we also examined how home range and movement patterns of male and female turtles during the active seasons differed between 2011 and 2012. To make the

comparison valid, we only included individuals that had been tracked for the majority of

the active season (3 months) in both years, and which were associated with a minimum of

10 radio-locations in each year. We also calculated mean daily movements of turtles in

GB using locations that were at least 13 hours apart, and determined these separately by

sex and for the three behavioural seasons. The pre-nesting season lasted from the first day

of tracking (21 April 2011) until the first female was found to begin her nesting migration

(1 Jun 2011); the nesting season lasted from the end of the pre-nesting season until the

day that the last female being tracked returned to her residence wetland from her nesting

migration (17 July 2011); the post-nesting season began the last day of the nesting season

to the last day of tracking and prior to hibernation (19 Sep 2011).

In addition to the current study, there are nine other radio-tracking studies of

Blanding's turtles in North America that report the mean home range sizes of males and

females using MCP or comparable methods. We have listed these locations in order of

high to low latitude in Table 3 and noted their geographic locations relative to each other

in Figure 2. Using site descriptions within these publications, we assigned each study site

into two categories for availability of aquatic habitat (high or low), and degree of human

disturbance (high or low), to allow for a better discussion around these two important site

variables.

Statistical Analysis

All data were analyzed with JMP 9.0 statistical software. We used a t-test to

compare the mean home ranges of males and females between GB and RD in 2011, and

the mean home ranges of males and females in 2011 and 2012 combined. We used a

paired t-test to compare home ranges obtained for each single-year (2011, 2012) to combined two-year home ranges (2011 combined with 2012). We normalized the movement data using a log transformation, and performed a two-way ANOVA to test the effects of behavioural season and sex on the mean daily movement rates.

<p style="text-align:center">***RESULTS***</p>

Comparison between GB and RD

We first compared the ranges and movement patterns of Blanding's turtles in both study sites during a period when turtles are expected to travel widely and have the highest rate of movement. In 2011, this occurred between 12 April and 18 July in 2011 which included pre-nesting and nesting seasons. The Blanding's turtles on Beausoleil island used dystrophic bogs (<2m deep) as residence wetlands where they spent the majority of the active season as well as the hibernation period. During the study period, two of the six male turtles in GB remained within a single residence wetland (GBM4, GBM5), three moved between two residence wetlands (GBM1, GBM2, GBM6; centroids of residence wetlands are approximately 330m apart) and the remaining (GBM3) moved a considerable distance (approximately 1 km) from the residence wetland to a small isolated wetland near the lake shore (Figure 3). Five of the female turtles used one of two residence wetlands throughout the entire comparison period (excluding nesting migration of all females), with only one of the females (GBF4) moving between residence wetlands (Figure 4).

By comparison, the Blanding's turtles in Rondeau used open water marsh areas as residence wetland habitat. The four male turtles in RD each occupied a much larger area than did the females, dispersing from their initial point of capture by 600 to 2 500 m (Figure 5). During the period of observation, males moved throughout the contiguous wetland habitat in Rondeau, making use of many types of wetland habitat before returning to the same wetland in which they were initially captured by mid-summer. All females remained within marsh habitat and did not appear to use terrestrial habitat (Figure 6). This is likely an underestimate of their home range and movements, however, since we missed the nesting migrations due to our restricted sampling schedule (no female turtles moved beyond 250 m from their initial point of capture).

When we compared the home ranges of turtles from RD and GB (Table 4), we found that RD males (n=4) had the largest mean home range of 19.30 ± 6.86 SE ha, with individual home ranges varying from 7.14 to 32.57 ha. The GB males (n=6) had individual home ranges that varied from 0.35 to 8.83 ha, and a mean range of 2.88 ± 1.26 SE ha. Using a t-test, the GB males home range was significantly smaller than the mean range calculated for RD males ($t(8)=2.90$, $p=0.020$). RD females (n=3) had a mean range of 0.60 ± 0.23 SE ha, which was larger than 0.40 ± 0.09 SE ha for the GB females (n=6), although these means were not significantly different ($t(7)=0.97$, $p=0.362$).

Seasonal and annual differences in GB

Our second objective was to compare the home ranges and movement patterns of Blanding's turtles within Georgian Bay Island National Park in two consecutive years. Six male and six female turtles were tracked throughout the majority of each active

season (at least 3 months including the pre-nesting, nesting and post-nesting periods) in 2011 and 2012. In 2011, five of the six male turtles remained within two residence wetlands for the entire active season. One male turtle (GBM3) moved approximately 1 km to lake habitat and small wetlands adjacent to the western shoreline (Figure 7), later returning to the residence wetlands in the post-nesting season. Four of the six males (GBM1, GBM2, GBM3, GBM6) moved between the two residence wetlands mainly during the pre-nesting season, with occasional inter-wetland movement during the nesting season, while GBM4 and GBM5 made use of only one residence wetland. By the end of the nesting season the males were no longer observed moving between wetlands, remaining within a single wetland until hibernation.

Although a similar pattern of movement was observed for males in both years, movements to ephemeral wetland habitat, peripheral to the main residence wetlands (max 150m) were observed for 3 males (GBM3, GBM4, GBM5) in 2012 (data not shown). In both years, the majority of the movements between residence wetlands took place during the pre-nesting season, with few inter-wetland movements occurring in the nesting season; no movements between wetlands were observed during the post-nesting season. GBM3 repeated the same extended movement to the lakeshore in 2012 as he had made in 2011, departing from and returning to the residence wetlands at roughly the same time in both years. It is noteworthy that no other male from these residence wetlands made this type of extensive migration to lake habitat during the study.

In 2011, the female Blanding's turtles remained within one of two residence wetlands for the entire pre-nesting season; no inter-wetland movement or use of

ephemeral wetland habitat was observed. All of the females in our study were determined to be gravid in both seasons prior to the nesting migration. During the nesting season in 2011 (1 June to 18 July) all females moved first into marsh habitat north of their main residence wetlands before moving to terrestrial habitat to nest (Figure 8). After nesting, each female was observed to return to the same wetland from which they departed at the beginning of the nesting season. During the 2011 season, only one female (GBF4) was observed moving between the two residence wetlands after nesting. During the post-nesting season all of the female turtles remained in their residence wetlands until hibernation.

Female turtles made spatial and temporal movements in 2012 that were similar to that in 2011, except for two female turtles (GBF3, GBF4) that made use of ephemeral wetland and marsh habitat prior to their nesting migration. The main difference between years was the timing of the nesting migration, which occurred 8 days earlier in 2012 (24 May to 9 July) than in 2011 (1 June to 17 July). Females nested after moving to the same marsh habitat during their terrestrial migrations. One female (GBF3) made extensive use of lake and marsh habitat for 16 days prior to, and 10 days after her terrestrial nesting event on 10 June 2012 before returning to her residence wetland. Following nesting, all females remained within their residence wetlands until hibernation.

We found considerable variation in home range sizes among individuals, between males and females and between years (Table 5). The mean home range for males ranged from 0.90 to 25.72 ha, and was only slightly larger in 2011 (mean of 6.66 ± 3.85 SE) than in 2012 (mean of 6.53 ± 4.62 ha). The mean home range for females was smaller in 2011

(mean of 14.27 ± 6.07 ha) compared with that in 2012 (mean of 18.12 ± 8.02 ha), with individual home ranges varying from 4.84 to 57.34 ha. In both years, mean female home range was larger than that for males (20.87 ± 8.54 vs 10.37 ± 6.92 ha, respectively), although the difference was not found to be statistically significant (t(10)=0.95, p=0.36).

To determine differences between single-year and combined two-year home ranges we compared each single year (2011, 2012) to the combined two-year (2011 combined with 2012) mean home ranges for males and females (Table 5). The mean differences between the 2011 home range and the combined 2011 and 2012 home range for males was 3.71 ± 3.10 ha, and for females was 6.60 ± 2.88 ha; however, there was no statistically significant difference for males (t(5)=1.20; p=0.28) or females (t(5)=2.28; p=0.07). The mean differences between the 2012 home range and the combined 2011 and 2012 home range for males was 3.84 ± 2.32 ha and for females was 2.75 ± 0.72 ha respectively; there was a statistically significant difference for females (t(5)=3.81; p=0.01), and no significant difference for males (t(5)=1.66; p=0.16).

In GB we calculated the mean daily movements for both males and females in 2011. Movement rates varied considerably between males and females and among the pre-nesting, nesting, and post-nesting seasons (Figure 9). Male movement distance decreased from its peak during the pre-nesting season (mean ±SE: 33.76m ±14.06) to the nesting season (mean ±SE: 26.16m ±7.11), and reached its lowest point during post-nesting season (mean ±SE: 10.88m ±6.80). Female movement distance peaked during the nesting season (mean ±SE: 64.60m ±5.57), followed by the pre-nesting season (mean ±SE: 14.71 ±9.52), with the least movement during the post-nesting season (mean ±SE:

9.78 ±6.46). The data were normalized with a log transformation for two-way ANOVA (see Table 6 for log transformed values). We found a statistically significant main effect of season ($F(2,241)=27.00$, $p<0.001$), and sex ($F(1,241)=4.23$, $p=0.041$), as well as a significant interaction of sex and season ($F(2,241)=5.60$, $p=0.004$). Using Tukey HSD, we found that females moved significantly more during the nesting season than during both the pre-nesting and post-nesting seasons. Tukey HSD also revealed a significantly higher rate of movement for males during the nesting season than during the post-nesting season (Table 9).

DISCUSSION

Thus far, we have presented information to address the first two objectives of the study. First, we investigated the differences in movements of Blanding's turtles in two study locations with contrasting habitat and landscape features. In GB where wetland habitats are small, isolated, and less productive, we expected that male and female Blanding's turtles would need to move more frequently and use more habitat to satisfy their resource requirements and to maximize mating opportunities. Conversely, in RD we anticipated that the abundant and highly productive wetland habitats would provide male and female Blanding's turtles with ample resources and numerous mating opportunities in much smaller areas. We therefore predicted that turtles in GB would have larger home ranges than those in RD.

Comparison between GB and RD

The results of our study were contrary to our expectations; we found that the males in RD had a significantly larger mean home range size than did males in GB, and we found no significant difference between the mean home range size of the GB and RD females. The direction of the observed differences may reflect the substantial impediments to movement of Blanding's turtles through the Shield landscape. Additionally, the limited suitable habitat for turtles within the boundaries of Beausoleil Island may have discouraged exploratory behaviour by male turtles. In contrast, an abundance of resource-rich aquatic habitat combined with high habitat connectivity in RD may have facilitated or even encouraged movement of male turtles. Maintaining larger home range size where extensive suitable habitat is available may increase the frequency of mating opportunities (Morreale et al., 1984; Piepgras & Lang, 2000; Rowe & Moll, 1991). This unexpected finding also supports the proposal by Hamernick (2000) that Blanding's turtle home range size may vary with availability of aquatic habitat. Although we did not find a difference in female home ranges during the comparison period, our findings suggest that for males, landscapes that include an abundance of suitable aquatic habitat may support larger home ranges. The females in both of our study sites maintained much smaller home ranges than did males during the comparison period. Having multiple mates may not be as beneficial for female turtles as it is for male turtles (Morreale et al., 1984; Pearse & Avise, 2001), and female Blanding's turtles are not reported to actively seek mating opportunities; instead they strive to conserve energy for clutch development and their nesting events (Congdon, 1989). Therefore, the small home

ranges maintained by females, exclusive of the nesting migration, may reflect a consistency among populations where energetic constraints from female reproductive requirements are more influential on movement patterns than the potential benefits of a larger home range. Even though many other studies report large female home ranges in areas with high aquatic habitat availability (Table 3), they do not report what proportion of the home range is related to movements of females during the nesting period.

Seasonal and annual differences in GB

Our second objective was to investigate the differences in home ranges and movement patterns of Blanding's turtles over two consecutive years within the GB study site. GB is underlain with Shield landscape, and provides a patchy distribution of suitable habitat for Blanding's turtles. Within such a landscape, terrestrial movements between isolated wetlands are often required, especially when females are seeking appropriate nesting sites. In GB there are also substantial seasonal changes in aquatic habitat availability over the course of each year. During the spring and early summer, ephemeral wetland habitat is more abundant across Shield landscapes, and this may motivate males to move greater distances to seek resources and mating opportunities. We therefore anticipated that female turtles would have larger annual home ranges than male turtles in GB, and that seasonal differences would reveal greater male movement during the pre-nesting season and greater female movement during the nesting season.

