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Movement Patterns and Habitat Selection of Common Map Turtles (*Graptemys geographica)* in St. Lawrence Islands National Park, Ontario, Canada

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Movement patterns and habitat selection of common map turtles (*Graptemys geographica*) in St. Lawrence Islands National Park, Ontario, Canada.

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ABSTRACT

Understanding the spatial ecology and habitat use of declining species is essential for their management and successful recovery. I examined the movement patterns and habitat selection of map turtles (*Graptemys geographica*), a species at risk, in St. Lawrence Islands National Park. Adult females moved longer distances and had larger home ranges than juvenile females and males. The longest distances moved by adult females occurred during nesting excursions. Examining movements allowed for critical habitat locations to be found (nesting sites, hibernacula). My data on movements will allow St. Lawrence Islands National Park to mitigate development plans and regulate visitor impacts on these sites.

I examined habitat selection at multiple spatial scales. Map turtles generally avoided deep water (>2 m) and selected home ranges in waters <1 m deep with significantly more natural than developed shoreline. Adult females used deep water more often and males preferred areas with surface cover. Management effort should implement regulations concerning further shoreline development.

RÉSUMÉ

Une bonne connaissance des motifs de mouvements ainsi que des habitats utilisés par une espèce en péril nous permet de formuler des stratégies de sauvegarde plus appropriées. J'ai examiné les mouvements et la sélection d'habitats des tortues géographiques (*Graptemys geographica*), une espèce en péril, dans le Parc National des Îles du St-Laurent. Les femelles adultes se déplaçaient plus loin et avaient de plus grands domaines vitaux que les femelles juvéniles et les mâles. Les plus grandes distances parcourues par les femelles adultes étaient lorsqu'elles se rendaient à leur site de ponte. Une connaissance des mouvements nous permets d'identifier les habitats essentiels (site de ponte, hibernacles pour cette espèce. De plus, le Parc National peut maintenant adapter les plans de développement ainsi que mitiguer l'impact des visiteurs.

J'ai étudié la sélection d'habitats à l'échelle du domaine vital et à l'échelle du site. Les tortues évitaient généralement l'eau profonde (>2 m) et sélectionnaient des domaines vitaux dans l'eau de <1 m de profondeur. Les domaines vitaux contiennent significativement plus de rives naturelles que de rives artificielles. Les femelles adultes utilisaient plus l'eau profonde tandis que les mâles préféraient les endroits avec beaucoup de végétation de surface. La gestion des habitats doit incorporer des mesures pour limiter le développement des berges.

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INTRODUCTION

In recent years, biodiversity conservation has received increasing attention as mounting evidence points to rapid loss of species and habitats worldwide (Soulé 1985, Cracraft 1995, Eken et al. 2004). Habitat destruction or modification is one of the leading causes of decline for all animals (Tear et al. 2005), including reptiles (Gibbons et al. 2000). In Canada, seven of the twelve species of turtles are listed as species at risk by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Under the Canadian Species At Risk Act (SARA), every species listed receives a recovery or management plan that comprises the legal protection of their critical habitat. Recovery plans become the main tools for the management of listed species and must therefore be appropriately suited to each species' situation and biology to be effective (Boersma et al. 2001). A similar process is triggered in the USA under the Endangered Species Act (ESA). Since conservation of declining species directly entails habitat management, understanding the relationship between animals and their environment becomes the foundation to their successful recovery.

The spatial ecology of a species reflects the effects of space on the structure, dynamics, and stability of populations (Tilman and Kareiva 1997). Movement patterns and home range estimates are important elements of spatial ecology and contribute to proper management of declining species. Examining movement patterns for example, allows for the identification of objective portions of the critical habitat of listed species, such as nesting and hibernation sites. Movement patterns have also been found to be linked with functions such as food acquisition, aestivation and reproduction, which in turn are correlated with reproductive success (Doody et al. 2002, Litzgus and Mousseau

2004) and therefore population growth. Home ranges represent the area traversed by an individual during its normal activities such as foraging, mating and caring for young (Burt, 1943). Home ranges therefore estimate the size and shape of the area used by an animal, which allows proper delineation of regions that need to be protected (Murphy and Noon 1992, Linnell et al. 2004).

Determining which habitat an animal chooses for living is also fundamental for conservation. Habitat selection studies reveal specific habitat types that are used and needed by the species. Once identified, such critical habitat types can then be protected. Selection can occur at multiple spatial scales, from geographical distribution, to the composition of home ranges within a landscape, to specific areas within the home range. When all elements of selection are examined at multiple scales, management actions will clearly reflect the needs of the species (Morin et al. 2005).

The common map turtle (*Graptemys geographica*) and the stinkpot turtle (*Sternotherus odoratus*) are two species at risk listed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as special concern and threatened, respectively. There has been little research done on either of these species and much of their biology is still unknown. Since properly designed research helps improve recovery planning and guide the management actions intended to help species at risk (Boersma et al. 2001, Tear et al. 2005), this study will further conservation efforts by expanding our knowledge of the biology of these little known species. Both of these species are at the northern limit of their range in Canada and, therefore, are of additional conservation concern since it has been found that populations along the periphery of a range can persist better than those at the core (Channell and Lomolio 2000).

The first chapter describes the movement patterns of the common map turtle (*Graptemys geographica*). Spatial ecology will also be examined in Appendix two with preliminary data for stinkpot turtles (*Sternotherus odoratus*). In chapter two, I examine habitat selection at the macrohabitat and microhabitat scales for map turtles in the St. Lawrence River. In addition, preliminary demographic information, such as population estimate and sex ratio for the map turtles are presented in Appendix one. Demographic information is essential in assessing the conservation status of listed species. Documenting population trends is also the only tool that allows us to measure the efficacy of our conservation actions.

CHAPTER 1

Movement patterns of map turtles (*Graptemys geographica*) in St. Lawrence Islands National Park, Ontario, Canada

INTRODUCTION

Legal mandates for the protection of species at risk have become more prevalent in recent years as the environment becomes an ever-increasing concern. In Canada, the Species at Risk Act (SARA) is a federal legislation designed to help prevent species at risk from becoming extinct and provides a legal requirement for recovery and protection of their critical habitat on federal lands. In the USA, the Endangered Species Act (ESA) has a very similar purpose. Once a species is listed under either of these acts, a recovery plan is required by law for the species. Recovery plans become the main tools for the management of listed species and must therefore be appropriately suited to each species' situation and biology to be effective (Boersma et al. 2001). In addition, since habitat loss is the primary threat to most species at risk, SARA and ESA afford protection to their critical habitat. What constitutes critical habitat has been the focus of much debate within academia and government agencies that are charged with applying the act (Sidle 1987, Patlis 2001). Clearly, however, defining the critical habitat for a listed species requires an understanding of how the species interacts with its environment.

Movement patterns reveal, at least partly, the interaction between an individual and its environment. Movement patterns allow the identification of objective portions of the critical habitat for listed species, such as nesting and hibernation sites. Examining movement patterns can also lead to a better understanding of many aspects of a species' ecology (Swingland and Greenwood 1983, Gibbons et al. 1990, Doody et al. 2002, Litzgus and Mousseau 2004) that are relevant to conservation. Home ranges, for example, are used in conservation to delineate areas that need to be protected by estimating the size and shape of the area used by an animal (Murphy and Noon 1992, Linnell et al. 2004). The social structure of a species (Ferner 1974) as well as site fidelity between years (Kernohan et al. 2001) can also be examined by calculating home range overlap. Evidence of site fidelity can increase a species' vulnerability since it may be less adaptable to habitat loss (Warkentin and Hernández 1996, Rimmer and McFarland 2001). Movement patterns have also been found to be linked with functions such as food acquisition, aestivation and reproduction, which in turn are correlated with reproductive success (Doody et al. 2002, Litzgus and Mousseau 2004) and therefore population growth.

The general goal of this first chapter is to describe the movement patterns and home ranges of the common map turtle (*Graptemys geographica*), a species listed as special concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), in St. Lawrence Islands National Park. The population studied is at the northern limit of the species' range. The conservation of peripheral populations of declining species is extremely important to their long-term survival since it has been found that populations along the periphery of a range can persist better than those at the core (Channell and Lomolio 2000). Research in the northern part of the species' range is also important because in wide-ranging species like *G. geographica* (Horne et al. 2003) the spatial ecology may differ as a function of latitude due to variations in the length of the active season. Climate may contribute to geographic variation in movement patterns, such as smaller home ranges or shorter nesting excursions, due to more restricted active seasons.

G. geographica exhibits remarkable sexual size dimorphism. Males and females differ greatly in adult body size and age at maturity. Females grow significantly faster and become significantly larger than males (Iverson 1988), but reach sexual maturity at a later age (Vogt 1980). Body size directly affects how an animal uses its resources because it is related to its energetic requirements and to its susceptibility to predators (Werner and Gilliam 1984). In previous studies it has generally been found that larger turtles tend to move more than smaller ones (Gibbons et al. 1990). Body size has also been found to be positively correlated with home range size (Hecnar 1999). I will investigate the movement patterns in relation to body size within each reproductive class. Larger map turtles have greater swimming ability (Pluto and Bellis 1986) that may allow them to fight currents better and to access deeper and faster waters. Therefore, I expect that larger individuals should move more and have larger home ranges.

In aquatic turtles, movements often differ between the sexes (MacCullogh and Secoy 1983, Pluto and Bellis 1988, Doody et al. 2002). The reproductive strategy hypothesis (Morreale et al. 1984) predicts that during the mating season males should move more than females, but that during the nesting season females should move more than males. These patterns have been reported in many aquatic turtles (Obbard and Brooks 1980, Gibbons et al. 1990, Jones 1996, Piepgras and Lang 2000, Doody et al. 2002, Litzgus and Mousseau 2004). The predictions are based on the assumptions that males should become more active to increase their chances of mating and that females should move great distances in search of favourable nesting sites. However, since map turtles mate in spring and fall while both sexes are at the communal hibernacula (Vogt 1980), males do not have to increase their movements during the active season to mate. The reproductive hypothesis also assumes that food resources are similar between the sexes, a criterion that may not hold in *G. geographica* because females are exclusively molluscivorous whereas males are more insectivorous (White and Moll 1992, Lindeman 2006). Nevertheless, both the molluscs and aquatic insects used as food sources are found in the same habitat (Stewart et al. 1998, Horvath et al. 1999). Therefore, I expect that adult females should move more and have larger home ranges due to nesting. Males and juvenile females, which do not have the necessity to nest, should move less and have smaller home ranges.

METHODS

Study Area

I conducted this study from May 2005 to September 2006 on the St. Lawrence River in the Thousand Islands Ecosystem. The study site was located between Mallorytown and Rockport Ontario, Canada covering an area of approximately 11 km x 4 km surrounding Grenadier Island, one of St. Lawrence Islands National Park's largest islands (Fig 1-1). Numerous islands of various sizes are found in this area and 3.8 km^2 of the 12 km^2 of land belong to Parks Canada. The small boat channel as well as the major seaway of the St. Lawrence River run through the study area.

Radio-telemetry and data collection

I captured turtles mainly with basking traps and by snorkeling near areas of aggregation. I also captured some turtles with a dip net directly from a boat. All individuals captured were brought back to the lab and were marked using a hand-held high-speed drill (see Appendix I). I drilled 3-mm holes into the marginal scutes of the carapace (excluding marginal scutes attached to the bridge). Using different combinations of holes, each individual received a unique marking code. Turtles were then measured to the nearest 1 mm for carapace length, carapace width, plastron length, and carapace height with forestry calipers. I weighed turtles in a bucket to the nearest 5 g with a spring scale. Sex was determined by size, carapace shape, and preanal tail length. Any injuries or scars were noted for each individual.

Subsets of individuals from three reproductive classes were fitted with radio-transmitters (Holohil SI-2FT 16 g, battery life of 28 mo, SI-2FT 12 g, battery life of 18 mo and SB-2FT at 6 g battery life of 12 mo). I fitted 31 map turtles with transmitters over the two years of the study (12 adult females, 9 juvenile females, and 10 adult males). Transmitters were bolted to the rear marginal scutes of the carapace using stainless steel screws, washers, and nuts. I used marine silicone to cover screws and transmitter edges to aid in adhesion and to seal any openings between shell and transmitter where macrophytes could snag. Transmitters (including screws, nuts, and silicone) represented at most 5% of the turtle's body mass. Transmitters were removed from the turtles at the end of the study.

Turtles were released at their site of capture the following day and tracked every 2-3 days using a telemetry receiver (Teletonics, Mesa AZ) and a directional antenna. At each location, I recorded the Universal Transverse Mercator (UTM) coordinates (3D differential receiver status, NAD83 datum) with a GPSmap72 (Garmin International Inc, Olathe, KS) at an estimated accuracy of < 3 meters. I also noted the behaviour (swimming, basking, or immobile underwater) of the turtle when located.

Movement Patterns

I derived movement statistics from 28 turtles (12 adult females, 9 juvenile females, and 7 males) located 1302 times. I followed 11 individuals (8 adult females and 3 juvenile females) for two years and therefore I had data for 20 adult female "turtle-years", 11 juvenile female "turtle-years", and 7 male "turtle-years". I used the recorded UTM coordinates to measure distances moved between locations in ArcView 3.2 (ESRI 2000b) equipped with the Animal Movements Extension 2.0 (Hooge and Eichenlaub 2000). Movements were measured as straight-line distances between relocations. Map turtles are highly aquatic, only using land to nest or bask. Therefore, any straight-line movements crossing land were modified to represent the shortest distance in water between points. I averaged distances moved for each individual for the period of interest before analyses.

I first examined the effect of reproductive class (adult female, juvenile female, and male) and body size (carapace length) on the mean distance moved per day. I examined these effects independently since the sexual size dimorphism in map turtles results in no overlap in body size between adult males and females (Fig.1-2). I also examined the effect of reproductive class on the total mean distance moved per month. Mean distance per day included all turtle years ($n = 40$) but the analysis per month used data from 2006 only ($n = 25$) since all these individuals were tracked regularly throughout a whole active season (June, July, and August).

Home Ranges

I estimated the aquatic home range (excluding all land) for each individual with the minimum convex polygon method (MCP). MCP's are calculated by creating the smallest possible convex polygon that encompasses all known locations for an individual. MCP's are the most commonly used method to estimate animal home ranges (Powell 2000). The downfall of this method is that it tends to incorporate large areas that are never used by the animal (Powell 2000). However, Row and Blouin-Demers (2006) found that MCP's accurately represent the maximum home range area for reptiles. I calculated MCP's using Hawth's Tools (Beyer 2004) an animal movement extension for ArcMAP 9.0 (ESRI 2000a).

The accuracy of home range estimates, including MCP's, is affected by some sampling considerations. The first of these considerations is the time between consecutive locations (Swihart and Slade 1985a, 1985b, Kernohan et al. 2001). Assuming a fixed time between relocations, autocorrelated data could be created when an animal has too little time to move between relocations, when an animal simply does not move between relocations, or when an animal periodically returns to a previously used portion of its range (Hansteen et al. 1997). Although turtles use the same locations multiple times, creating some autocorrelation, the sampling period I used (2-3 days) is ample time for an individual to traverse its entire home range if it wished so. Therefore, when a turtle remained in the same location it chose to do so, it was not because it did not have enough time to reach a new location. Removing autocorrelation in this case reduces the biological relevance of the home range estimate (DeSolla et al. 1999). In addition, as long as the time interval between successive relocations remains constant (DeSolla et al. 1999) and that the time frame of the study is adequate (Otis and White 1999), autocorrelation should not reduce the validity of the home range estimate.

A second important consideration is the number of observations used to obtain the estimate (Jenrich and Turner 1969, Powell 2000, Kernohan et al. 2001). The accuracy of a home range will increase with more data points until home range size reaches an asymptote (Swihart and Slade 1985b, Seaman et al. 1999). It is suggested to examine plots of home range size as a function of the number of successive relocations to ensure an asymptote is reached, indicating that the sampling duration covers the full range of the animal's behaviour. Using the ArcGIS map document tool ABODE.mxd (Laver 2005), I ran an asymptote analysis for all individuals. Because turtles often stayed in one location for long periods, home range size as a function of the number of successive relocations showed a series of plateaus, not an asymptote. Therefore, I calculated home ranges only for individuals that were tracked for an entire active season (June, July, and August). Based on this criterion, I calculated home ranges for 27 individuals (11 adult females, 9 juvenile females, and 7 males) for a total of 39 "turtle-years" (20 adult females, 12 juvenile females, and 7 males).

Statistical Analyses

I performed statistical analyses with JMP version 5.0.1 (SAS Institute 2002). Transformations were performed on some variables to meet the assumptions of homogeneity of variance and of normality. All means are reported ± 1 SE and I accepted significance of tests at $\alpha = 0.05$.

RESULTS

Movement Patterns

ANOVA revealed that reproductive class had a significant effect on the mean distance (log transformed) moved per day ($R^2 = 0.49$, $F_{2,37} = 18.1$, $p < 0.001$). A Tukey-Kramer HSD test indicated that adult females moved significantly more than both males and juvenile females (Fig 1-3). Two adult females moved considerably longer distances than the other females (Fig 1-3), one of which traveled a mean of 331. 9 m/day. Both individuals traveled long distances to reach their nesting sites where they remained 1-2 days before returning to their original location. This voyage was repeated later in the summer since map turtles nest twice per year and are faithful to their nesting sites. In addition, these two turtles used hibernations sites that were further from the main study area than the other study turtles, increasing their rate of movement in spring and fall.

To determine whether larger individuals moved more than smaller ones, I ran a simple linear regression examining the effect of carapace length (CL) on the mean distance moved per day for each sex. The regression for females indicated that the relationship was not linear. Inspection of the data revealed that the pattern of movement as a function of size was very different for juvenile (< 20 cm CL) and adult females (> 20 cm CL). Thus, I ran separate linear regressions for juveniles and adults. For adult females, the mean distance moved increased significantly as a function of size ($R^2 = 0.23$, $F_{1,18} = 5.4$, $p = 0.03$), but there was no relationship between CL and distance moved in juvenile females ($R^2 = 0.13$, $F_{1,10} = 1.46$, $p = 0.25$). Male size also had no effect on distance moved ($R^2 = 0.25$, $F_{1,6} = 2.0$, $p = 0.21$, Fig. 1-4), but the power of this test was lower due to a smaller sample size.

I also tested whether the mean distance moved between relocations (log transformed) varied monthly while controlling for reproductive class. A repeated measures ANOVA indicated a significant effect of reproductive class ($R^2 = 0.33$, $F_{2,96} = 4.3$, $p = 0.04$), month ($R^2 = 0.33$, $F_{4,96} = 3.1$, $p = 0.02$), and their interaction ($R^2 = 0.33$, $F_{8,96} = 3.04$, $p = 0.004$). Following the significant interaction, I used repeated measures ANOVAs to examine the effect of reproductive class on the mean distance moved each month (May-September). Adult females moved more than males and juvenile females in June ($R^2 = 0.42$, $F_{5,19} = 2.7$, $p = 0.05$) and July ($R^2 = 0.47$, $F_{5,19} = 3.3$, $p = 0.02$, Fig. 1-5).

There was a significant difference in behaviour at time of telemetry location between reproductive classes ($\chi^2_{6,\,1223} = 36.7$, $p < 0.0001$). Turtles were immobile underwater the majority of the time (78.5%), but juvenile females were located underwater more often than adult males and females (Fig 1-6). Adult females were observed swimming more often than males and juvenile females (Fig 1-6).

Home Ranges

Home range size varied greatly between individuals, ranging from 17 to 1075 ha with a mean of 247 ± 32 ha (Table 1-1). ANOVA revealed a significant effect of reproductive class on home range size (log transformed) ($R^2 = 0.25$, $F_{2,36} = 6.05$, $p = 0.005$). A Tukey-Kramer HSD test indicated that adult females had larger home ranges than males (Fig 1-7). One adult female had a very large home range (1075 ha) compared to the other females (Fig 1-7). This female had her nesting and hibernation sites further away from her main areas of activity.

I used simple regression analyses to examine the effect of carapace length (CL) on home range size for each sex. Because the relationship between CL and home range size was clearly different for juvenile (< 20 cm CL) and adult females (> 20 cm CL), as was the case for the distances moved, I ran separate regressions for each reproductive class. A significant relationship was only found in adult females where home range size increased as body size increased ($R^2 = 0.26$, $F_{1,18} = 6.4$, $p = 0.02$).

Home range overlap, defined as the area of an MCP overlapping the MCP of another individual, was measured within all three reproductive classes. Plotting all MCP's together (n = 27) revealed areas of concentrated overlap. Juvenile female home ranges had 95.4% overlap, adult females had 90.5% overlap, and males had 82.65% home range overlap. These are minimum estimates because I only had MCPs mapped for a small subset of the population.

Site fidelity, measured as the home range overlap between years for the same individual, was very high in adult females (mean = 73.2 ± 4.97%, n = 9). Pearson's product correlation indicates that home range size is repeatable between years (r = 0.76, p = 0.02). Site fidelity in juvenile females was much more variable (mean = 49.7 ± 25.3%, n = 3) with no significant correlation in home range size between years (r = 0.9, p = 0.30) but the sample size was very small. Home range fidelity between years could not be calculated for males because I only had home range estimates for 2006.

DISCUSSION

Movement Patterns

Adult female *G. geographica* moved over longer distances than juvenile females and males. Body size only influenced movements in adult females. As adult females increased in size, they traveled longer distances between relocations and had bigger home ranges. This result is similar to that obtained in a study of slider turtles where body mass was positively correlated with home range size in females but not in males (Schubauer et al. 1990). Because female map turtles are larger than males, females may need to move more to satisfy their greater energy requirements. This trend is well documented in mammals (McNab 1963) where large species use more energy and therefore use a bigger area to acquire this energy. However, this pattern is not always found in turtles since Galois et al. (2002) found no relationship between body size and home range size in a northern population of spiny softshell turtles (*Apalone spinifera*) which, like *G. geographica*, exhibit considerable female-biased sexual size dimorphism.