We observed a greater mean home range size for females relative to males in both the 2011 and 2012 periods of data collection, and when data were pooled for both seasons, they were more than twice the size of the males; however, our results did not

reach statistical significance. Female Blanding's turtles expanded their use of habitat

during the nesting season, which greatly increased their home range. Prior to nesting the

female turtles each left their residence wetland to a staging area where they used lake and

marsh habitat before heading into terrestrial habitat to nest. Except for one male, no other

male turtles were observed moving beyond the two residence wetlands during the entire

study period. In addition to the large variation in home range we found between

individuals and between sexes, we also found differences between single-year and

combined two-year home ranges (Table 5). Other studies have reported that a single year

of data collection may substantially underestimate lifetime home ranges of Blanding's

turtles (Congdon et al., 2011; Schuler & Thiel, 2008). We found this to be true even for

the island population in GB where habitat that is suitable for long-term residence and

hibernation is limited, and home ranges are confined to smaller locales.

In 2011 we examined the mean daily movements of male and female turtles

throughout the pre-nesting, nesting, and post-nesting seasons (Figure 9). Male rates of

movement were highest during the pre-nesting season, and during the nesting season they

were significantly higher than during the post nesting season. The highest frequency of

mating usually takes place during the pre-nesting period and at the beginning of the

nesting season, and this is also the time when ephemeral wetland habitat is most likely

available. Male Blanding's turtles were found to use ephemeral wetland habitat during

both years of our study, and other studies have also reported the movement of Blanding's

turtles to ephemeral habitat during the spring (Grgurovic & Sievert, 2005; Joyal et al.,

1996). These temporary wetlands contained numerous amphibian egg masses and other

invertebrates that may be an important food source (Beaudry et al., 2009; Calhoun et al., 2003), and may increase seasonal movement beyond residence habitat while this temporary habitat it is available. Majority of this habitat dried by the middle of the summer, and turtles were no longer located in these areas anytime after the nesting season. For females, we found significantly higher rates of movement during the nesting season relative to both the pre-nesting and nesting seasons. Variation in rates of movement for male and female Blanding's turtles in this study correspond with seasonal differences in foraging behaviour and sex-specific reproductive behaviour, and support the predictions of the reproductive strategies hypothesis (Beaudry et al., 2009; Congdon, 1989; Morreale et al., 1984, Millar & Blouin-Demers, 2011; Pearse & Avise, 2001).

Populations of Blanding's turtles that exist within landscapes that share features similar to those found in GB may be particularly vulnerable to habitat loss and human disturbances. Only few wetlands within GB provide suitable residence and hibernation habitat for Blanding's turtles, and habitat productivity has been found to influence the reproductive output of other freshwater turtles (Brown et al., 1994; Kennett, 1999). Remote residence wetlands that are surrounded by an upland matrix that restricts movement may have a low probability of recruitment, and may increase genetic isolation of that population. Nesting requires extensive terrestrial movement, during which adult females are at greater risk of mortality. Management planning for these populations must take into consideration male and female spatial requirements and the timing of migratory behaviour, and include the protection of substantial areas of terrestrial habitat surrounding residence wetlands.

Comparison among North American study sites

Studies throughout the Blanding's turtle species distribution report great variability in mean home range size (Table 3). They vary for males from 94.9ha in a Minnesota study (Hamernick, 2000), to as small as 0.8ha in a study in Wisconsin (Ross & Anderson,1990), and for females from 61.2ha in a study conducted in Algonquin Park, Ontario (Edge, et al., 2010), to 0.6ha in Wisconsin (Ross & Anderson, 1990). We suggest that availability of suitable aquatic habitat within the landscape may be a key determinant of turtle home range size. Other studies have reported that the degree of human disturbance has a significant impact on turtle populations and is likely another key determinant of turtle home range size and movement patterns (Aresco, 2005; Gibbs & Shriver, 2002; Refsnider & Linck, 2001). Increased mortality associated with movements among habitat in developed areas may lead to reduced movement among individuals remaining in populations. To enable comparisons among study sites, we used site descriptions within these publications to assign each study site into two categories for availability of aquatic habitat (high or low), and degree of human disturbance (high or low).

Three of the study sites (WC, IL, and RD) of the 11 listed in Table 3 either did not include the female nesting migration in the calculation of home range, or did not include long distance movements for males or females and thus were not suitable for comparison with other sites. Of the eight remaining sites in Table 3, the largest mean home ranges for males and females were all found at sites listed as having a high availability of aquatic habitat, while the sites with low aquatic habitat availability had the smallest mean home

ranges. Only two of these eight sites (NY and NH) were listed as having a high degree of human disturbance, both of which corresponded with the smallest mean home ranges for males and females. None of the study sites that report a high degree of human disturbance, and a high amount of aquatic habitat availability; it is most likely that highly degraded areas no longer contain high amounts of suitable aquatic habitat for Blanding's turtles.

These data suggest that in absence of disturbance, regardless of sex, animals have larger home ranges when there is a high availability of aquatic habitat. Although Blanding's turtles are semi-aquatics with impressive terrestrial capabilities, it is most likely that landscapes with high amounts of aquatic habitat create the most favourable conditions and facilitate travel among preferred habitat locations, which permits larger home ranges. A high degree of human disturbance can reduce Blanding's turtle home ranges in a population and may have a greater impact on female home range than on male home range. Female Blanding's turtles, particularly those with the largest home ranges and longest nesting migrations in a population may face higher rates of road mortality in areas with higher road density. The remaining female members of these populations may have smaller nesting migrations and use smaller home ranges, and would therefore be less frequently exposed to roadways. This interpretation is consistent with the findings from a study by Attum et al., 2008, who found that two highly vagile semi aquatic species with larger home ranges were less likely to occur in ponds that are in closer proximity to roads, when compared to two semi-aquatics that have a lower tendency to undertake terrestrial movements and have smaller home ranges.

We would also expect these populations to have a male biased sex ratio as a result sex-specific terrestrial movements and high female mortality, as has been found by many other studies of freshwater turtle species in North America (Aresco, 2005; DeCatanzaro & Chow-Fraser, 2010; Marchand & Litvaitis, 2004; Steen & Gibbs, 2004; Steen et al., 2006). This interpretation of reported home range data from across the North American species distribution suggests that landscape features may have sex-specific effects on home range size, and that further investigation is required to understand precisely how these environmental features interact with other influences on Blanding's turtle spatial requirements.

Limitations

In 2011 our study initially focused on data collection in two study sites, and later shifted our focus to a single study site after the mid-summer period when turtle movement was expected to decrease. We have limited locational data for individual turtles in the RD population, and our analysis may significantly underestimate the total area of habitat used by both male and female turtles. Most studies recommend researchers obtain a far greater number of locations over the majority of at least one complete active season for a robust estimate of home range (Millar & Blouin-Demers, 2011; Powell et al., 2000; Schuler & Thiel, 2008; Swihart & Slade, 1985). Although our estimations of range for turtles in RD cannot be considered robust, each of the turtles had returned to their residence wetland location by the last day of data collection in 2011; it is likely that the locations we gathered captured a significant portion of each turtle's home range in 2011, which enables us to draw reasonable conclusions for this comparison study. The derived means of home

ranges for male and female Blanding's turtles in RD should be considered the minimum expected during a single season.

In both populations, we found high variability in home range size among individual turtles, and large differences between sexes. Although there was low inter-annual variation in mean home range size for both males and females, the difference between mean home range size when calculated for either 2011 or 2012 alone, and the home range size when calculated for both years combined was substantial (Table 5). We recommend that future home range studies of Blanding's turtles and other vagile semi-aquatic species prioritize tracking a larger number of individuals of both sexes to observe the large individual variation that can exist in populations. Additionally, if home range data for a single year is used to delineate the required area of protection for any population, a buffer should be used to account for anticipated differences in single versus multiple-year home range size. Within these buffered areas, preferred habitat should be carefully mapped to determine key sites that Blanding's turtles are likely to inhabit during each of the three behavioural seasons, as well as the corridors for movement between these sites.

Conclusion

Populations of Blanding's turtles are continuing to decline as a result of human encroachment. An understanding of the unique spatial requirements of distinct populations of Blanding's turtle is essential for conservation planning, and for managers who must make precise decisions regarding the protection of critical aquatic and terrestrial habitat for this at-risk species. This study provides detailed information

regarding the home ranges and movements of Blanding's turtles in two distinct eco-regions of Ontario where their spatial requirements had not previously been examined. Our findings also contribute to the growing literature base that proposes that landscape characteristics, in particular aquatic habitat availability and connectivity, are important determinants of Blanding's turtle spatial behaviour. Future studies should empirically examine how differences in landscape connectivity influence home range, movements and habitat selection by Blanding's turtles.

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Table 1.   Characteristics of Beausoleil Island in Georgian Bay Islands National Park, and Rondeau Provincial Park.

	Study site location	
Site Characteristics	GB	RD
Setting	Protected island	Protected peninsula
Approximate size	1100ha	3250ha
Blanding's population size (relative)	Small [a]	Large [b]
Aquatic habitat availability	Low	High
Aquatic habitat connectivity	Low	High
Productivity of residence wetland habitat	Low	High
Productivity of surrounding habitat	Low	High
Human disturbance	Low	Low

[a] We conducted a mark recapture study of Blanding's turtles in GB during 2012 (data not shown); however, the number of captures was inadequate to permit estimation of population size, and therefore we have inferred that the population must be small.

[b] A herpetofaunal survey was conducted in RD in 2000 and 2001 which revealed that the population of Blanding's turtles is much larger than the population in GB (Gillingwater, 2001)

Table 2.   Dates corresponding to initial capture of each Blanding's turtle in the study

sites.

Site	Sex	ID code	Initial date captured
GB	Male	GBM1	27-April-2011
		GBM2	28-April-2011
		GBM3	4-May-2011
		GBM4	5-May-3011
		GBM5	19-May-2011
		GBM6	25-May-2011
RD	Male	RDM1	12-April-2011
		RDM2	20-April-2011
		RDM3	20-April-2011
		RDM4	21-April-2011
GB	Female	GBF1	27-April-2011
		GBF2	27-April-2011
		GBF3	3-May-2011
		GBF4	4-May-2011
		GBF5	18-May-2011
		GBF6	31-May-2011
RD	Female	RDF1	11-May-2011
		RDF2	11-May-2011
		RDF3	2-June-2011

Table 3. Comparison of home-range size (ha) for male and female Blanding's turtles reported from other studies sites in North America as of November, 2012. Numbers in bracket refer to the sample size used to calculate the home range in each study.

Province/State		Latitude	Longitude	Method used	Availability of aquatic habitat	Degree of human disturbance	Male HR	Female HR
Minnesota (Central) Piepgras & Lang, 2000	MC	46.18	-94.44	MCP	High	Low	38.4 (6)	35.4 (13)
Wisconsin (Wood County) Schuler & Thiel, 2008	WC	45.28	-90.17	MCP	High	Low	26.1 (9)	20.7 (9)
Ontario (Algonquin Park) Edge et al., 2010	AP	45.15	-78.00	MCP[a]	High	Low	57.1 (8)	61.2 (13)
Ontario (Georgian Bay Islands National Park), current study	GB	44.88	-79.86	MCP	Low	Low	10.4 (6)	20.9 (6)
New York Crockett, 2008	NY	44.45	-74.95	MCP[d]	Low	High	7.5 (7)	12.3 (17)
Ontario (St. Lawrence Island) Millar & Blouin-Demers, 2011	SL	44.40	-75.87	MCP	High	Low	8.5 (20)	20.3 (18)
Minnesota (Southeast) Hamernick, 2000	MN	44.15	-91.55	MCP	High	Low	94.9 (8)	60.8 (16)
Wisconsin Ross & Anderson, 1990	WC	44.11	-89.96	MPM[b]	Low	Low	0.8 (2)	0.6 (4)
New Hampshire (Stratford) Innes et al., 2008	NH	42.83	-71.62	MCP[d]	Low	High	3.7 (4)	1.5 (3)
Illinois Rowe & Moll, 1991	IL	42.46	-88.17	MPM[e]	Low	High	1.4 (4)	1.2 (3)
Ontario (Rondeau Bay), current study	RD	42.28	-81.85	MCP[e]	High	Low	19.3 (4)	0.6 (3)

[a] An adaptive kernel with a smoothing factor for home range to equal 100% of MCP was used
[b] Nesting migration and long distance movements not included, MPM is equivalent to MCP
[c] Study shows median values instead of averages,
[d] Study used only 95% of locations to calculate MCP
[e] Female nesting migration not included

Table 4. Estimated size (ha) of home ranges (HR) for male and female Blanding's turtles living in Georgian Bay Islands National Park (GB) and Rondeau Provincial Park (RD). Home ranges were estimated from locational data obtained from the time of their initial capture (see Table 2) until 18 July 2011.

Site	Sex	ID code	# locations included in calculation of HR	HR size
GB	Male	GBM1	12	2.29
		GBM2	13	3.15
		GBM3	11	8.83
		GBM4	11	0.35
		GBM5	10	0.68
		GBM6	9	2.00
				$\bar{x} = $ **2.88 ± 1.26 (SE)**
RD	Male	RDM1	8	32.57
		RDM2	9	7.76
		RDM3	8	29.73
		RDM4	9	7.14
				$\bar{x} = $ **19.30 ± 6.87 (SE)**
GB	Female	GBF1	14	0.29
		GBF2	12	0.57
		GBF3	9	0.52
		GBF4	12	0.23
		GBF5	10	0.12
		GBF6	9	0.66
				$\bar{x} = $ **0.40 ± 0.09 (SE)**
RD	Female	RDF1	7	1.02
		RDF2	8	0.55
		RDF3	3	0.21
				$\bar{x} = $ **0.60 ± 0.23 (SE)**

Table 5.　Estimated size (ha) of home ranges (HR) for male and female Blanding's turtles living in Georgian Bay Islands National Park (GB). Home ranges were estimated from locational data obtained from the time of their initial capture in April until September in 2011 and from April until August in 2012 (see Table 2 for dates of initial capture).

Sex	Year	ID code	# locations included in calculation of HR	HR size
Male	2011	GBM1	21	4.01
		GBM2	22	4.01
		GBM3	19	25.72
		GBM4	20	1.48
		GBM5	19	0.90
		GBM6	18	3.84
				$\bar{x} =$ **6.66 ± 3.85 (SE)**
Female	2011	GBF1	40	12.40
		GBF2	21	3.85
		GBF3	34	44.10
		GBF4	21	9.96
		GBF5	32	7.07
		GBF6	18	8.26
				$\bar{x} =$ **14.27 ± 6.07 (SE)**
Male	2012	GBM1	11	3.01
		GBM2	12	2.17
		GBM3	16	29.60
		GBM4	10	1.92
		GBM5	11	1.22
		GBM6	11	1.25
				$\bar{x} =$ **6.53 ± 4.62 (SE)**
Female	2012	GBF1	17	9.86
		GBF2	13	8.18
		GBF3	46	57.34
		GBF4	27	11.17
		GBF5	12	4.84
		GBF6	12	17.34
				$\bar{x} =$ **18.12 ± 8.02 (SE)**
Male	2011+2012	GBM1	32	4.81
		GBM2	34	4.07
		GBM3	35	44.92
		GBM4	30	2.34
		GBM5	30	2.20
		GBM6	29	3.90
				$\bar{x} =$ **10.37 ± 6.92(SE)**
Female	2011+2012	GBF1	57	12.91
		GBF2	34	10.49
		GBF3	80	63.02
		GBF4	48	12.09
		GBF5	44	8.31
		GBF6	30	18.40
				$\bar{x} =$ **20.87 ± 8.54 (SE)**

Table 6. Rates of movement for male and female Blanding's turtles in each of the pre-nesting, nesting and post-nesting seasons in Georgian Bay Islands National Park. The data presented were normalized with a log transformation.

Sex	Season	Log(distance/day) (m)
Male	Pre-nesting	$\bar{x} = 1.26 \pm 0.16$ (SE)
	Nesting	$\bar{x} = 1.17 \pm 0.08$ (SE)
	Post-nesting	$\bar{x} = 0.83 \pm 0.08$ (SE)
Female	Pre-nesting	$\bar{x} = 0.87 \pm 0.11$ (SE)
	Nesting	$\bar{x} = 1.45 \pm 0.06$ (SE)
	Post-nesting	$\bar{x} = 0.79 \pm 0.07$ (SE)
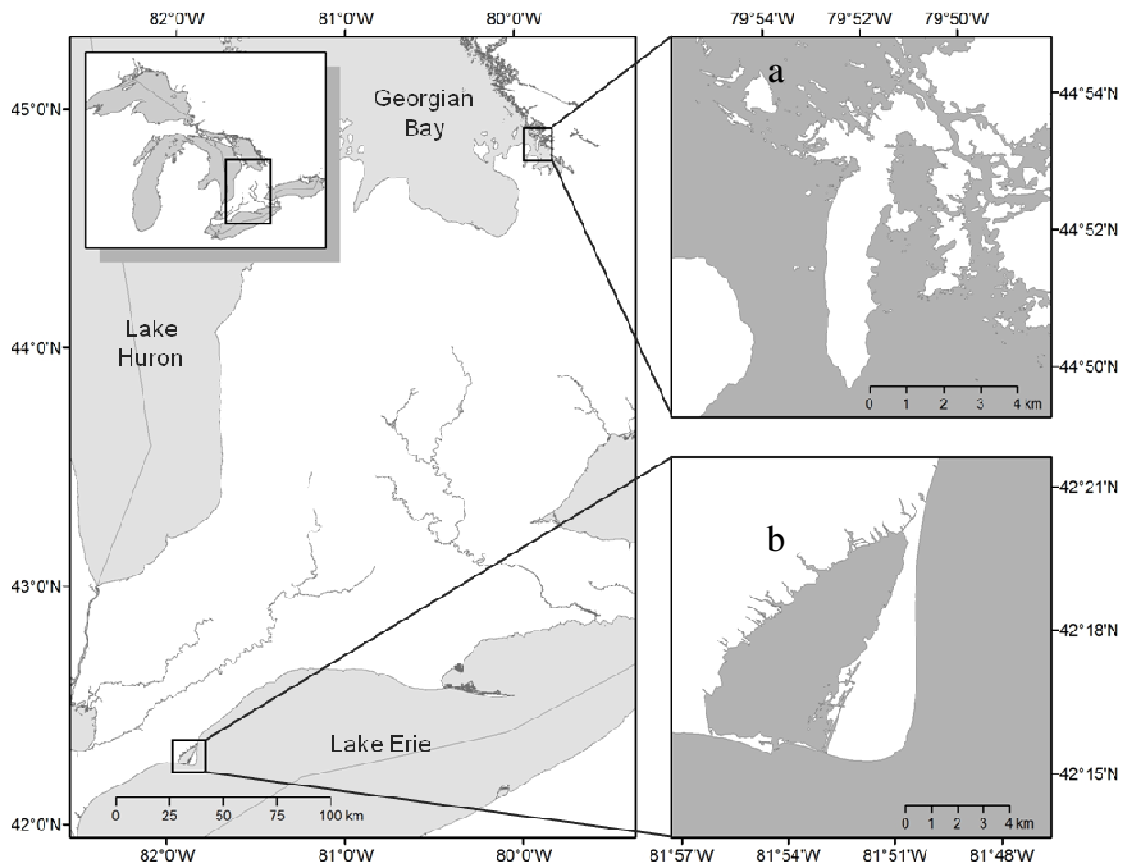
Figure 1. The two study sites, a) Beausoleil Island in Georgian Bay Islands National Park, and b) Rondeau Provincial Park, both located in the coastal regions of the Great Lakes in Ontario, Canada.
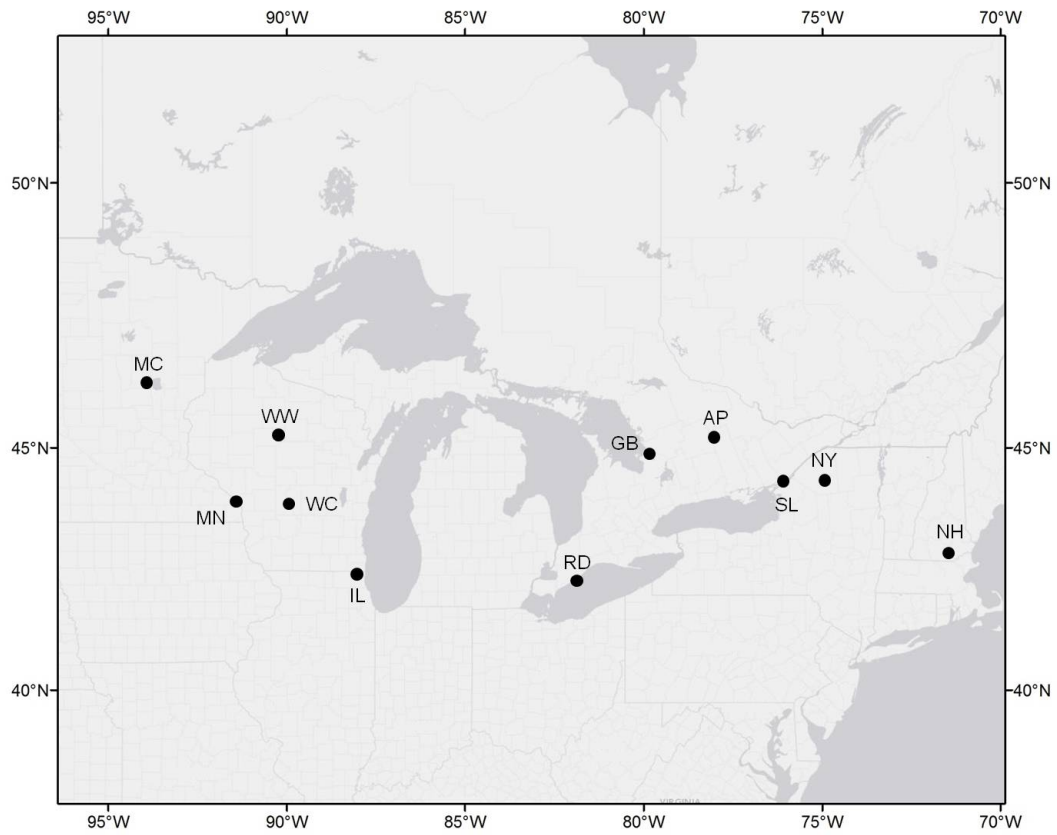
Figure 2. Locations of study sites throughout the Blanding's turtle North American

species range that have calculated home range size for Blanding's turtles as of

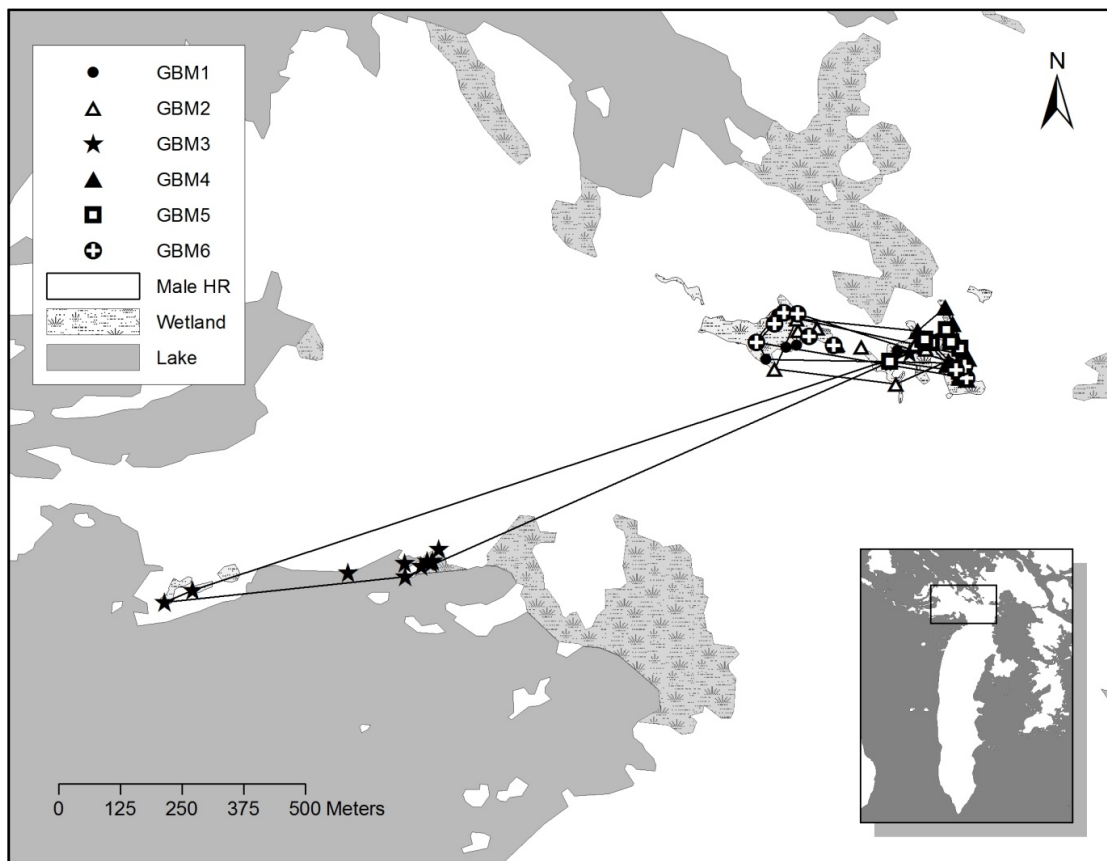November 2012 (see Table 3 for abbreviations).