The proposition that bigger home ranges are required to accommodate larger energy demands assumes that food is limiting; larger energy needs could be accommodated in a small area if food is superabundant. The type and availability of food consumed will therefore also influence movements and home ranges (McNab 1963, Lindstedt et al. 1986). Female map turtles often feed on zebra mussels (Serrouya et al. 1995, Lindeman 2006, Bulté et al. submitted). In the St. Lawrence River, this introduced food source is very abundant (Ricciardi et al. 1996). Hence, map turtles do not have to travel long distances to feed on zebra mussels. Although energy requirements cannot be ruled out to explain the differences in movement patterns, better swimming ability (Pluto and Bellis 1986) in larger individuals might simply allow larger females to traverse larger areas. Traveling long distances is also necessary for females to seek out appropriate nesting sites.

Based on the reproductive strategy hypothesis (Morreale et al. 1984), I expected that females should move more than males during the nesting season. As expected, females traveled longer distances than males, moving their longest distances in June and July, when nesting. In fact, when examining the longest distance moved by each adult female, it was nearly always to reach their nesting site. Some females traveled as much as 5 km to nest. Long-distance movements in turtles has often been related to finding suitable nesting sites (Obbard and Brooks 1980, Jones 1996, Litzgus and Mousseau 2004) since finding an optimal nesting location results in a higher fitness for the offspring (Gibbons et al. 1990).

Because mating occurs in the spring and fall at the communal hibernacula (Vogt 1980, current study), I expected male map turtles to move less than females. In accordance with my expectation, I found that male map turtles had stable movement patterns over time, with no obvious changes across the active season. A stable movement pattern in males has previously been observed in *G. flavimaculata* (Jones 1996) and in *G. geographica* (Flaherty 1982). In addition, in spotted turtles that also aggregate during mating, males did not increase their rates of movements during the mating season (Litzgus and Mousseau 2004).

Since juvenile females do not nest, smaller movements compared to those of adult females were anticipated. Juvenile females had similar movements to males. The similarity can be explained because (1) males do not have to travel far to mate due to their hibernacula mating, (2) juvenile females do not nest, and (3) males and juvenile females are similar in size.

Home ranges

I observed high individual variation in home range size, a trend that is consistent with many other studies on turtles (Pluto and Bellis 1988, Kramer 1995, Jones 1996, Galois et al. 2002). As expected, adult females had larger home ranges than juvenile females and males. Previous studies have also found that female turtles have larger home ranges than males (Doody et al. 2002, Galois et al. 2002, Litzgus and Mousseau 2004), but few studies have examined map turtles. Pluto and Bellis (1988) found conflicting results in *G. geographica*, finding that males had larger home ranges than females. However, they did not use radio-telemetry but sightings data. Sightings underestimate the total area used by individuals because turtles spend a lot of time underwater. I found turtles underwater 78.5% of the time, outlining the importance of using radio-telemetry to obtain reliable information on movement patterns, at least in aquatic turtles. Gordon and MacCullogh (1980) found that female *G.geographica* moved greater distances than males. In a northern population in Québec, Flaherty (1982) found that females had larger home ranges than males. The large home ranges in adult female map turtles may result directly from nesting excursions, resulting in more area being covered. However, differences in habitat selection between classes may also be playing a role in the observed disparity of home range size.

I found substantial home range overlap. This is not surprising because *G. geographica* is known to aggregate at hibernation sites and to bask collectively throughout the active season. Comparing overlap using MCPs, however, only reveals the overlap of the outer boundary of a home range and tells us little about the intensity of use within these overlapping sites (Kernohan et al. 2001). Examining overlap with kernel distributions, which measure intensity of use, would reveal if individuals use these overlapping sites heavily, possibly revealing shared resource selection (Galbraith et al. 2000). This type of overlap will be examined in Chapter 2.

Adult females continued to use the same home range between years, showing evidence of site fidelity. Nesting information from radio-telemetry also suggests that adult females are faithful to their nesting sites, both within year (when they double-clutch) and between years. Home range fidelity was less pronounced in juvenile females. Although the sample size was small for the latter (n = 3), one individual had no overlap in home range between successive years. This suggests that juvenile females are more likely to disperse and may not yet have settled into a permanent home range. This type of movement patterns in juveniles is consistent with studies of birds and mammals where dispersal is most likely to occur before sexual maturity (Johnson and Gaines 1990).

Conservation Implications

My study helps expands our knowledge of the movement patterns of map turtles. Identifying areas used by individuals of this listed species will help define the minimum effective size of protected areas. The nesting and hibernation sites located on federal lands can be protected immediately by St. Lawrence Islands National Park (SLINP). Determining when and where map turtles are moving will help SLINP to mitigate development plans and regulate visitor impacts.

Future studies should focus on the factors influencing movements. Although reaching nesting sites is likely a driving factor behind adult females traveling long distances, it would be interesting to examine further the energetic costs of movements in this species. For instance, do females generally move more due to their greater swimming ability or due to increased energy needs? Do differences in diet play a significant role in the intersexual differences in movements? Are intersexual differences in habitat selection influencing movement patterns?

Table 1-1. Year tracked, number of relocations and body size (CL) for adult female (20 'turtle years'), juvenile female (12 'turtle years'), and male (7 'turtle years') map turtles followed by radio-telemetry in the St. Lawrence River, Ontario, Canada and used to generate minimum convex polygon (MCP) home ranges.

		Home Range Estimate Summary Statistics			
Transmitter frequency	Sex	Year tracked	# Relocations	Carapace length (cm)	MCP area (ha)
172.149	F	2005	48	24.2	246.68
172.149	F	2006	32	24.4	167.83
172.029	F	2006	23	28.1	708.69
172.029	F	2005	22	28	545.64
172.340	F	2005	30	26.8	180.23
172.340	F	2006	25	26.8	159.03
172.459	F	2005	45	23.1	154.65
172.459	F	2006	32	23.3	173.09
172.490	F	2005	37	24.5	223.93
172.490	F	2006	31	24.9	152.58
172.560	F	2005	47	25.7	413.48
172.560	F	2006	29	25.7	223.27
172.702	F	2005	45	24.3	205.17
172.702	F	2006	29	24.3	171.51
172.762	F	2005	45	27.2	438.82
172.790	F	2005	27	23	187.81
172.790	F	2006	27	23	159.72
172.832	F	2005	34	23.8	672.98
172.832	F	2006	21	24.8	280.90
172.943	F	2005	42	26.3	1074.47
172.120	F juv	2005	32	17.2	202.80
172.120	F juv	2006	26	18.3	225.99
172.160	F juv	2006	26	16	230.45
172.169	F juv	2005	36	16.8	250.82
172.169	F juv	2006	21	19.1	22.93
172.240	F juv	2006	20	15.3	101.06
172.059	F juv	2005	26	15.6	171.72
172.059	F juv	2006	26	17	218.69
172.070	F juv	2006	23	15.2	156.12
172.713	F juv	2006	26	15.9	279.10
172.722	F juv	2006	27	13.1	192.85
172.818	F juv	2006	25	15.3	188.05
172.101	M	2006	20	15.1	166.49
172.018	M	2006	27	13.2	185.13
172.385	M	2006	27	13.4	160.18
172.479	M	2006	25	13	88.20
172.501	M	2006	23	12.3	109.37
172.581	M	2006	22	14.3	17.05
172.613	M	2006	27	13.1	123.02

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Figure 1-1. Study site for conservation research on the common map turtle (*Graptemys geographica*) in the St. Lawrence River, Ontario, Canada. Park land represents property owned by St. Lawrence Islands National Park.

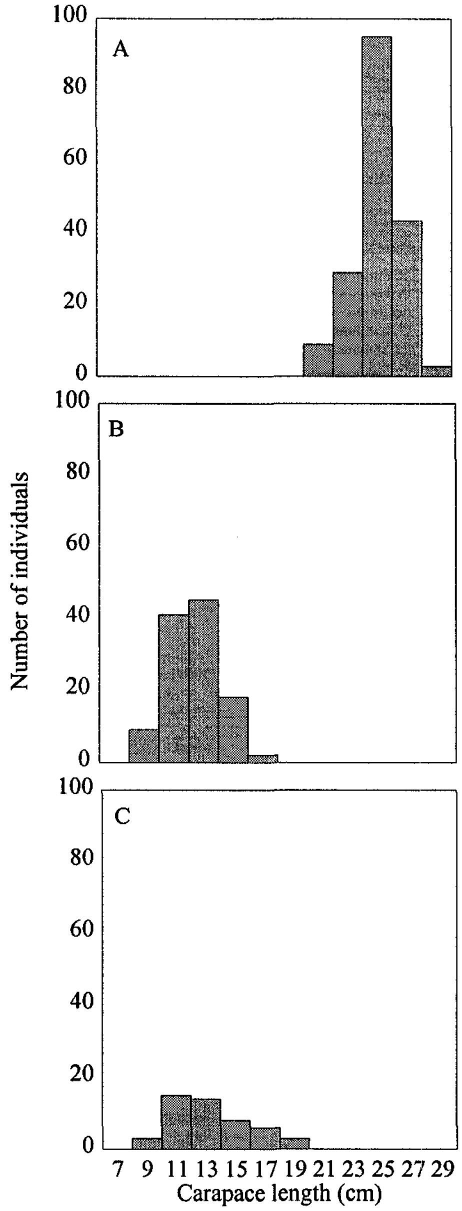

Figure 1-2. Size distribution by carapace length (cm) for adult female (A), male (B), and juvenile female (C) map turtles (*G. geographica*) captured in the St. Lawrence River, Ontario, Canada (n = 346).

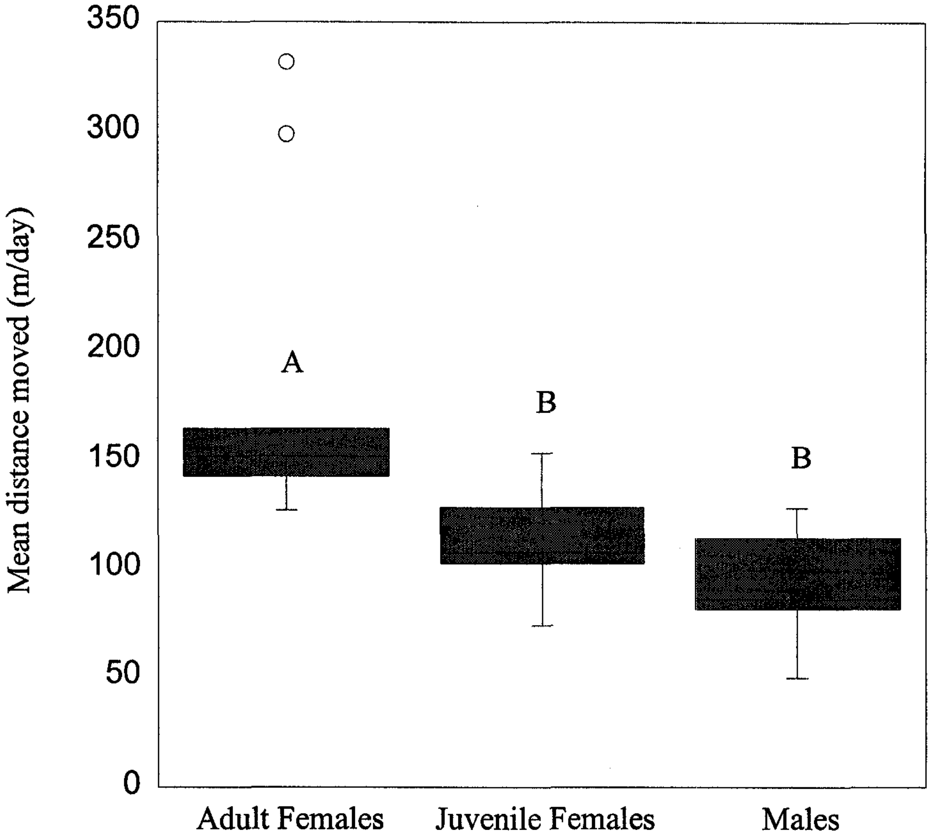

Figure 1-3. Mean distance moved per day (m/day) for each reproductive class of map turtles (*G. geographica*) followed by radio-telemetry in the St. Lawrence River, Ontario, Canada. Means with the same letters are not significantly different.