Figure 3.   Locations and the home ranges of six male turtles from capture in 2011 (see
Table 2 for dates of initial capture for each turtle) until 18 July 2011 in
Georgian Bay Islands National Park
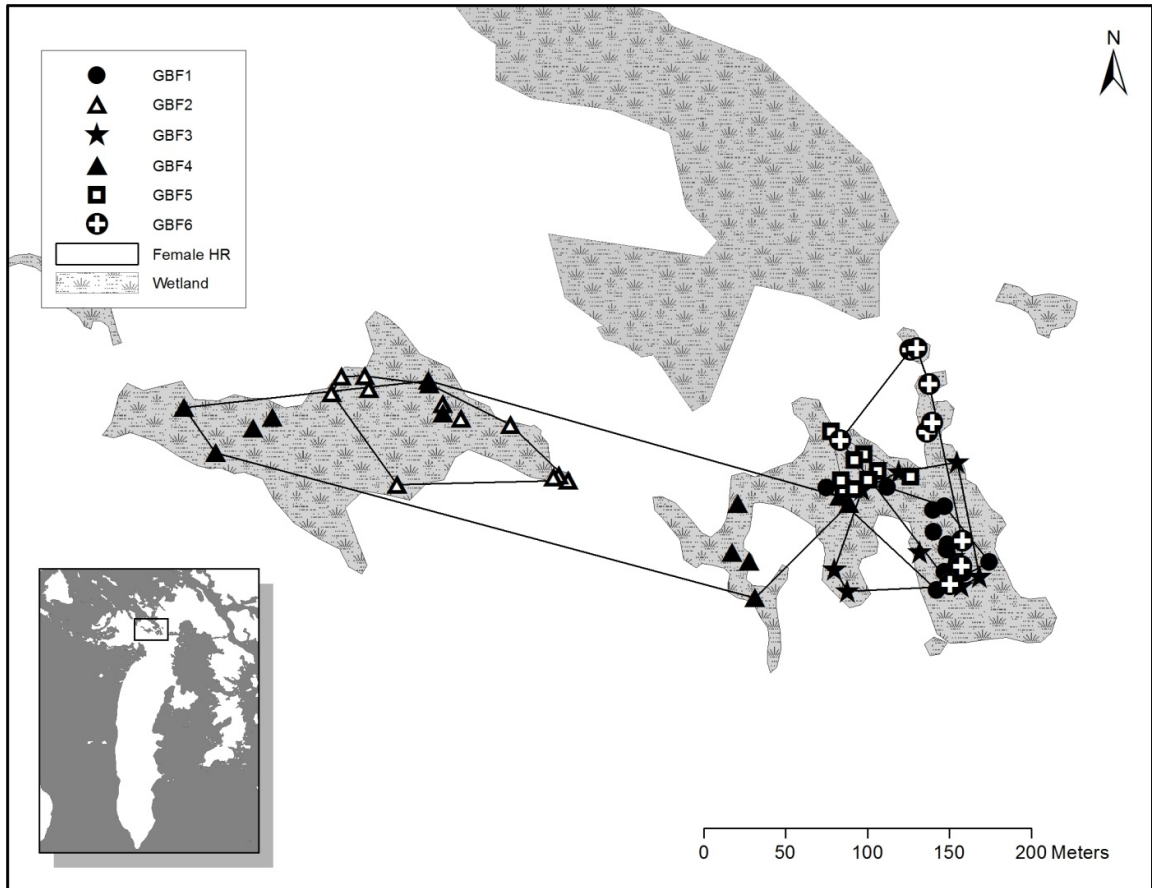
Figure 4. Locations and the home ranges of six female turtles from initial capture in 2011 (see Table 2 for dates of initial capture for each turtle) to 18 July 2011 in Georgian Bay Islands National Park. The nesting migrations of the females are not included in this figure.
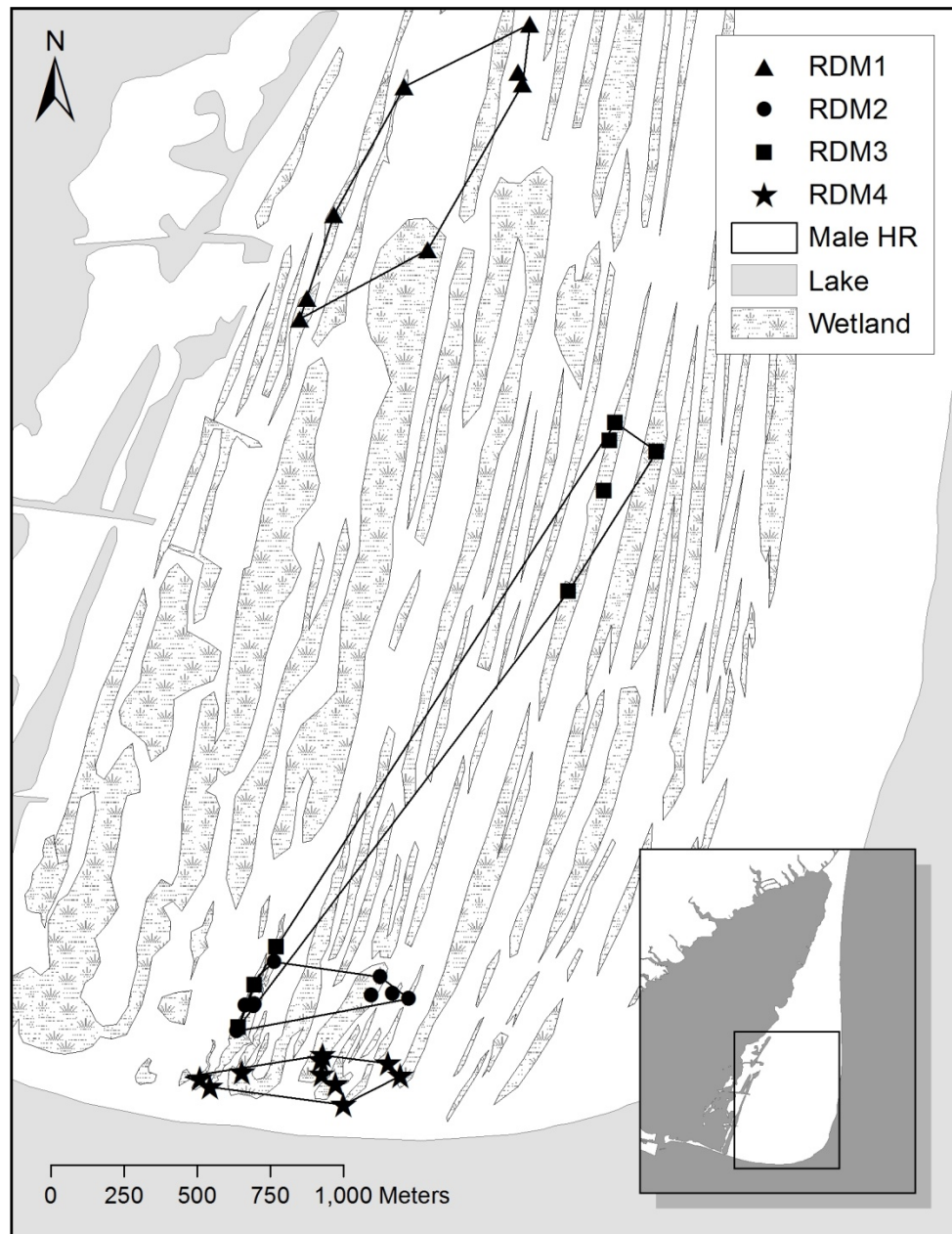
Figure 5. Locations and the home ranges of four males turtles from capture in 2011 (see Table 2 for initial dates of capture for each turtle) until 18 July 2011 in Rondeau Provincial Park.
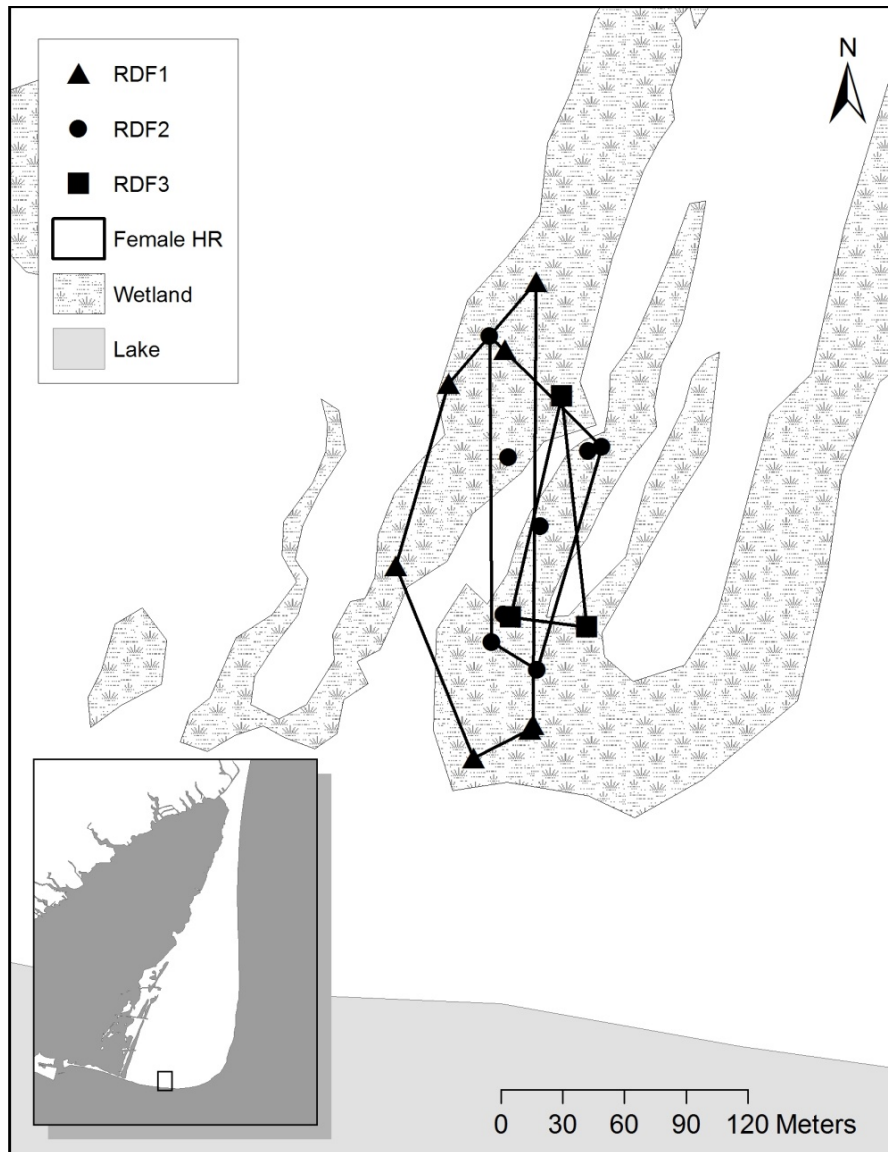
Figure 6.   Locations and the home ranges of the three female Blanding's turtles from capture in 2011 (Table 3) to 18 July 2011 in Rondeau Provincial Park.
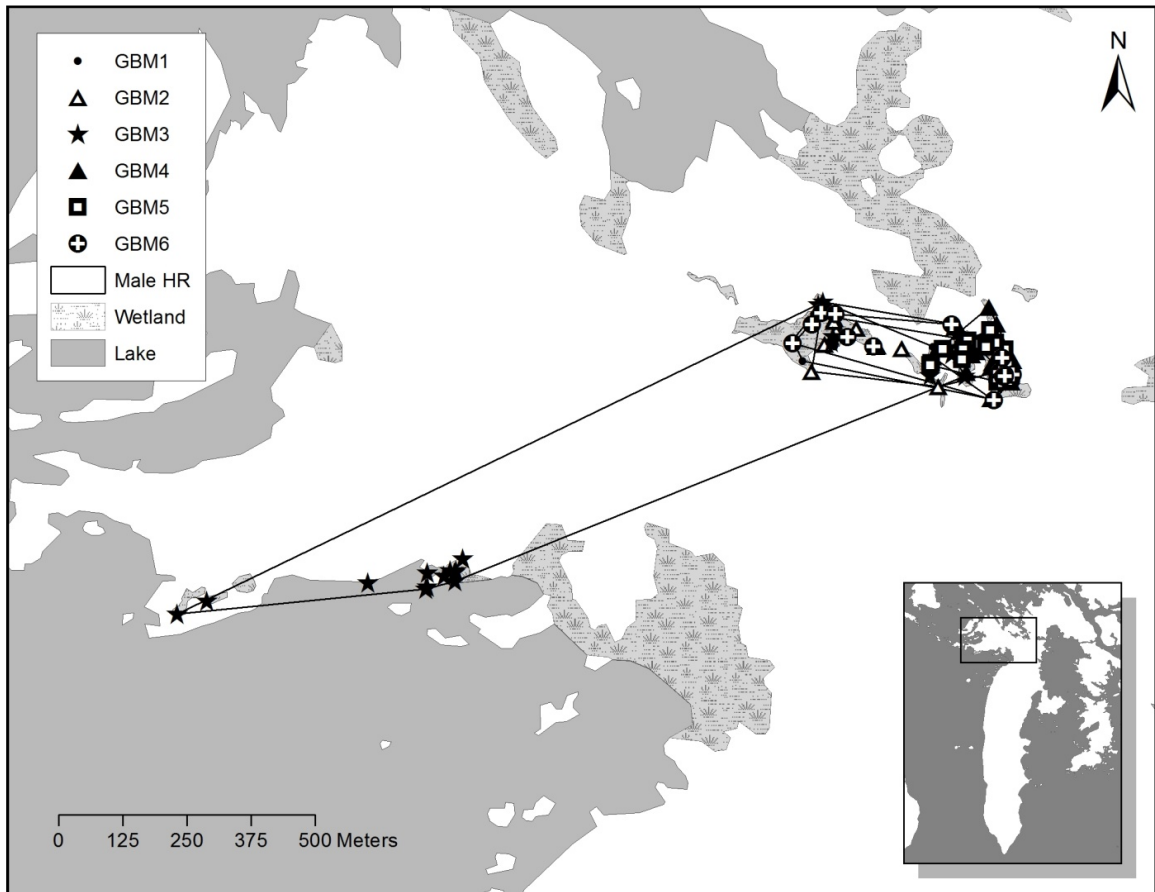
Figure 7. Locations and home ranges for six male Blanding's turtles from initial capture in 2011 (Table 3) until August 23, 2011 in Georgian Bay Islands National Park.
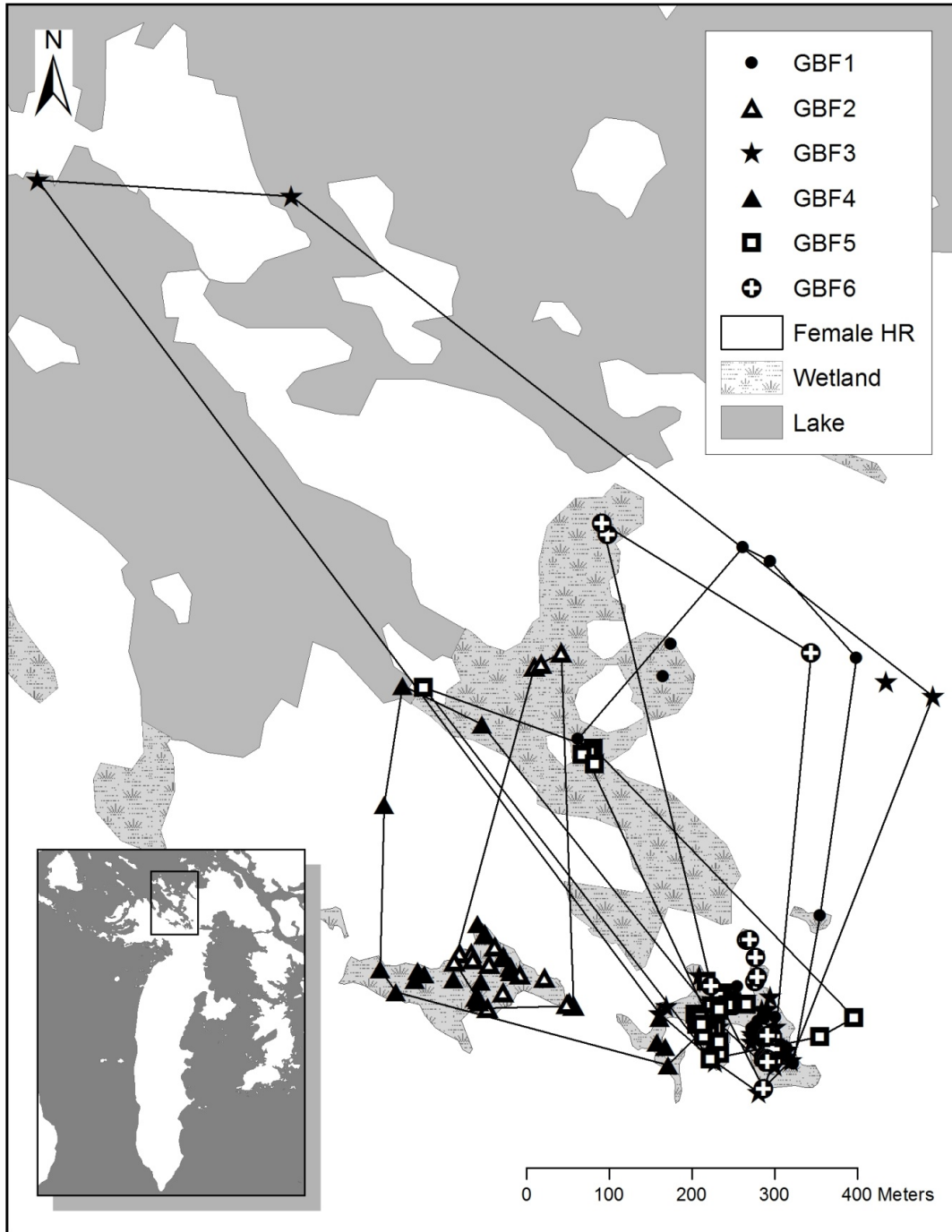
Figure 8.   Locations and home ranges for six female Blanding's turtles from initial
capture in 2011 (Table 3) until August 23, 2011 in Georgian Bay Islands
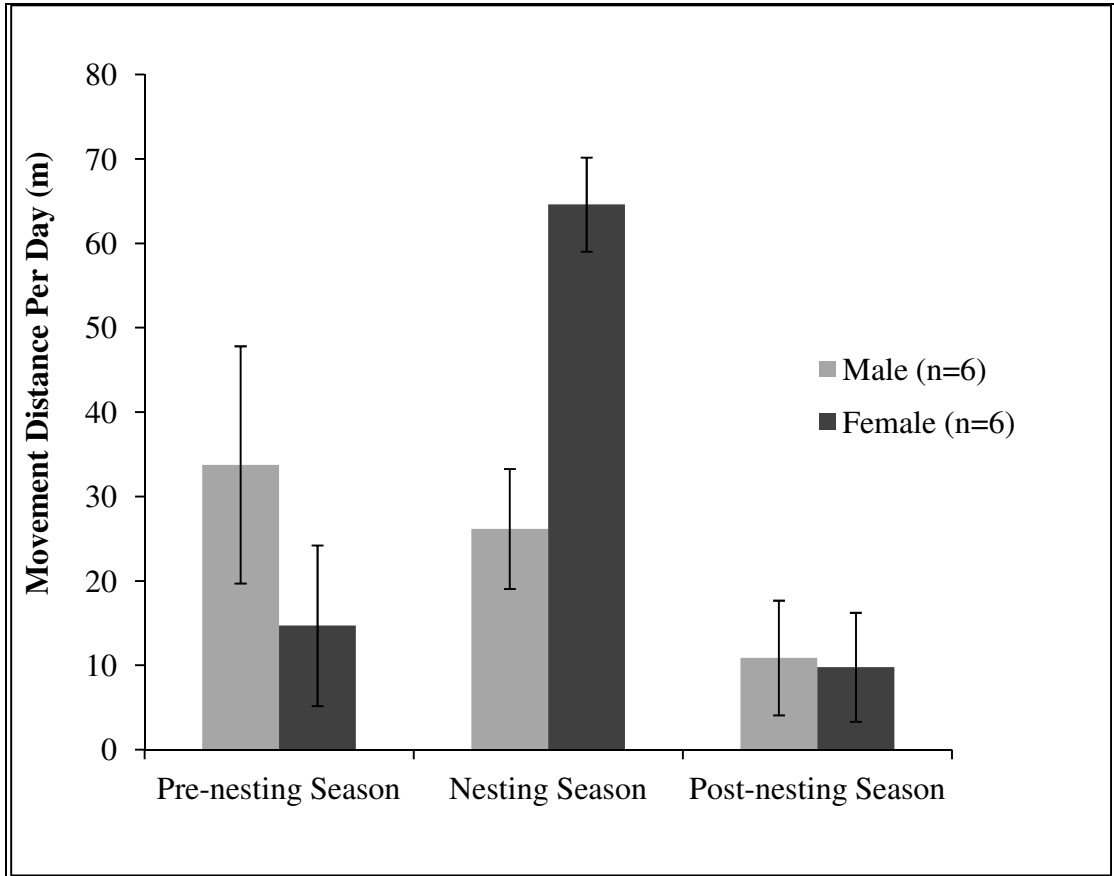National Park.