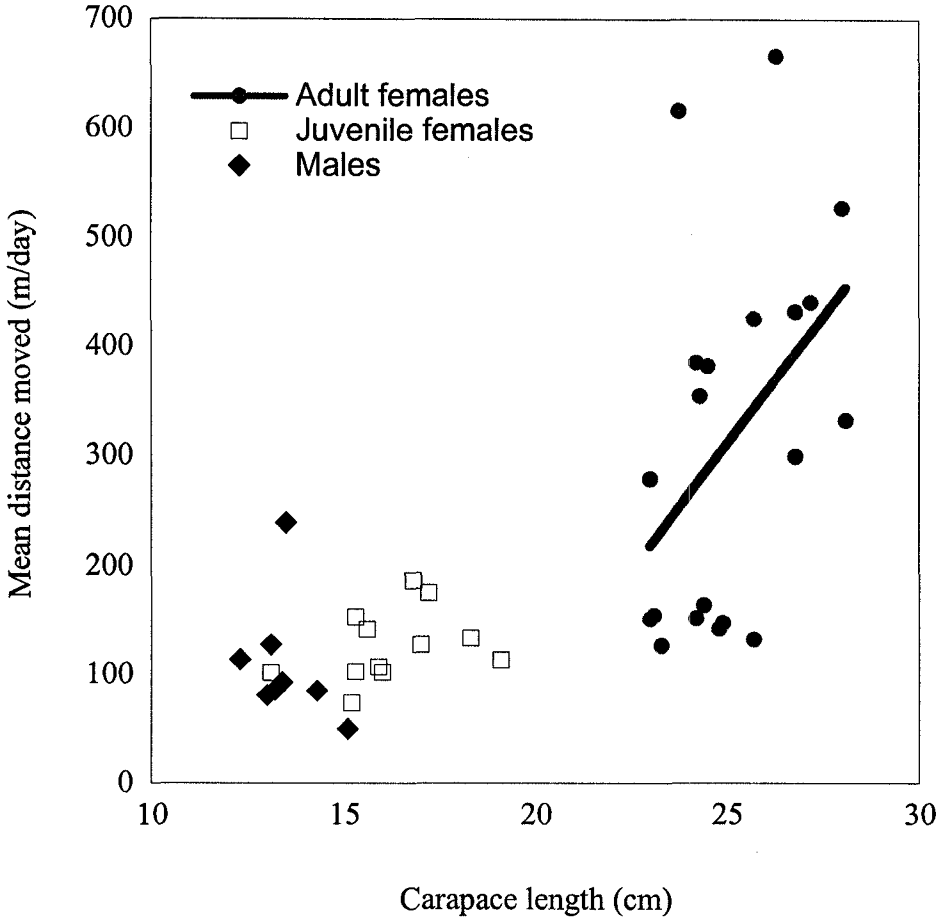

Figure 1-4. The effect of body size (carapace length (cm)) on the mean distance moved per day (m/day) for male, juvenile female, and adult female map turtles (*G. geographica*) followed by radio-telemetry in the St-Lawrence River, Ontario, Canada.

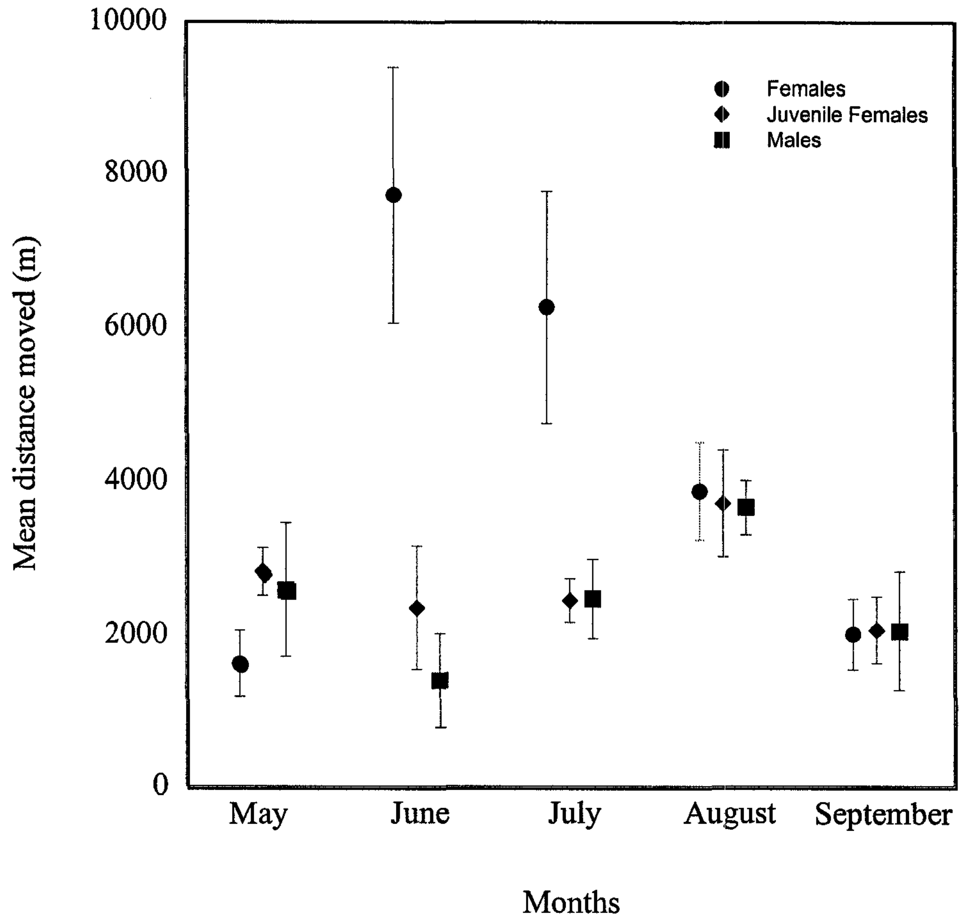

Figure 1-5. Mean distances moved between relocations (m) in each month of the active season for all reproductive classes studied of map turtles (*G. geographica*) in the St. Lawrence River, Ontario, Canada.

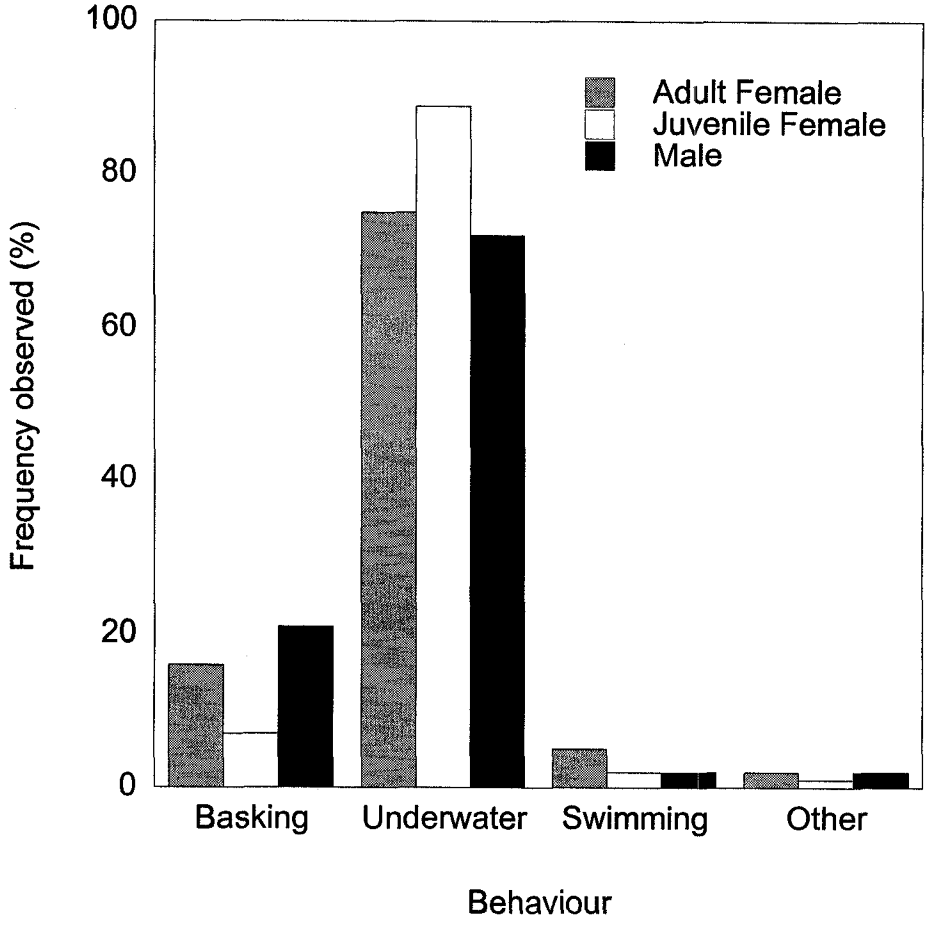

Figure 1-6. Behaviour exhibited at relocation points (n = 1232) for map turtles fitted with transmitters in the St. Lawrence River, Ontario, Canada. Behaviour described as "other" includes nesting (n = 2), captured in basking traps (n = 24) or floating on surface (n = 7).