Figure 9. Mean daily movement distance (see Methods) for six male and six female Blanding's turtles from initial capture in 2011 (Table 2) until August 23, 2011, in Georgian Bay Islands National Park. For two-way ANOVA, movement data from this figure were first normalized (see Table 6).

CHAPTER 2   USE OF GPS LOGGERS TO ENHANCE RADIO-TRACKING STUDIES OF FRESHWATER TURTLES

ABSTRACT

Radio-tracking of freshwater turtles typically involves the manual collection of locational data at a rate of once per day to once per week. This is costly, logistically burdensome, and can disturb the animal from its natural patterns of behaviour. Furthermore, even with high-intensity tracking regimes, there are insufficient data to resolve short-term sojourns and travel corridors, and the use of temporary habitats by the focal species is often missed. Though Global Positioning System (GPS) logging devices have proven to be useful for tracking many terrestrial and some aquatic animal species, their utility in the tracking of freshwater turtles has not previously been examined. We used GPS loggers to supplement our radio-tracking study of three female Blanding's turtles in Georgian Bay Islands National Park in the 2011 field season, and two male and two females during the 2012 field season. We determined that GPS loggers in combination with radio-tracking can effectively track the movements of this semi-aquatic species with a higher temporal and spatial resolution than by radio-tracking alone. The GPS loggers provided additional data to: 1) arrive at a more complete mapping of habitat used by the Blanding's turtles; 2) identify novel areas of critical habitat that were not discovered during the process of radio tracking; 3) reveal movement corridors between critical habitat locations; and 4) uncover fine scale patterns of movement within wetland habitat. We discuss the advantages, disadvantages and limitations of GPS logging

technology, and provide an approach to maximize their effectiveness for tracking

freshwater turtles.

Radio-tracking is widely used to observe movement patterns of animals to determine their home range size, rates of dispersal, areas of activity, use of travel corridors, and habitat preferences and requirements (White & Garrot, 1990). This method can be very labour intensive, typically requiring researchers to locate animals at a rate of once per week to as regularly as several times per day during their active seasons (Dowling et al., 2010; Harris et al., 1990; Rowe & Moll, 1991). Although this frequency of tracking is required to generate sufficient data to accurately map an animal's home range (Swihart & Slade, 1985; Kie et al., 2010), the researcher's constant presence may affect the animal's natural movements; therefore, radio-tracking is not ideal for determining habitat that is rarely used or used only for short durations (e.g. travel corridors), or for delineation of fine-scale movement patterns. The recent introduction of GPS-enabled logging devices has solved some of these problems. When used in conjunction with traditional radio-tracking, researchers have been able to increase both the frequency and spatial resolution of data collected (Cagnacci, 2010; Johnson et al., 2002; Schwartz & Arthur, 1999).

Advantages of GPS loggers include their ability to record relatively precise global positioning data at different times during the day, in most weather conditions, and under a variety of vegetative types and canopy cover (Cagnacci, 2010). Most can be programmed to record positional fixes at pre-determined intervals ranging from a near-continuous setting to weekly or monthly rates and greater, and they are also cost-effective, capable of collecting and storing large amounts of data (Cagnacci, 2010; Recio et al., 2011). GPS

loggers aren't, however, without limitations. Their high upfront purchase price is a deterrent for programs with small budgets since radio-tracking equipment is already costly (Hebblewhite & Haydon, 2010). The upper limit of battery size and weight (i.e. battery life) is dictated by size of the animal under investigation, and since battery life diminishes with frequency of attempts at positional fixes, there is a limit to how useful they can be for studying fine-scale movements of small animals (Recio et al., 2011; Quaglietta et al., 2012). Finally, their inability to obtain positional fixes while submerged under water is a serious limitation for studying species that are semi-aquatic (Quaglietta et al., 2012).

When GPS loggers were initially introduced for the study of spatial ecology, they were large and heavy, and were only practical for use on large terrestrial animals. They were first used for tracking elephants, caribou, moose and bears (Douglas-Hamilton, 1998; Johnson et al., 2002; Rodgers et. al., 1996; Schwartz & Arthur, 1999). Recent improvements in battery performance and circuitry have resulted in miniaturized lightweight devices (as little as 8 grams) that are feasible for tracking a wider range of terrestrial animals including small mammals, birds and reptiles (Cagnacci, 2010; Kotzerka et al., 2009; Recio et al., 2011). Despite this, the effectiveness of GPS loggers for use with aquatic and semi-aquatic species has not yet been thoroughly examined (Quaglietta et al., 2012) and there are no published studies on use of GPS loggers to supplement radio-tracking studies of freshwater turtles.