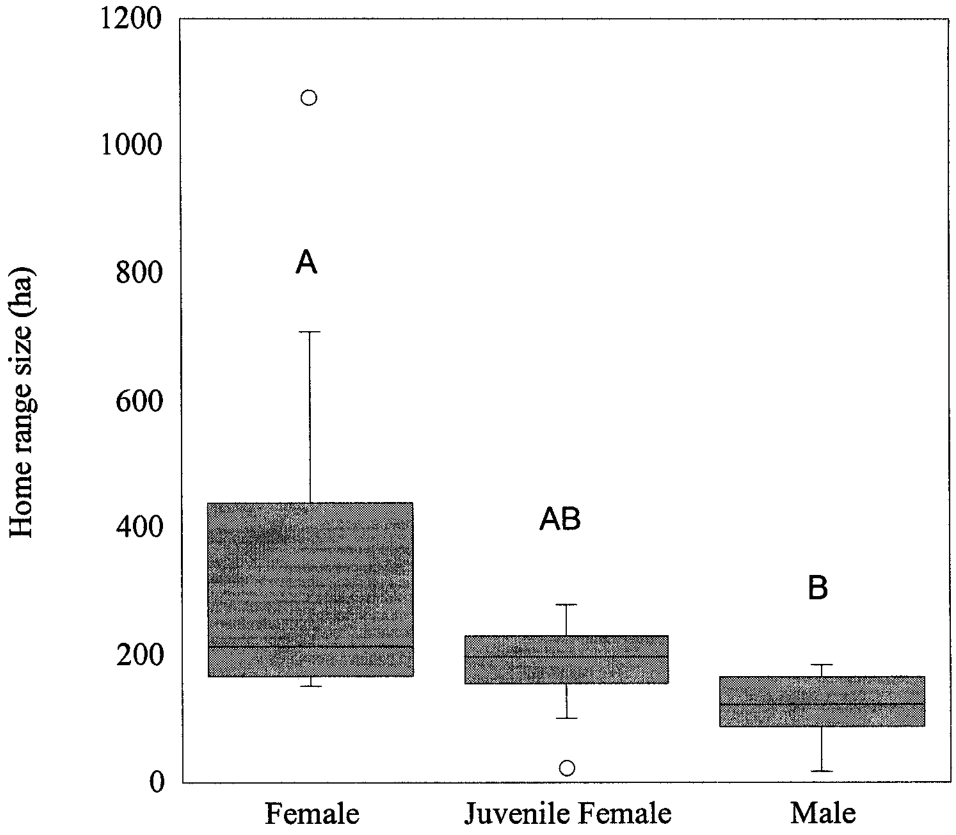

Figure 1-7. Total home range size (ha) measured with minimum convex polygons for each reproductive class of map turtles (*G. geographica*) tracked in the St. Lawrence River, Ontario, Canada. Reproductive classes with the same letters are not significantly different.

CHAPTER 2

Habitat selection at multiple scales by common map turtles (*Graptemys geographica*) in St. Lawrence Islands National Park.

INTRODUCTION

Habitat destruction or modification is one of the leading causes of decline for all animals (Tear et al. 2005), including reptiles (Gibbons et al. 2000). In addition to loss of terrestrial ecosystems, North America's freshwater habitats are also facing threats from degradation, alterations, and land use changes (Abell et al. 2000). Turtles are directly affected by aquatic habitat losses. In Canada, seven of the twelve species of turtles are listed as species at risk by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Under the Canadian Species At Risk Act (SARA), every listed species is assigned a recovery plan that provides the legal protection of their critical habitat. A similar process is triggered in the USA with the Endangered Species Act (ESA). Since conservation of declining species directly entails habitat management, understanding the relationship between these animals and their habitat becomes the first step for their successful recovery.

Habitat selection directly examines how an animal chooses its habitat. This selection process can be quantified at several spatial scales. First-order selection distinguishes the geographic range of the species, second-order selection determines the composition of home ranges within a landscape, and third-order selection is the selection of specific locations within the home range (Johnson 1980). Since these orders are interconnected, habitat selection represents a hierarchical process. However, habitat selection patterns at one scale are not necessarily a good predictor of the patterns at the other scales (McLoughlin et al. 2002, Morin et al. 2005). Differences in selection pressures and limiting factors can sometimes lead to differing (Orians and Wittenberger 1991, Luck 2002) and conflicting (Compton et al. 2002) patterns of selection at multiple scales. Therefore, key factors involved in habitat selection may not be detected from study of a single scale. When all elements of selection are examined at multiple scales, management actions will clearly reflect the needs of the species (Morin et al. 2005). Surprisingly, however, very few habitat selection studies on reptiles have been conducted at multiple spatial scales. In this chapter, I will examine habitat selection at two spatial scales, macrohabitat and microhabitat, which relate to the second and third order of selection, respectively, and are the most common scales of study in habitat selection research (Aebischer et al. 1993, Compton et al. 2002, Luck 2002, Morin et al. 2005, Row and Blouin-Demers 2006). I will investigate habitat selection at each of these scales in the common map turtle (*Graptemys geographica),* a species listed as special concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), in St. Lawrence Islands National Park.

Previous studies of habitat use in *Graptemys* sp. have found that females use deeper, faster water further from shore than males (Pluto and Bellis 1986, Jones 1996, Bodie and Semlitsch 2000). However, these studies assessed habitat use by comparing capture locations or telemetry location between the sexes, without considering the influence of habitat availability. Habitat use changes depending on what is available to an individual (Garshelis 2000). Thus, since not all habitats are equally available, no actual selection process could be inferred from these studies. Furthermore, none of these studies examined selection at multiple spatial scales. A multiple scale study on wood turtles (*Clemmys insculpta*) found selection at both scales, but conflicting selection was found between the macro and microhabitat scale, likely due to trade-offs between feeding and thermoregulation (Compton et al. 2002). Evidence of such selection patterns in other turtles highlights the importance of multiple scales when investigating habitat selection.

I expect that map turtles should use their habitat non-randomly at both the microhabitat and macrohabitat scales. *G. geographica* exhibits remarkable sexual size dimorphism. Females grow significantly faster and become significantly larger than males (Iverson 1988). Therefore, I also expect that habitat selection will differ between sexes at each scale. I expect that all turtles should prefer relatively shallow water with macrophytes because these are ideal foraging areas (Vogt 1980) but since larger map turtles have greater swimming ability (Pluto and Bellis 1986), I expect that adult females will more often use deep water, further from shore.

METHODS

Study Area

This study was conducted on the St. Lawrence River between Mallorytown and Rockport Ontario, Canada from May 2005 to September 2006. The study area was approximately 11 km x 4 km and surrounded Grenadier Island, one of St. Lawrence Islands National Park's largest islands. Many islands of various sizes are found throughout this part of the river since it is part of the Thousand Islands Ecosystem. Although some islands are owned and protected by Parks Canada, most are residential properties with private landowners. Both a small boat channel and part of the major international shipping channel pass through the study area. This region has been subjected to increased development in recent years and is under growing influence of anthropogenic stress (Environment Canada 2007).

Radio-telemetry and data collection

Basking traps and snorkeling near areas of aggregation were the most successful methods for capturing map turtles. I also captured some turtles with a dip net directly from a boat. I brought all individuals captured to the lab for processing. Each individual received a unique marking code in the marginal scutes of the carapace (excluding marginal scutes attached to the bridge) using a hand-held high-speed drill. Using forestry calipers, I measured each turtle to the nearest 1 mm for carapace length, carapace width, carapace height, and plastron length. I weighed turtles in a bucket to the nearest 5 g with a spring scale. Sex was determined by size, carapace shape, and preanal tail length. I also noted any injuries or scars for each individual.

I selected 31 map turtles (12 adult females, 9 juvenile females, and 10 adult males), from all the study animals captured, to be fitted with radio-transmitters (Holohil SI-2FT 16 g battery life of 28 mo, SI-2FT 12 g battery life of 18 mo and SB-2FT 6 g battery life of 12 mo). Transmitters were bolted to the rear marginal scutes of the carapace using stainless steel screws, washers, and nuts. I used marine silicone to cover screws and transmitter edges to aid in adhesion and to seal any openings between the shell and transmitter where macrophytes could snag. Transmitters (including screws, nuts, and silicone) represented at most 5% of the turtle's body mass. Transmitters were removed from the turtles at the end of the study.

Turtles were released at their site of capture the following day and tracked every 2-3 days using a telemetry receiver (Teletonics, Mesa AZ) and a directional antenna, from early spring (late April-early May) until their return to hibernation sites in September. At each location, I recorded the Universal Transverse Mercator (UTM) coordinates (3D differential receiver status, NAD83 datum) with a GPSmap72 (Garmin International Inc, Olathe, KS) at an estimated accuracy of < 3 meters.

Kernel Densities

In the first chapter, I calculated home ranges for each individual using minimum convex polygons (MCP). Although MCPs are an accurate home range estimator for reptiles (Row and Blouin-Demers 2006), they ignore patterns of selection within a home range (Powell 2000) making them less ideal for use in habitat selection studies. Kernels, another type of home range estimator, quantify the intensity of use and form a great basis for quantitative analysis (Seaman and Powell 1996). The density measured at a location by the kernel method represents the amount of time an individual spent there. Thus, to examine habitat use I used kernel density estimates as the home range estimators.

The most important and difficult aspect in developing kernel density estimators is choosing an appropriate smoothing factor (h) (Worton 1989, Seaman and Powell 1996, Powell 2000). The h value chosen has a large effect on the size and shape of the home range. Even with the most recommended method for choosing h (least-squares cross-validation), kernels are inconsistent and often overestimate the size of the home range in reptiles (Row and Blouin-Demers 2006). Therefore, I followed the method suggested by Row and Blouin-Demers (2006) and combined the MCP and kernel method to analyze habitat selection. I adjusted the h value until the area of the 95% kernel (excluding land) was equal to the area of the MCP (excluding land). The 95% kernel probability level is usually used as the arbitrary area for home ranges since a probability of 1 (100% kernel) is extremely unlikely (Powell 2000, Vokoun 2003). I also calculated a 50% kernel for each individual to allow comparison of habitat selection between two levels of use intensity.

Kernel densities also form a basis for measuring home range overlap in terms of area and intensity of use (Seaman and Powell 1996). I compared kernel home range overlap between years to examine site fidelity for adult females and juvenile females who were tracked consistently throughout two full active seasons (June-August). This resulted in a total of 24 "turtle-years" (18 "adult female years" and 6 "juvenile females years"). No males were tracked in 2005 and thus overlap could not be compared. Kernels were calculated using the Animal Movement extension for ArcView 2.0 (Hooge and Eichenlaub 2000).

Macrohabitat Characterization

Macrohabitat was characterized using high resolution digital aerial orthoimagery from New York State GIS Clearinghouse (2006). The orthoimagery was produced in 2003 at a 0.6m pixel resolution in color infrared, and projected in NAD83 UTM datum zone 18. For added accuracy I referenced habitats seen in the orthoimagery to those of GoogleEarth (v.4.0.13). A nautical chart layer (NAD83, 1:25000 scale) from Fisheries and Oceans Canada was superimposed to classify depths. I used ArcMap 9.0 (ESRI 2000a) to classify five different habitat types: open reeds, matted marsh, shallow water (<1 m), intermediate water (1-2 m) and deep water (>2 m).

For the purpose of this study, I defined open reeds as sparse aquatic emergent vegetation that is present throughout the entire study season. A matted marsh consists of dense aquatic vegetation, with little to no open water between plants. Water depths obtained from the nautical chart layer were cross-referenced to turtle telemetry locations where depth had been measured in the field to determine accuracy.

I also classified shoreline type into natural or developed. Shoreline width was considered as 5 m onto land. Developed shoreline referred to any continuous expanse of shoreline greater than 50 m, that was parallel to the edge of the lake, that had a minimum of 50% noticeable, long-term habitat alteration, such as cleared land, lawns, landscaping, buildings, and roads. Undeveloped shoreline was defined as any continuous stretch of shoreline greater than 50 m, parallel to the edge of the river, with greater than 50% intact natural habitat, and little to no sign of regular human use (Traut and Hostetler 2003).

Macrohabitat Selection

To determine selection at the macrohabitat scale, habitat encompassed by the home range was compared to available habitat for each individual. At macrohabitat scale, available habitat has often been defined as the total study area (Carroll et al. 1995, Rao et al. 2003), which is usually an arbitrary boundary (Johnson 1980). My study area is not homogeneous and is not necessarily available to each individual. Therefore, for each individual, I used the composition of a circle centered on its hibernation site with a radius equal to the furthest recorded location from that point. To quantify habitat use and availability, I calculated the percentage of open reeds (REEDS), matted marsh (MARSH), shallow water (SHALLOW), intermediate water (INTER) and deep water (DEEP) in the 95% and 50% kernels and in the circle of available habitat for each individual. Because map turtles are highly aquatic, land was excluded.