In this paper, we determine how GPS loggers in combination with radio-tracking can be used to follow the seasonal movements of Blanding's turtles on an island in a

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Canadian national park. These semi-aquatic turtles spend much of their time underwater in wetlands, but rely on many types of terrestrial habitats for throughout the season (Innes et al., 2008; Joyal et al., 2001; Piepgras & Lang, 2000; Rowe & Moll, 1991). We therefore assessed how combining GPS with radio-tracking can improve home-range mapping and determination of critical habitat and migration routes within the park. This is important for developing conservation strategies for Blanding's turtles because they are known to have a relatively large nesting migration (commonly >1.5km) and can vary widely from study to study with respect to type of landscape features used for nesting (Edge et al., 2010; Joyal et al., 2001; Standing et al., 1999). If the addition of GPS loggers to traditional radio-tracking can significantly improve spatial and temporal resolution of the Blanding's movements, then this technology should be adopted for future studies.

METHODS

Location of Field Study

We conducted a field study of the spatial ecology of Blanding's turtles on Beausoleil Island of Georgian Bay Islands National Park in Ontario Canada using radio-tracking techniques, and examined the effectiveness of GPS loggers in supplementing the collection of locational data. Beausoleil Island is located in Georgian Bay, the eastern arm of Lake Huron (Figure 1). The portion of the island included in this study is dominated by Canadian Shield landscape features with mixed boreal and deciduous forest, and contains many wetland habitats such as marshes, bogs, swamps and vernal pools. These wetland habitats are naturally fragmented by rocky outcrops, making it an ideal location to

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examine how semi-aquatic species use upland habitat and corridors that connect these critical habitats.

Field Techniques

In April and May of 2011 and 2012, we captured Blanding's turtles by hand, dipnet, or in hoop nets baited with canned sardines or cat food, placed in areas of open water. Sex was determined by identifying male secondary sexual characteristics (Ernst & Lovich, 2009), and each turtle was marked for future identification by filing a unique combination of notches into their marginal scutes (Cagle, 1939). We recorded straight carapace length and width, plastron length and width, and shell depth for each turtle. We also weighed each turtle using a scale (Starfrit Digital Scale, acc. ±1g) to ensure that each turtle was sufficiently large to carry the weight of the tracking devices (the combined weight of the GPS loggers, radio-transmitters and fittings was required to be <5% of body weight); this weight is widely considered to be acceptable for tracking devices and fittings on freshwater turtles to avoid significant impact on the turtle's behaviour (Edge, et al., 2010; Innes et al., 2008; Millar & Blouin-Demers, 2011).

We attached radio transmitters (Holohil Systems Ltd., Carp, Ontario, Canada; Model AI-2F 19g) to the rear marginal scutes of each turtle using fast-drying epoxy (LePage Speed Set Epoxy) and plumber's epoxy (Oatey Epoxy Putty). These radio transmitters were designed to have a battery life of at least 24 months to ensure that two field seasons of tracking was possible. We also attached GPS loggers (Lotek Wireless, Newmarket, Ontario; GPS Bug, approximately 12.5g, 10m accuracy) to three adult female Blanding's turtles in 2011 and two adult females and two adult males in 2012. In

2011, the GPS loggers were attached to the left rear marginal scutes with the same

techniques and materials described for the radio transmitters. During the 2012 field

season, we also used a GPS logger from Telemetry Solutions, California (Quantum

4000E Mini bird GPS Logger, approximately 30g, 10m accuracy). In 2012, we attached

the GPS loggers to the left rear costal scutes using a brass base plate; this positioning is

considered a safe alternative to the location for attachment we used in 2011 (Boarman et

al., 1998). Positioning the GPS logger closer to the top of the carapace improved the

likelihood of obtaining GPS locations. The base plate allowed us to remove the device

from the turtle to download data and recharge the device. The total weight of the devices

and fittings (radio transmitter only 25g, radio transmitter and Lotek GPS Logger 40g,

radio transmitter and Telemetry Solutions GPS Logger 60g) was <5% of total body

weight of the adult turtles to which they were attached. Once we confirmed that the

devices were firmly attached, the turtles were returned to their point of capture.

We radio-tracked the Blanding's turtles using a Lotek Biotracker Receiver (Lotek

Wireless, Newmarket, Ontario, Canada) and a Yagi antenna (Wildlife Materials

International, Murphysboro, Illinois, USA). Given the variable terrain and wetlands of

our study site, we were able to receive a signal from the radio-transmitters when the

turtles were within 1.25 km. Their locations were verified one to two times per week

between April and September. Once located, the time of day and position were recorded

with a handheld GPS unit (Garmin, Kansas City, Kansas, USA). Additional information

recorded include the activity of the animal at the time of capture, water depth when in

aquatic habitat, dominant substrate, dominant vegetation, and a digital photo of each location.

GPS logger Device Settings

The Lotek GPS loggers and the Telemetry Solutions loggers used for this study could be programmed to provide positional fixes at almost any time interval, from near continuously, to weekly, monthly and even longer durations. The GPS loggers were deployed from 17 May 2011 until 19 September 2011, and from 4 May 2012 to 19 July 2012. To retrieve logged GPS data and to recharge the devices, turtles were recaptured (through radio-tracking) four to eight times over the field season. Approximately every 80 to 150 fix attempts, the devices required a two-hour recharge that was accomplished by connecting them to a PC with either a Lotek DL-4 communication cable for the Lotek devices, or a micro USB cable for the Telemetry Solutions device. Data were downloaded to a PC with either the software program GPS3000 Host Application (Version 2.4.88.1., Lotek), or Quantum GPS Collars SW (Version 0.160, Telemetry Solutions). The GPS loggers were pre-programmed to attempt a locational fix according to a user-defined schedule. A fix required detection of three or more satellites for a period sufficiently long to trilaterate and log its location. We programmed the devices to attempt position fixes at different time intervals depending on the type of movement information we were interested in obtaining. Shorter time intervals were used to determine finer scale movement including movement corridors, and larger intervals were used to determine locations at least twice weekly to map main activity centers of the animals.

During the 2011 and 2012 field seasons, we used GPS loggers to track the

movements of Blanding's turtles in addition to a standard weekly radio-tracking regime.

These devices were deployed for a total of 471 days over the two seasons, and were

programmed to obtain 1693 fixes. Of these, the total number of realized fixes was 373,

indicating that on average 22.0 % (min 7.8%, max 43.7%) of total attempts resulted in a

locational fix.

During the 2011 field season, we examined the relationship between the

percentage of realized fixes and the time period of day (Figure 2, A). To test for

differences among time periods, we used data that were collected when the devices were

programmed to obtain fixes successively (every 1.5-h, 2-h, or every 4-h) throughout each

day it was deployed; we omitted data when device schedules were focused on specific

time periods to maximize battery efficiency (Figure 2, B). The percentage of realized

fixes varied significantly throughout the 24-h period of each day (χ^2 (5, $n = 624$) =

67.62, $p < 0.001$), with the highest percentage of fixes occurring between 08:00 and

20:00, and peaking at between the 12:00-16:00 period (27%, Figure 2, B). During the

three other time periods the percentage of realized fixes was consistently low (<2%). This

information was used to guide us in programming the devices to obtain the desired type

of locational information while maximizing the battery life and the time between required

recharge periods.

When we used the GPS loggers to track the movements of females during the

nesting season, we programmed the devices to record their positions during evening and

overnight hours in addition to mid-day hours to capture detail in regards to the nesting

migration corridor and the nesting area. Over a 15-d period between 7 June and 20 June

in 2011, a female turtle was located four times by radio-tracking, but 27 times by GPS

logger (Figure 3). The GPS logger obtained additional locations that revealed a migration

route that could not have been identified with the conventional tracking regime of one to

two locations per week by radio-tracking. In addition, we were able to confirm: (1) the

use of marsh habitat as a staging area for four days from 11 June 2011 (Day-6) to 14 Jun

2011 (Day-9); (2) the precise timing of the movement from the staging area to the nesting

area on Day-9 and the actual nesting area based on the timing of her terrestrial activity

from 4:00 to 21:00 that same day and; (3) the duration of the nesting event that lasted

from 14 June (Day-9) to 16 June (Day-11), after which the female moved away from the

terrestrial nesting area and returned to her residence wetland.

The additional data obtained by the GPS logger were also useful for delineation of

activity centers for individual turtles. We collected 53 locations of an adult female

Blanding's turtle from 24 May 2012 to 20 June in 2012. Six of these locations were

obtained by radio-tracking and corresponded to a polygon with an area of 14.6 ha; the

additional 47 locations were obtained by the GPS logger, and yielded a polygon with an

area of 42.2 ha (Figure 4). This larger area also encompassed the habitat used by the

female for nesting as determined by the timing of recorded terrestrial activity from

10:00am on 10 June until midnight on 11 June 2012. This female was also observed

spending an additional nine days in marsh and lake habitat after her terrestrial nesting

migration, before returning to her residence wetland.

We made seven comparisons of annual home range estimates (three in 2011 and four in 2012) for turtles that had been equipped with both radio transmitters and GPS logging devices (Table 2). The estimated home range size for all turtles increased from 1.7 to 48.4% when data from the loggers were included (mean increase of 24.7%). The mean size difference between methods was 3.4 ha but these differences were not statistically significant ($t(6)=2.3$, $p=0.060$).

Blanding's turtles make use of a single residence wetland for the majority of the active season. To track the fine-scale movements of two female turtles within their residence wetland, on 8 August 2011, we programmed GPS loggers to record a location every 10 minutes starting at 4:00, the earliest time of day we expected the turtles to be active above the water surface (Figure 5). Female 2 was active at the surface from 9:30 until 12:10, and again from 18:00 until 23:50; 49 locations were logged, with the majority of these within a distinct, deep (1m-1.5m) area of the residence wetland. By comparison, female 3 was only active at the surface from 13:50 until 17:10; 18 locations were logged, and these were primarily within a nearby but distinctly different pool (1m-1.5m) in the same wetland. Given that the horizontal accuracy of these locations is ±10 m, we cannot ascertain the short-term movement patterns of the turtles, but can conclude that the two females spent their day in two distinctly different pools.

DISCUSSION

We used GPS loggers in addition to radio tracking to follow the fine-scale movements of Blanding's turtles and to delineate their home ranges during the 2011 and

2012 field seasons. This is the first study to examine the utility of GPS loggers for tracking the movement of semi-aquatic turtle species. We found that the GPS loggers were effective at providing additional spatial and temporal information that could not have been obtained with a radio tracking regime in which turtles are located only one to two times per week. These additional data points revealed travel corridors during migration, the locations of critical staging and nesting habitat areas, the timing of movement between critical habitat locations, a significantly better mapping of seasonal and annual home range requirements, and fine scale movements on a single day within a residence wetland.

Initially, we focused our efforts on maximizing the proportion of positional fixes as well as prolonging battery life of the devices between recharge periods. During the 2011 field season, we investigated which time periods during the day resulted in the highest percentage of realized fixes and found that most positional fixes occurred between 08:00 and 20:00, with the highest frequency (27.0% of scheduled fixes) between 12:00 and 16:00. Blanding's turtles are known to exhibit a diurnal activity pattern, and have been found to have their highest level of activity during morning and evening hours, decreasing activity during the hottest hours in the afternoon (Rowe & Moll, 1991). Our observed unimodal distribution of surface or terrestrial activity is consistent with this, and we recommend that GPS loggers be programmed to take readings at mid-day during the pre-nesting and nesting seasons (April to June) to take advantage of the time when turtles are most likely to be basking. During the post-nesting period (July - August), however, it may be better to program the loggers to take readings during the morning and later

evening hours to coincide with greater surface and terrestrial activity that is expected

when daily high temperatures often exceed Blanding's turtles preferred temperature range

(Nutting & Graham, 1993; Rowe & Moll, 1991).

During the 2011 and 2012 season, positional fixes obtained during the less active

hours (i.e. between 0:00 to 04:00 and 20:00 to 24:00) were primarily associated with the

nesting migrations of two females in June, as well as one female who continued to be

active above the surface in early August in her residence wetland. Therefore, if the

objective is to capture the nesting migration of females, then we recommend

programming the devices to take positional fixes more regularly during evening and

overnight hours when she begins to depart from the residence wetland.

Our GPS logger captured fine-scale movements of one female over a 15-d nesting

migration that would not have been possible with radio-tracking alone (Figure 2). From

radio-tracking data alone, we knew that the female left the residence wetland on 6 June

(Day 1), and entered a vernal pool surrounded by forest the next day. The next time we

radio-tracked her, she was in terrestrial habitat over 400 m from the residence wetland.