The proportions of the five habitat types sum to one, thus creating non-independence. Log-ratio transformation is used to remove this linear dependency. If x_i is the proportion of use in *i* habitat and x_j is the proportion of available habitat, $y_i = \ln(x_i/x_j)$ renders y_i linearly independent (Aitchinson 1986). Because this transformation is equivalent to centering each observation on the log transformed mean, the result is independent of the denominator chosen (x_j) (Aebischer et al. 1993).

Groups of animals within a population can use habitat differently, such as by age and sex. Thus, I used a MANOVA on the transformed data to test for nonrandom habitat selection with respect to reproductive class (adult female, juvenile female, and male). Wilk's lambda (Λ) was used as the test statistics for the group contrast. In the case of a significant difference among groups, separate analyses for each class were included instead of pooling all individuals.

I analyzed preferences for habitat types with a use versus availability compositional analysis (Aebischer et al 1993). Compositional analysis considers the animal rather than the telemetry locations as the sample unit and therefore avoids the non-independence problem of location data (Aebischer et al. 1993). A compositional analysis is based on pairwise differences ($d = yU - yA$) of the log ratio transformations of the used (U) and available (A) habitat composition (y) for each animal. This analysis tests the null hypothesis that turtles use habitat types in proportion to their availability. When habitat use was found to be significantly non-random, a matrix was created comparing all possible habitat type pairs and I ranked each habitat in order of use. I then used t-test values in the ranking matrix to assess if the differences between the ranks of each habitat were significant.

To avoid pseudoreplication, and for comparison with the microhabitat selection, each animal was represented by a single seasonal home range in the analysis even if monitored over two years. This resulted in 28 individuals (12 adult females, 9 juvenile females, and 7 males). I replaced habitat proportions of zero with a value of 0.0001 as suggested by Aebischer et al. (1993).

Shoreline was defined as either natural or developed and used as another habitat variable. This variable was analyzed separately from the other habitat types since it is measured as a straight-line distance not an area. The total length of each shoreline type was calculated in both kernel density estimates and in the circle of available habitat for each individual. I then compared the percentage of use to the percentage of availability of each shoreline type using a compositional analysis as described above for the other habitat types.

Microhabitat Characterization

Habitat was also quantified directly at locations used by turtles. To keep sampling manageable, I quantified the habitat only at every second relocation. I did not conduct habitat characterizations at locations where turtles were swimming since these individuals may have been disturbed by our approach and habitat used at these sites may not represent true choice. When a turtle was found basking, the aquatic habitat directly adjacent to its basking site was characterized. This approach limited sampling to aquatic habitats.

I quantified 7 habitat variables (Table 2-1). Water temperature was measured directly below the surface using a digital thermometer. I measured water depth using a brick attached to a rope and measuring its length with a meter stick to the nearest 1 cm. The substrate type at the turtle location was categorized into silt, sand, gravel, or rock. I estimated percent surface cover in a 1 m radius around the turtle location. Because the water in the St. Lawrence is very clear, a Secchi disk was not useful in measuring turbidity. Instead, turbidity values were measured in various locations throughout the study area with a colorimeter (LaMotte, Smart2) and four categories were created to fit the range of values; 0 FTU, 1-10 FTU, 11-20 FTU and 21-30 FTU. Turbidity at habitat locations was then visually compared and classified into one of these categories. The percentage of macrophytes, defined as submerged aquatic plants, was estimated in a 1 m radius around the turtle location. Lastly, distance to shore was measured using the GPS location of the turtle in ArcMAP 9.0 (ESRI 2000a).

To measure habitat availability, random locations were also characterized. A random location was identified by randomly selecting a direction (by spinning a bearing dial on a compass) from the characterized turtle location and driving a distance of 400 m by boat. Although this distance may seem arbitrary, it represents the median of the distance moved by individuals in 2005. Such a distance ensures that the random location selected is indeed available to the turtle. I quantified the random locations the same day as the paired turtle location to ensure that no temporal or environmental changes affected the measured variables. I only determined random habitat points at every fourth turtle location to keep sampling manageable.

Microhabitat Selection

To examine habitat selection within the turtles' home ranges, I used matched-pairs logistic regression. This analysis is the most appropriate at this fine scale because it keeps paired data together, such as the observed turtle location to its paired random location.

Pairing the data controls for changes in environmental conditions through time and also ensures that the random locations are actually available to each individual (Compton et al. 2002). An assumption of using a logistic regression in habitat selection studies is that the random locations are composed of almost exclusively unused locations (Keating and Cherry 2004). Although I cannot completely rule out the use of the random locations by turtles, it is expected that use at these sites would be rare since no turtles were ever seen at these locations. Because the probability of use at the random location is a rare event, I could treat my data as a case-control design and proceed with the matched-pairs logistic regression (Keating and Cherry 2004).

In the matched-pairs logistic regression, values for each random point are subtracted from the values of each paired turtle location. A standard logistic regression with the constant term removed is then used to fit a response between presence and absence (all 1's) to the differences in habitat values between used and random locations. The resulting estimated coefficients, β_i, are interpreted the same way as with a standard logistic regression. An n-unit increase in the habitat variable results in an $e^{n\beta_i}$ increase in the odds ratio. Positive coefficients represent increased selection toward that particular habitat type, whereas negative coefficients represent a decrease in selection toward that habitat. An important difference in matched-pairs logistic regression is that the model is interpreted as differences in habitat, not as absolute values (Hosmer and Lemeshow 2000, Compton et al. 2002).

Another assumption of the logistic regression is that each observation is independent. Although using radio-telemetry as the sample unit causes pseudoreplication (Aebischer et al. 1993), it is difficult to avoid when few locations are taken for each individual. I collected microhabitat use data on 12 adult females, 9 juvenile females, and 7 males. Although it would have been better to fit models separately for each individual, in many cases I had too few locations per individual to allow such analyses. However, since no individual represented a large proportion of the total locations (median = 3.2%, max = 5.1%), no individual had the opportunity to unduly bias the group means.

Map turtles exhibit remarkable sexual size dimorphism. Since size dimorphism in a species may influence habitat use (Shine 1989), I constructed separate models for each reproductive class to allow for comparison. Univariate analyses were run for each habitat variable. Variables with p-values less than 0.25 were selected as candidates for subsequent multivariate analyses (Hosmer and Lemeshow 2000). Candidate models were fit using a backward stepwise regression to select the most parsimonious model. The final model was selected based on the lowest Akaike's Information Criterion (AIC) score. AIC scores help identify the model that accounts for the most variation with the fewest variables and are the most powerful approach for model selection (Burnham and Anderson 1998, Boyce et al. 2002). Lastly, the fit of the model was evaluated using the likelihood-ratio statistic (LR) (Hosmer and Lemeshow 2000).

Statistical Analyses

I performed compositional analyses using the computer program Resource Selection For Windows (Leban 1999). Matched-pairs logistic regressions were done in R version 2.4.0 (R Development Core Team 2006). All other statistical analyses were performed with JMP version 5.0.1 (SAS Institute 2002). Unless otherwise stated, I accepted significance of tests at $\alpha = 0.05$.

RESULTS

Home Range Overlap

Kernel home range overlap between years was measured at both the 50% and 95% probability levels as a measure of site fidelity. At the 95% kernel, home range overlap was similar for adult females (mean = 59.5 ± 1.53%, n = 9) and juvenile females (mean = 48.4 ± 11.22%, n = 3), although site fidelity in juvenile females was much more variable and this group was represented by few individuals. Overlap of the 50% kernels between years was very high for adult females (mean = 85.8 ± 1.44%, n = 9). Juvenile females demonstrated lower site fidelity and once more showed considerable variation (mean = 64.4 ± 16.6%, n = 3).

Macrohabitat Selection

Habitat was used non-randomly at both the 95% kernel ($\chi^2_4 = 74.49$, $p < 0.0001$) and the 50% kernel ($\chi^2_4 = 43.05$, $p < 0.0001$) for all individuals. All preferred habitat rankings (from most to least preferred) along with their associated t-test and p-values are shown in Table 2-2. At the 95% kernel for pooled individuals the ranking was SHALLOW > REEDS > MARSH > INTER > DEEP. At the 50% kernel the ranking was similar with SHALLOW > INTER > REEDS > MARSH > DEEP. For both kernel densities, deep water was used significantly less than all other habitat types. While marsh was used significantly less than both shallow and intermediate water at the 50% kernel, shallow water was used significantly more than intermediate water at the 95% kernel.

MANOVA showed a difference in habitat selection with respect to reproductive classes ($\lambda = 0.74$, $F_8 = 3.2$, $p = 0.002$) so each class was analyzed separately. For each reproductive class, the habitat used was significantly different from the habitat available at both the 95% kernel (adult females: $\chi^2_4 = 27.03$, $p < 0.0001$, juvenile females: $\chi^2_4 = 29.47$, $p < 0.0001$, males: $\chi^2_4 = 21.14$, $p < 0.0001$) and the 50% kernel (adult females: $\chi^2_4 = 12.56$, $p = 0.02$, juvenile females: $\chi^2_4 = 20.93$, $p < 0.0001$, males: $\chi^2_4 = 26.55$, $p < 0.0001$).

The overall ranking of habitats for adult females at the 95% kernel was SHALLOW > INTER > MARSH > REEDS > DEEP. The ranking was similar at the 50% kernel except REEDS > MARSH. No single habitat was preferred or avoided significantly relative to the next habitat variable in the ranking at either probability level (Table 2-3).

For juvenile females, the 95% kernel habitat ranking was a follows: SHALLOW > REEDS > INTER > MARSH > DEEP. Meanwhile, the ranking at the 50% kernel was similar to adult females with SHALLOW > INTER > REEDS > MARSH > DEEP. DEEP was significantly less used than all other habitat types at both probability levels (Table 2-4). At the 50% kernel SHALLOW was used significantly more than the adjacent habitat type; INTER.

The habitat ranking for males was the same at both the 95% and the 50% kernel: REEDS > SHALLOW > MARSH > INTER > DEEP. Although no habitat type was significantly preferred or avoided relative to its adjacent habitat type in the ranking, deep water was significantly less used than all other habitats at both probability levels (Table 2-5).

Compositional analysis of shoreline types revealed that shoreline types were being used non-randomly when all individuals were pooled, both for the 95% kernel ($\chi^2_1 = 16.7$,

$p < 0.0001$) and for the 50% kernel ($\chi^2_1 = 8.34$, $p = 0.005$). At both probability levels, natural shorelines were significantly preferred to developed shorelines (Table 2-6). When analyzing each reproductive class separately, a significant difference in shoreline selection was only found in the 95% kernel of adult females ($\chi^2_1 = 11.6$, $p < 0.0001$) and juvenile females ($\chi^2_1 = 6.95$, $p = 0.01$), both of which used natural shorelines more than developed shorelines at this probability level (Table 2-7).