Based on these radio-tracking data, we could not discern the exact path used by the

female during nesting migration or the location of the nest. With the GPS logger,

however, we were able to record the movement of this female from the vernal pool to the

coastal marsh on Day 6, where she remained for three days (Day 6 to Day 9) prior to her

nesting. On Day 9, this female moved from the coastal marsh to terrestrial habitat in late

evening (21:00). She was then radio-tracked on days 10 and 11 in terrestrial habitat,

before she returned to her residence wetland. Although we were able to obtain a number

of GPS logger locations that enabled a clear picture of this females nesting migration, the GPS loggers were only able to obtain positional fixes on 6 days of the 15-d migration due to battery life constraints and the amount of time this female spent submerged in aquatic refuge along the terrestrial migration corridor. Additionally, we were only able to capture detailed nesting migration activity of only one of three females that we equipped with GPS loggers during the 2011 nesting season; although the GPS loggers for the other two females yielded useful information regarding the migration routes (data not shown), they did not reveal precise location of the nesting areas or the timing of movement between these critical habitat areas.

During the 2012 field season, we programmed one of our GPS loggers to better map the area used by a female during the nesting season (Figure 4). To conserve battery life, the GPS logger was programmed to take positional fixes every day during the hours when surface or terrestrial activity was most likely to occur, with a limited focus on evening hours. During the 28-d period from 24 May to 20 June, the GPS logger was actively programmed to record locations on 22 days, and acquired positional fixes 47 times on 19 separate days. The additional information shows extensive use of aquatic habitat (wetland and lake) that had not been observed by radio tracking. Another benefit was the confirmation of the nesting location, and use of lake and marsh habitat for at least nine days following the nesting event for this individual. On Beausoleil Island, the Blanding's turtles with the largest home ranges travelled relatively long distances from their residence wetland (>750m) to the coastal marsh, and this was particularly difficult and time consuming to monitor with radio-tracking alone. Thus, the GPS loggers were

ideal for such overland migrations and enabled us to obtain an estimate of the nesting-season range that was three times larger than that produced by conventional radio-tracking (42.2 vs. 14.6 ha) (Figure 4).

In general, home range estimates associated with the radio-tracking + GPS method was larger than that associated with radio-tracking alone and this was expected because more data were collected (White & Garrot, 1990). Even though there were no significant differences in mean home range size between methods, for some individuals, the radio-tracking + GPS yielded home ranges that were as much as 48% larger (Table 2). The average increase of 24% for the seven individuals in this study demonstrate that radio tracking at a rate of only 1-2 times per week may be inadequate for demarcating the home ranges of the most vagile individuals from Blanding's turtle populations. Adult males and the oldest adult females are often associated with the largest home ranges, and population stability requires very high survivorship (>94%/year) of these adults in a population (Congdon et al., 1993). If the objective is to determine land protection requirements for maintaining population stability, GPS loggers would be helpful in mapping the largest home ranges of adult turtles in the population, and more accurately define the area required for protection of the population.

In addition to improved mapping of home range and migration routes, we also used the GPS loggers to track fine-scale movements of individuals within their residence wetland habitats. Blanding's turtles are known for their long migrations and use of multiple wetlands each season; however, the majority of each season is spent within a single residence wetland, and they make use of only a few residence wetlands for

majority of their adult lives (Congdon et al., 2011). Our understanding of fine-scale (daily, hourly) spatial and temporal use of this critical habitat is limited because recording individual locations with radio-tracking is time consuming, and the close proximity of the researcher required to determine precise locations may interfere with the animals' natural movements. For instance, on 8 August 2011, the GPS device revealed movement patterns of two Blanding's turtles that spent their time in two distinct deep pools within the same wetland habitat (Figure 5). The turtles remained spatially segregated within this wetland and each turtle had disparate surface activity at irregular intervals. With the conventional method of tracking, the observer would likely have influenced the behaviour of one or both of the turtles and led to different conclusions regarding use patterns. Blanding's turtles are reported to be primarily diurnal except during nesting migrations of females (Kofron & Schreiber, 1985; Rowe & Moll, 1991; Standing et al., 1991). During the post nesting season, the surface activity for one female in this study was logged as late as 23:59, at which time the GPS logger had depleted its battery. Even though there is no evidence that Blanding's are active overnight (except during the nesting period), future studies should employ these devices to more rigorously test this during the post-nesting season when overnight low temperatures remain within the preferred temperature range for Blanding's turtles (Graham, 1979; Nutting & Graham, 1993).

This is the first paper to assess the usefulness of GPS logging devices for studying movements of freshwater turtles. The GPS loggers enhanced our radio-tracking program by enabling a more accurate delineation of movement corridors, and revealing seasonal areas of habitat use including nesting locations and timing of movements between

habitats. They also improved home range mapping, and permitted the collection of data without researcher interference of the animal's natural movements. Our study shows that they can be used to answer research questions related to the spatial ecology of Blanding's turtle that may be difficult to answer even with high-intensity radio-tracking regimes, and can reduce the research effort required to obtain sufficient locational information for making important management decisions. The main limitations of GPS loggers include a high upfront purchase price, battery life constraints and their inability to log locations when submerged under water. Future studies should consider incorporating GPS loggers into their tracking program when their research requires a large amount of spatial or temporal detail, the location of the study is remote or difficult to access, or when terrain within a study site makes manual tracking a challenge to sustain throughout the season.

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TABLES AND FIGURES

Table 1.   Summary of GPS fixes obtained in this study. The devices required charging
approximately every 80-150 scheduled fixes.

Turtle ID	GPS Device	Year	Dates Deployed	# Days	# Scheduled Fixes	# Realized Fixes	% Fixes
Female 1	Lotek[a]	2011	May 17 - June 16	31	202	40	24.7
Female 2	Lotek	2011	May 17 - Sept. 19	126	477	37	7.8
Female 2	Telemetry Solutions[b]	2012	May 10 - July 19	71	373	163	43.7
Female 3	Lotek	2011	May 18 - Aug. 9	104	131	27	20.6
Female 4	Lotek	2012	May 4 - July 7	65	243	56	23.0
Male 1	Lotek	2012	May 5 - May 23	19	82	17	20.7
Male 2	Lotek	2012	May 24 - July 17	55	185	33	17.8

[a] Lotek GPS Logger: GPS Bug Bird Tag, approximately 10 grams
[b] Telemetry Solutions GPS Logger: Quantum 4000E Mini bird, approximately 30grams

Table 2.   Annual home ranges (estimated using the minimum convex polygon method) of individuals tracked using radio tracking only and radio tracking plus the additional locations from GPS Loggers. Locations were only used for MCP calculations if they were a minimum of 13-h apart.

| Turtle	Radio Tracking Locations	Radio Tracking + GPS Logger Locations	MCP Radio Tracking Only (ha)	MCP Radio Tracking + GPS loggers (ha)	Difference (ha)	Percent Increase
Female 1- 2011	26	40	6.40	12.40	6.00	48.4
Female 2- 2011	20	34	26.90	44.10	17.20	39.0
Female 3- 2011	22	32	6.49	7.07	0.58	8.2
Female 2- 2012	13	46	34.00	57.34	23.34	40.7
Female 4- 2012	14	27	9.71	11.17	1.46	13.1
Male 1- 2012	11	16	58.67	59.69	1.02	1.7
Male 2- 2012	9	16	24.44	29.60	5.16	17.4
$\bar{x}$			23.80	31.62	7.82	24.7
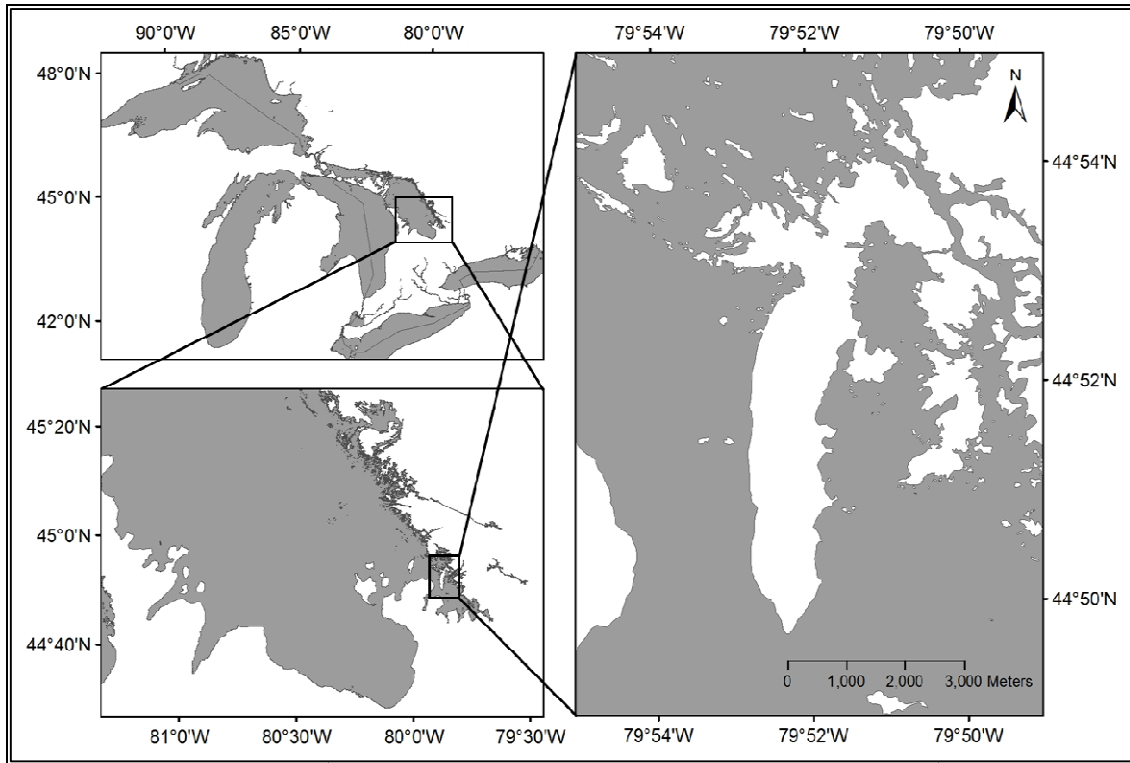
Figure 1.　Map of study site Beausoleil Island of Georgian Bay Islands National Park in Georgian Bay, the eastern arm of Lake Huron.
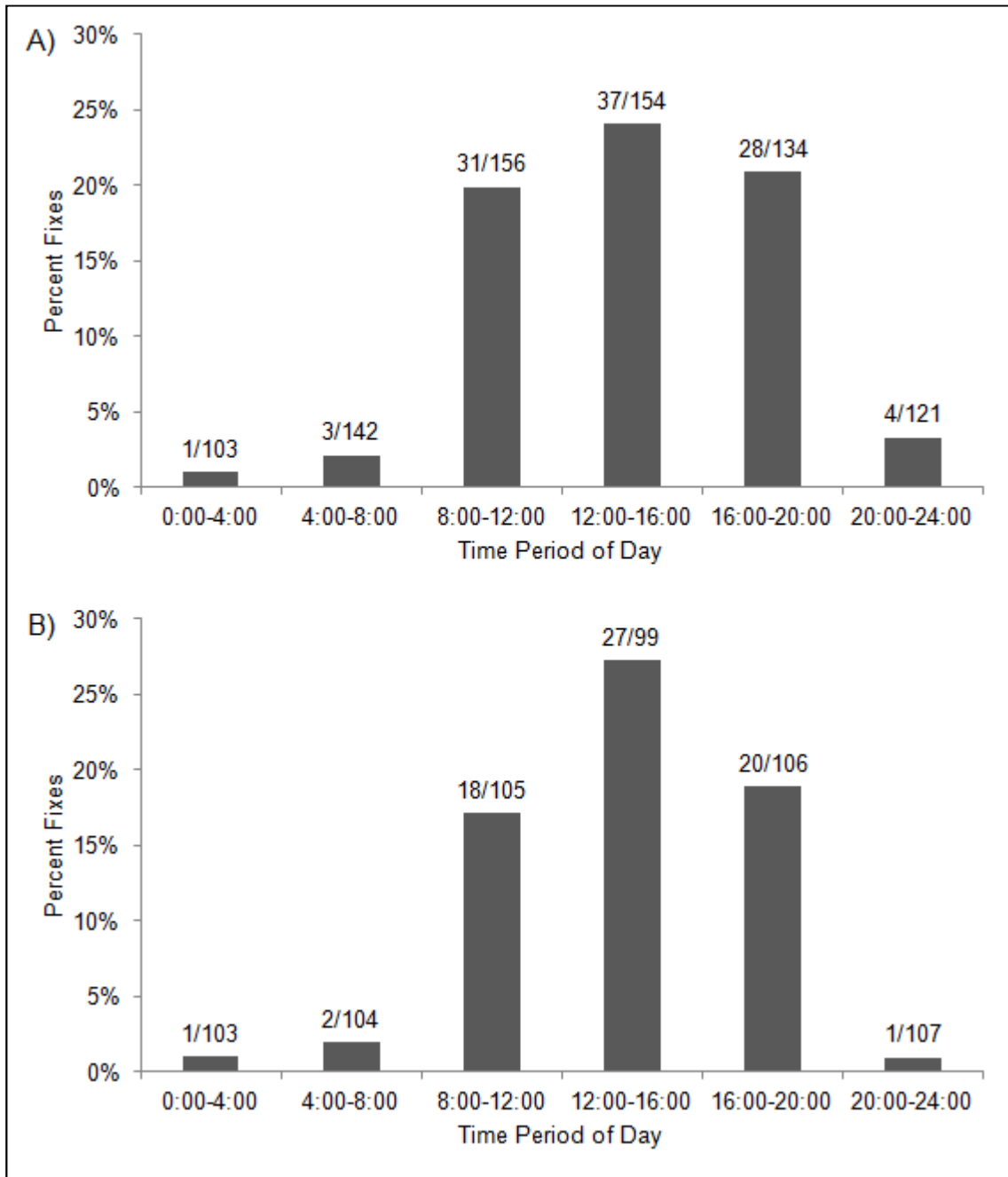
Figure 2.   Percent of realized fixes during 4-h daily time periods in the 2011 field season. Graph A (n=810) shows all of the scheduled and realized fixes in each time period throughout the entire 2011 season. Graph B (n=624), shows a subset of Graph A that was used to test for significant differences among time periods; only consistent 24-h fix schedules (every 1.5h, 2h, or 4h) were included in the analysis.
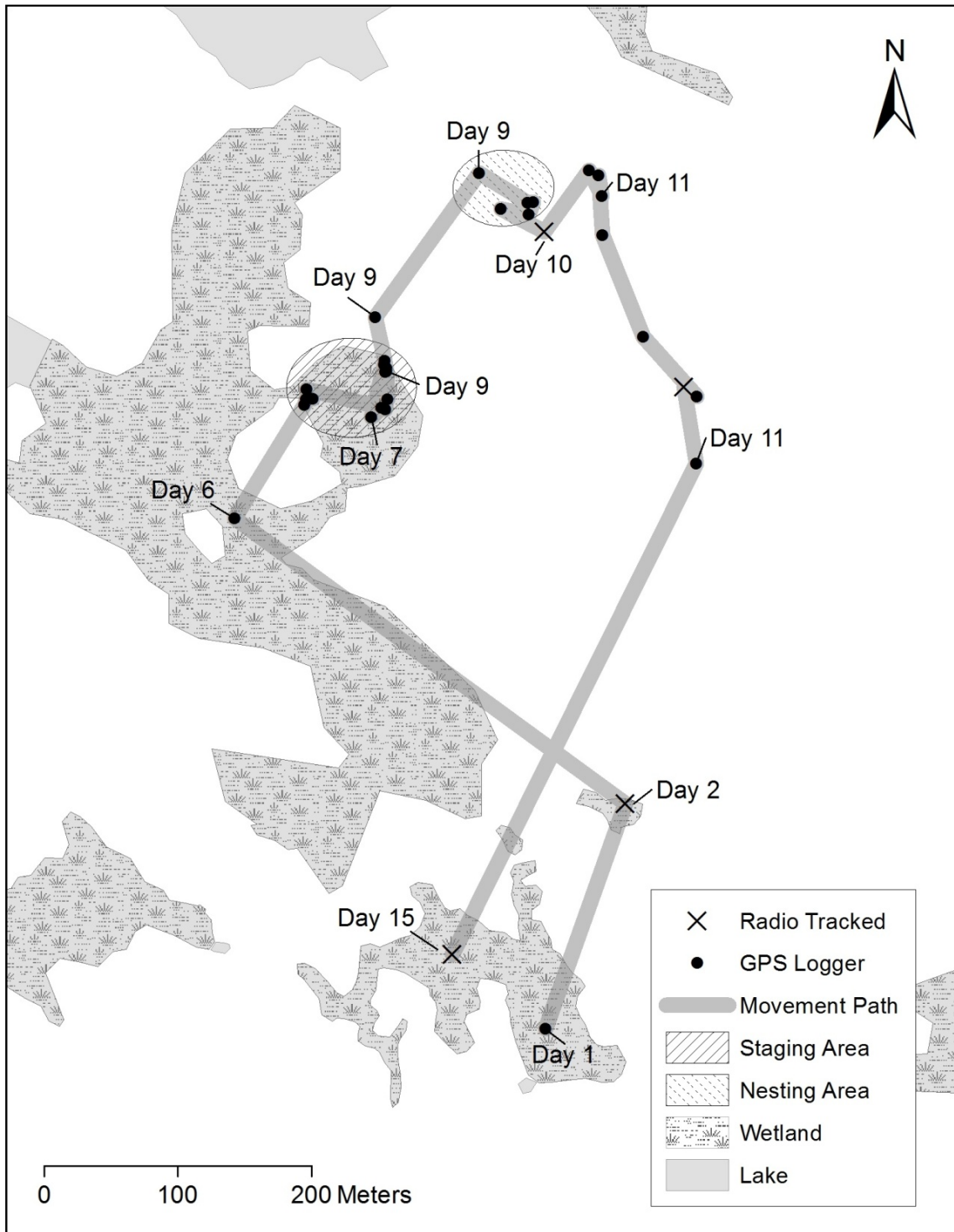
Figure 3. The path taken by an adult female Blanding`s Turtle over a 15-d period. The migration shown lasted from 6 June 2011 to 20 June 2011. The nesting area was determined by the timing of the recorded terrestrial activity.
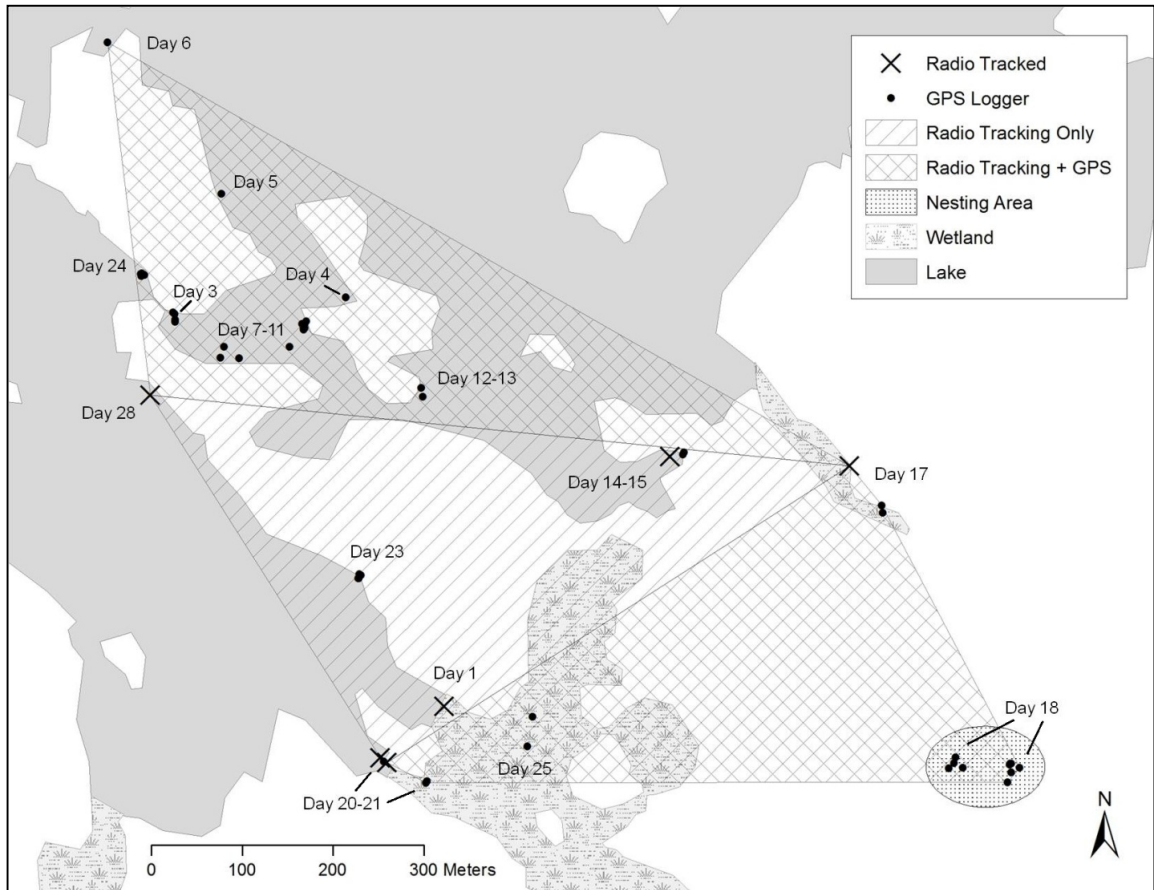
Figure 4. Locations of an adult female Blanding's Turtle during a nesting migration from 24 May 2012 to 20 June 2012. The GPS logger was set to record locations daily on 22 days of this 28 day period. The single hatched area shows the area used as determined by radio-tracking data, while the cross hatched area shows the additional area used as determined by the GPS loggers (both estimated using the MCP method). The stippled area shows this turtle's terrestrial nesting location which was determined by the timing of terrestrial activity (10:00 on 10 June 2012 until 24:00 on 11 June 2012). The female returned directly to her residence wetland after this 28-d period.
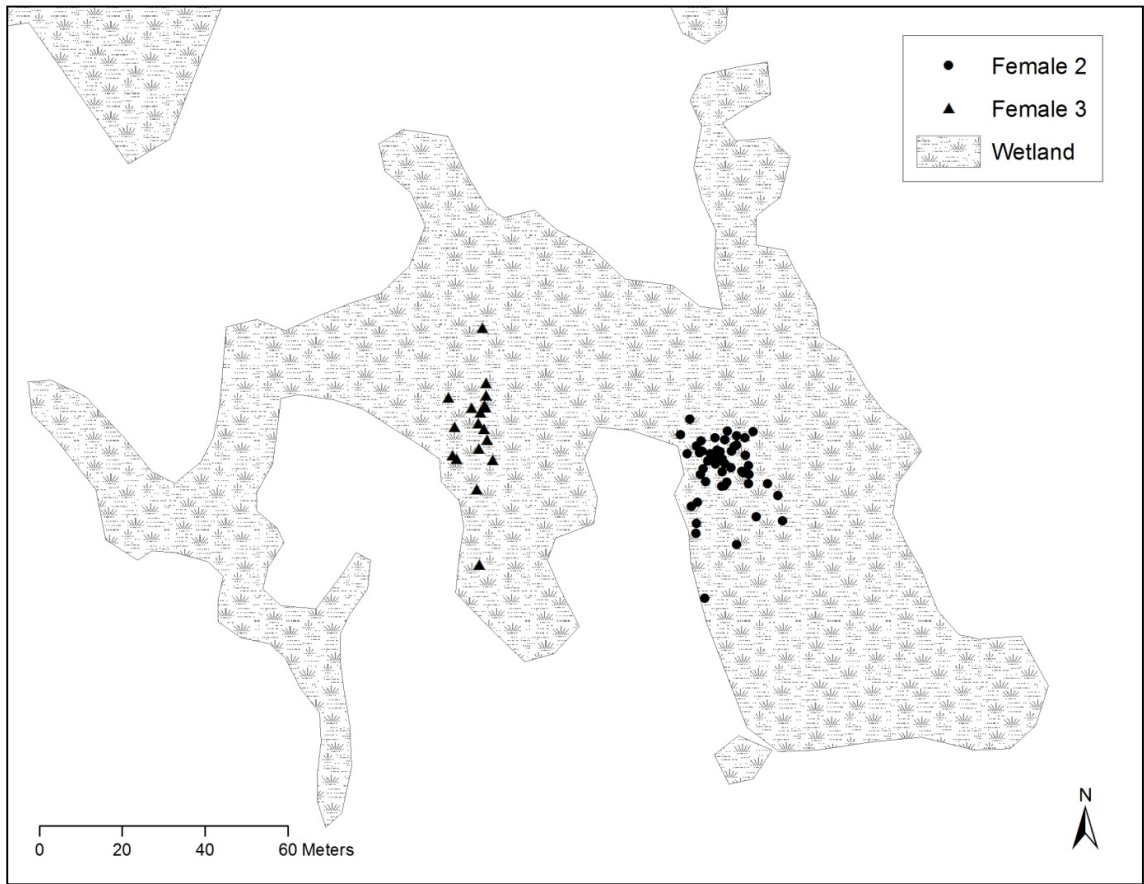
Figure 5.   Locations of two adult female Blanding's Turtles determined by GPS loggers (49 locations Female 2, 18 locations Female 3) within their residence wetland habitat on 8 August 2011 between 09:30 and 23:50.