Microhabitat Selection

I characterized the habitat at this scale for a total of 314 turtle locations (138 adult female, 96 juvenile female, and 80 male). The model with the lowest AIC value for both adult females and juvenile females had the same two variables (SHOREDIST + DEPTH) and were significant for both adult (AIC = 86.3, $LR_2 = 13.4$, $p = 0.001$) and juvenile females (AIC = 58.7, $LR_2 = 10.5$ $p = 0.005$). The best model for males also had two variables (DEPTH + SURFCOV) (AIC = 23.8, $LR_2 = 35.6$, $p < 0.001$) but differed from the females' model. Since SHOREDIST was a significant ($p = 0.0008$) candidate variable for model building in males, I added this variable to the male model to allow for a better comparison between the classes. This only slightly increased the AIC value to 25.1 and the model remained significant ($LR_3 = 36.3$, $p < 0.001$) and did not elicit much change in the resulting coefficients. I could not add SURFCOV to the females' models since this variable was not a significant candidate ($p > 0.25$) at the univariate stage for either adults or juveniles. Hence, surface cover was not a strong predicting variable and adding it would cause the model to be "overfit" (Hosmer and Lemeshow 2000).

Based on the resulting odds ratios (Table 2-8), male map turtles had a strong preference for shallow water: a 1 m increase in depth resulted in a 75% decrease in selection. Juvenile females also used areas of shallow water where a 1 m increase in depth resulted in a 33% decrease of selection. Although adult females used areas of shallow water, use of deeper water was more frequent than in the other classes; hence a 1 m increase in depth only resulted in a 12% decrease in selection. All three classes showed a preference for areas close to shore with juvenile females and males both decreasing selection by 18% when distance from shore increased by 50 m. In adult females, a 50 m increase in distance from shore resulted in a 26% decrease in probability of selection. Males also demonstrated a strong preference for areas with surface cover. As surface cover increased by 10%, males increased their probability of selection by 35%.

DISCUSSION

Hierarchical Habitat Selection

Map turtles use their habitat non-randomly at both micro and macrohabitat scales. Home range selection (macrohabitat scale), including the core areas of the home range where turtles spent 50% of their time, was non-random. Map turtles primarily selected home ranges in shallow waters. They preferred all tested variables with greater frequency than expected from their availability, except for deep water (>2 m) that was avoided (Fig 2-1). Although there was a significant difference in habitat selection between reproductive classes, final habitat rankings remained quite similar. Males do appear to select areas with open reeds more strongly than females. Turtles also selected home ranges with more natural shorelines and this trend was stronger in the core areas of the home range (Fig 2-2).

At the microhabitat scale I found that map turtles select areas of shallow water near shore. However, the probability of selection differs between the three reproductive classes studied (Fig 2-3 and 2-4). Although adult females chose areas near shore, they also selected areas that had deeper water. One adult female was located in water 14.6 m deep. This can be explained by the more common occurrence of adult females in the boat channel where the water levels are generally deeper but, due to the numerous islands in the area, shorelines are never very far.

Juvenile females and males chose to stay in shallow water. In fact, males strongly preferred shallow water and were never found in waters deeper than 2.4 m. Juvenile females also preferred shallow water but were found in areas as deep as 6.5 m. Although the probability of selection by males and juvenile females was the same for distance to shore, males were never found more than 230 m from shore whereas juvenile females were found as far as 482 m away. This difference in distance corresponds with the deeper areas sometimes used by juvenile females. Males also showed strong preference for areas with surface cover such as lily pads or other floating vegetation (Fig 2-5). Aquatic plants provide animals with important cover and food resources (Radomski and Goeman 2001). Since males are much smaller than females, it is possible that they are using surface cover to hide from possible predators. However, since males are mostly insectivorous (White and Moll 1992, Lindeman 2006), aquatic vegetation likely provides areas with abundant food resources, whereas females, who are molluscivorous (White and Moll 1992, Lindeman 2006), could just as easily find their prey items in open water.

Both swimming ability, as influenced by body size, and diet have been implicated to explain differences in habitat use between sexes in *Graptemys* sp. (Pluto and Bellis 1986, Jones 1996, Lindeman 2003). Juvenile females are intermediate in body size and diet; they overlap in body size with males and are more similar to adult females in diet composition. Lindeman (2003) suggested that if habitat use between adult females and juvenile females are the most similar, one could infer that the differences in habitat use are related to diet. Otherwise, if habitat use between juvenile females and males are most similar, swimming ability may be driving the observed differences. Although in this study it initially appeared that juvenile females are most similar to adult females, lack of significance in ranking orders at the macrohabitat scale and their intermediate levels in probability of selection at the microhabitat scale could not completely support the idea that differences in diet explain the difference in habitat use. Hence, although diet likely plays a role in habitat selection, swimming ability cannot be ruled out. Since *G. geographica* is typically found in larger rivers where depth and distance to shore are more variable than in smaller bodies of water, a better swimming ability may enable females to navigate through currents and deep water (Pluto and Bellis 1986).

Habitat selection studies at multiple scales are important because different factors can influence habitat use at different scales, creating non-congruent patterns of selection (Wiens et al. 1987, Luck 2002, Morin et al. 2005). Habitat selection patterns in map turtles were similar between scales, but investigation of both scales allowed for a more detailed understanding of the selection process. Hierarchical scales of habitat selection probably represent a continuum, but separate examination of these levels facilitates interpretation (Wiens et al. 1987).

Conservation Implications

Selection at both scales reveals a close association with natural shorelines. Turtles significantly selected natural shorelines over developed shorelines within their home ranges. At the microhabitat scale, all individuals demonstrated a tendency to stay near shore and males preferred areas with surface cover. These selection preferences reflect the importance of conserving shoreline habitat for these turtles. Rocks and fallen trees along shorelines are commonly used as basking sites by map turtles (Vogt 1980, Pluto and Bellis 1986, current study). These turtles aggregate to bask and it is not uncommon to find up to 30 individuals sharing a single site (current study). Removal of deadwood along a river has been found to lower basking densities in *Graptemys* spp. (Lindeman 1999). Thus, loss of natural basking sites could result in detrimental effects on the turtle population.

Shorelines also provide essential nesting sites for adult female map turtles. Some shoreline development, such as retaining walls, rip rap, boathouses, and marinas directly remove access to these indispensable nesting sites. Subtler shoreline developments, such as lawns to water edge, clearing of aquatic vegetation and docks can also have negative impacts on map turtles. These areas have substantially less emergent and floating vegetation than undeveloped shorelines (Radomski and Goeman 2001). Since male map turtles have a strong preferences for areas with surface cover, conservation of such natural areas is of crucial importance. In addition, increases in human activity are also closely tied with developed shorelines (Radomski and Goeman 2001). Basking and nesting behaviours in *Graptemys* sp. are altered by human recreational activities (Moore and Seigel 2006). Disturbances force females to increase the number of nesting attempts, resulting in more invested time and energy.

A further concern of developed shorelines is the presence of roads near the shoreline. A two-lane highway runs beside this portion of the St. Lawrence River. Female turtles use the gravel shoulders along the roads as nesting sites and often cross roads in search of these areas (Steen et al. 2006). Turtles are often killed by vehicles when crossing roads. Road mortality is a significant threat to the population viability of turtles (Gibbs and Shriver 2002, Aresco 2005) and of other long-lived reptiles (Row et al. 2007). Because turtles are long-lived, slow growing, experience late sexual maturity, and have high rates of mortality in eggs and hatchlings (Gibbons 1987), they are very sensitive to even slight increases in annual mortality rates (Brooks et al. 1991, Congdon et al. 1993, Gibbs and Shriver 2002). As little as 2-3% additive annual mortality on a turtle population is likely to cause a decline (Gibbs and Shriver, 2002). Mortality rates for map turtles in this area of the St. Lawrence is already quite high, representing 5.5% of the individuals captured.

Many species have well-documented associations with natural shorelines such as fish (Jennings et al. 1999), frogs (Woodford and Meyer 2003), and birds (Buehler et al. 1991). Conservation of natural shorelines should be a priority in the sustainability of these species and of local turtle populations. Evidence of site fidelity between years in adult female map turtles highlights the importance of conserving these habitats. Female turtles are loyal to their home ranges between years, with this trend being most pronounced at the 50% kernel. Despite severe habitat alteration and disturbances, some turtles (such as the ornate box turtle) returned to the same areas to breed, nest, and feed

(Doroff and Keith 1990, Bernstein et al. 2007). If adult turtles are unlikely to establish new areas of activity, increased development will result in greater disturbances. Species with high levels of site fidelity between years are less adaptable to habitat loss and degradation (Warkentin and Hernández 1996). Overall, developed shorelines have a negative impact on map turtles and proper management should be put into place. Management should be directed toward effective regulations concerning further shoreline development, increasing public awareness and education programs for shoreline property owners, and conserving the remaining natural shores.

Table 2-1. Habitat variables examined in the microhabitat analysis of map turtles (*Graptemys geographica*) followed by radio-telemetry in the St. Lawrence River, Ontario, Canada.

Variable	Description
DEPTH	Distance (m) from water surface to bottom
SHOREDIST	Distance (m) to nearest shore
WTMP	Temperature (°C) at water surface
% SURFCOV	Coverage (%) of floating/emergent aquatic vegetation
% MACRO	Coverage (%) of submerged aquatic vegetation
SUSBT	Categorical choices of silt, sand, gravel or rock
TURBID	Water transparency in four categories of FTU values

Table 2-2. Matrices of t-values and associated p-values comparing between-pairs of habitat types in the 50% and 95% kernel for pooled map turtles (n = 28) in the St. Lawrence River, Ontario, Canada. Preference rankings are in order of most (1) to least (5) preferred.

Habitat type	Value	REEDS	MARSH	SHALLOW	INTER	DEEP	Rank
50% Kernel							
REEDS	t-value		1.21	-1.77	-0.95	5.62	3
	p-value		0.24	0.09	0.35	<0.0001*	
MARSH	t-value			-3.19	-2.30	5.69	4
	p-value			0.004*	0.03*	<0.0001*	
SHALLOW	t-value				4.36	8.48	1
	p-value				0.0002*	<0.0001*	
INTER	t-value					8.18	2
	p-value					<0.0001*	
DEEP	t-value						5
	p-value						
95% Kernel							
REEDS	t-value		0.25	-0.34	0.26	5.17	2
	p-value		0.82	0.73	0.80	<0.0001*	
MARSH	t-value			-1.30	0.08	9.51	3
	p-value			0.20	0.94	<0.0001 *	
SHALLOW	t-value				2.73	16.58	1
	p-value				0.01*	<0.0001*	
INTER	t-value					16.84	4
	p-value					<0.0001*	
DEEP	t-value						5
	p-value						

* denotes significant difference

Table 2-3. Matrices of t-values and associated p-values comparing between-pairs of habitat types in the 50% and 95% kernel for adult female map turtles (n = 12) in the St. Lawrence River, Ontario, Canada. Preference rankings are in order of most (1) to least (5) preferred.

Habitat type	Value	REEDS	MARSH	SHALLOW	INTER	DEEP	Rank
50% Kernel							
REEDS	t-value		0.37	-1.78	-1.61	1.94	3
	p-value		0.72	0.10	0.14	0.08	
MARSH	t-value			-2.15	-1.90	2.10	4
	p-value			0.054	0.08	0.06	
SHALLOW	t-value				1.00	3.55	1
	p-value				0.07	0.005*	
INTER	t-value					3.43	2
	p-value					0.005*	
DEEP	t-value						5
	p-value						
95% Kernel							
REEDS	t-value		-0.58	-0.59	-0.58	1.73	4
	p-value		0.57	0.57	0.57	0.11	
MARSH	t-value			-0.23	-0.07	6.62	3
	p-value			0.82	0.94	<0.0001*	
SHALLOW	t-value				0.32	9.27	1
	p-value				0.75	<0.0001*	
INTER	t-value					8.78	2
	p-value					<0.0001*	
DEEP	t-value						5
	p-value						

* denotes significant difference

Table 2-4. Matrices of t-values and associated p-values comparing between-pairs of habitat types in the 50% and 95% kernel for juvenile female map turtles (n = 9) in the St. Lawrence River, Ontario, Canada. Preference rankings are in order of most (1) to least (5) preferred.

Habitat type	Value	REEDS	MARSH	SHALLOW	INTER	DEEP	Rank
50% Kernel							
REEDS	t-value		0.68	-.145	-0.89	3.78	3
	p-value		052	0.19	0.40	0.006*	
MARSH	t-value			-2.03	-1.51	3.62	4
	p-value			0.08	0.17	0.006*	
SHALLOW	t-value				3.97	6.46	1
	p-value				0.004*	0.0002*	
INTER	t-value					6.22	2
	p-value					0.0003*	
DEEP	t-value						5
	p-value						
95% Kernel							
REEDS	t-value		0.64	-0.97	0.75	7.20	2
	p-value		0.54	0.36	0.47	0.0001*	
MARSH	t-value			-1.54	-0.41	6.06	4
	p-value			0.16	0.69	0.0003*	
SHALLOW	t-value				7.11	13.57	1
	p-value				0.0001*	<0.0001*	
INTER	t-value					15.52	3
	p-value					<0.0001*	
DEEP	t-value						5
	p-value						

* denotes significant difference

Table 2-5. Matrices of t-values and associated p-values comparing between-pairs of habitat types in the 50% and 95% kernel for male map turtles (n = 7) in the St. Lawrence River, Ontario, Canada. Preference rankings are in order of most (1) to least (5) preferred.

Habitat type	Value	REEDS	MARSH	SHALLOW	INTER	DEEP	Rank
50% Kernel							
REEDS	t-value		2.26	2.42	8.22	7.97	1
	p-value		0.06	0.053	0.002*	0.0002*	
MARSH	t-value			-1.59	0.29	6.68	3
	p-value			0.16	0.79	0.0005*	
SHALLOW	t-value				2.52	7.99	2
	p-value				0.04*	0.0002*	
INTER	t-value					7.03	4
	p-value					0.0004*	
DEEP	t-value						5
	p-value						
95% Kernel							
REEDS	t-value		1.20	1.32	3.45	6.19	1
	p-value		0.28	0.24	0.01*	0.0008*	
MARSH	t-value			-0.35	0.42	3.59	3
	p-value			0.73	0.69	0.012*	
SHALLOW	t-value				1.19	6.95	2
	p-value				0.28	0.0004*	
INTER	t-value					7.85	4
	p-value					0.0002*	
DEEP	t-value						5
	p-value						

* denotes significant difference

Table 2-6. Matrices of t-values and associated p-values comparing shoreline types in the 50% and 95% kernels for pooled map turtles (n = 28) followed by radio-telemetry in the St. Lawrence River, Ontario, Canada.

Type	Value	Natural	Developed	Rank
50% Kernel				
Natural	t-value		3.06	1
	p-value		0.005*	
Developed				2
95% Kernel				
Natural	t-value		4.69	1
	p-value		0.0001*	
Developed				2

* denotes significant difference

Table 2-7. Matrices of t-values and associated p-values comparing shoreline types in the 95% kernels for adult (n = 12) and juvenile (n = 9) female map turtles in the St. Lawrence River, Ontario, Canada.

Type	Value	Natural	Developed	Rank
Adult Females 95% Kernel				
Natural	t-value		4.23	1
	p-value		0.0014*	
Developed				2
Juvenile Females 95% Kernel				
Natural	t-value		3.05	1
	p-value		0.016*	
Developed				2

* denotes significant difference

Table 2-8. Coefficients and odds ratios for the best models explaining microhabitat use by adult female, juvenile female and male map turtles (*Graptemys geographica*) in the St. Lawrence River, Ontario, Canada.

	Variables	Coefficient	SE	Increase	Odds ratio	95% CI^{+}
Adult Females						
	Depth	-0.127	0.12	1m	0.88	(0.7, 1.1)
	Shoredist	-0.006	0.003	50m	0.74	(0.55, 0.99)
Juv Females						
	Depth	-0.399	0.236	1m	0.67	(0.43, 1.1)
	Shoredist	-0.004	0.003	50m	0.82	(0.61, 1.1)
Males						
	Depth	-1.37	0.945	1m	0.25	(0.04,1.62)
	Shoredist	-0.004	0.005	50m	0.82	(0.5,1.34)
	SurfCov	0.03	0.02	10%	1.35	(0.91,1.99)

+ 95% confidence interval from odds ratios

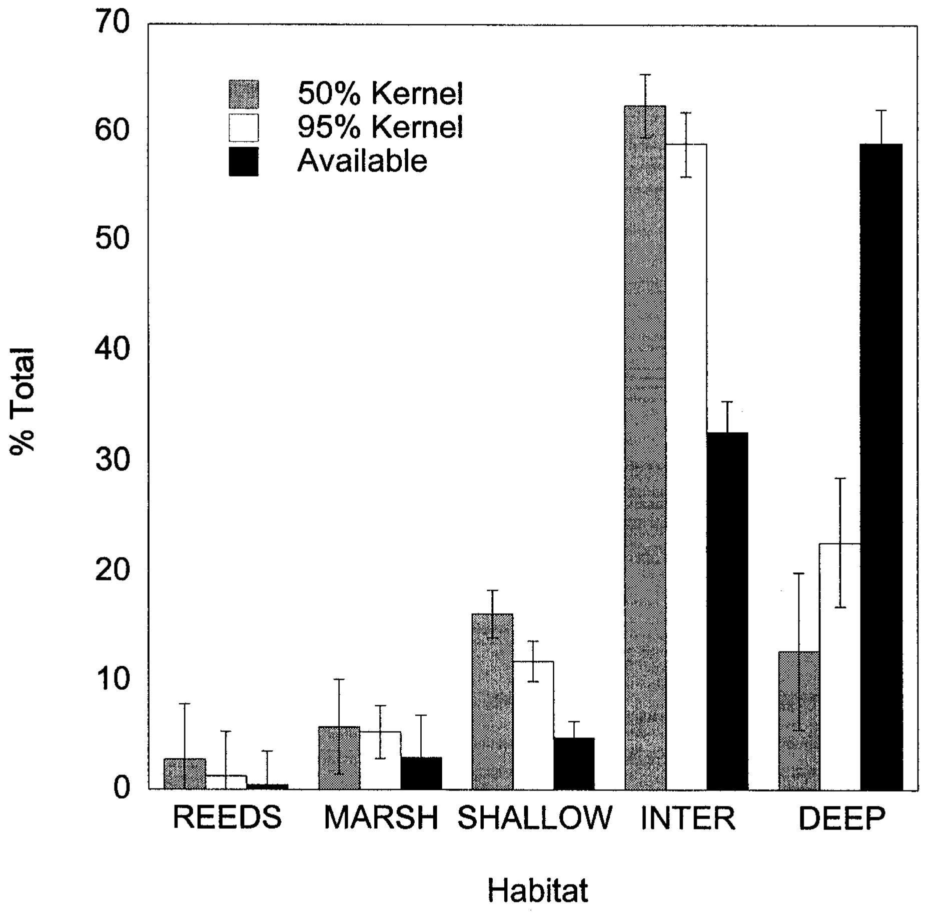

Figure 2-1. Mean percentage (± 1 SE) of the five macrohabitat types within the 50% and 95% kernel home ranges and the available habitat for all map turtles (*Graptemys geographica*) (n = 28) tracked in the St. Lawrence River, Ontario, Canada.

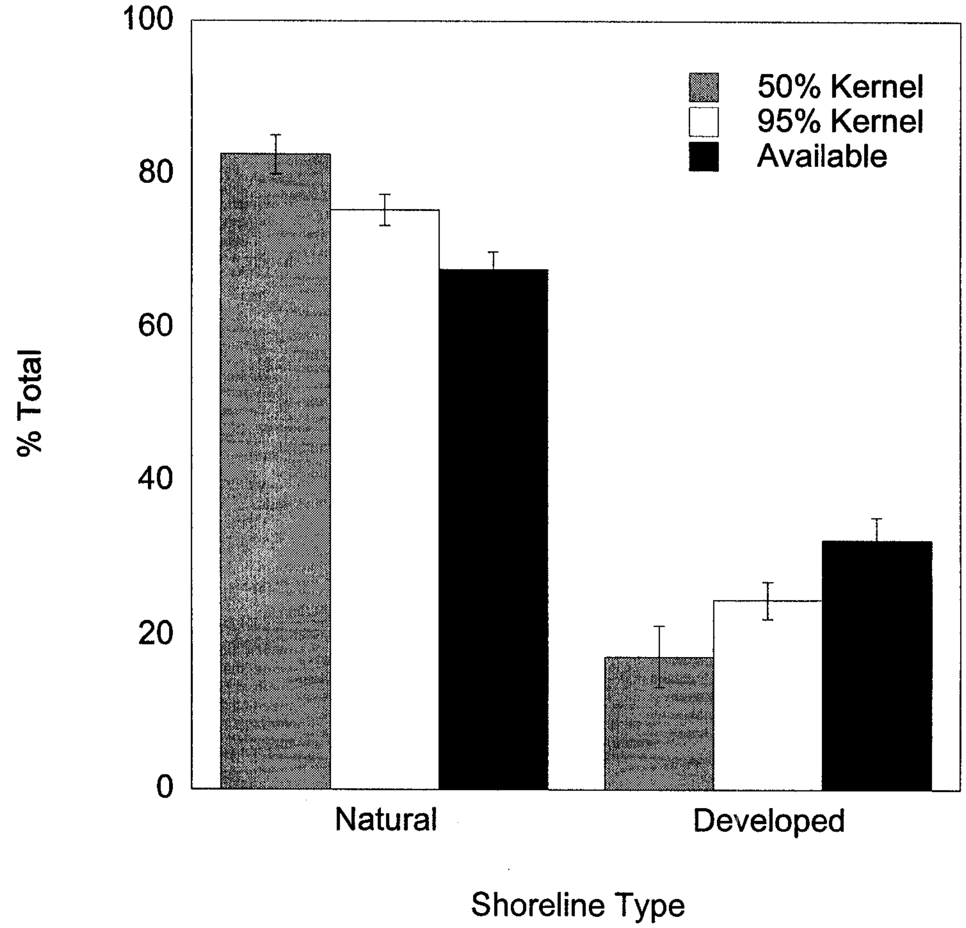

Figure 2-2. Mean percentage (± 1 SE) of the two shoreline types measured in both the 50% and 95% kernel home ranges and the available habitat for all map turtles (n = 28) tracked in the St. Lawrence River, Ontario, Canada.

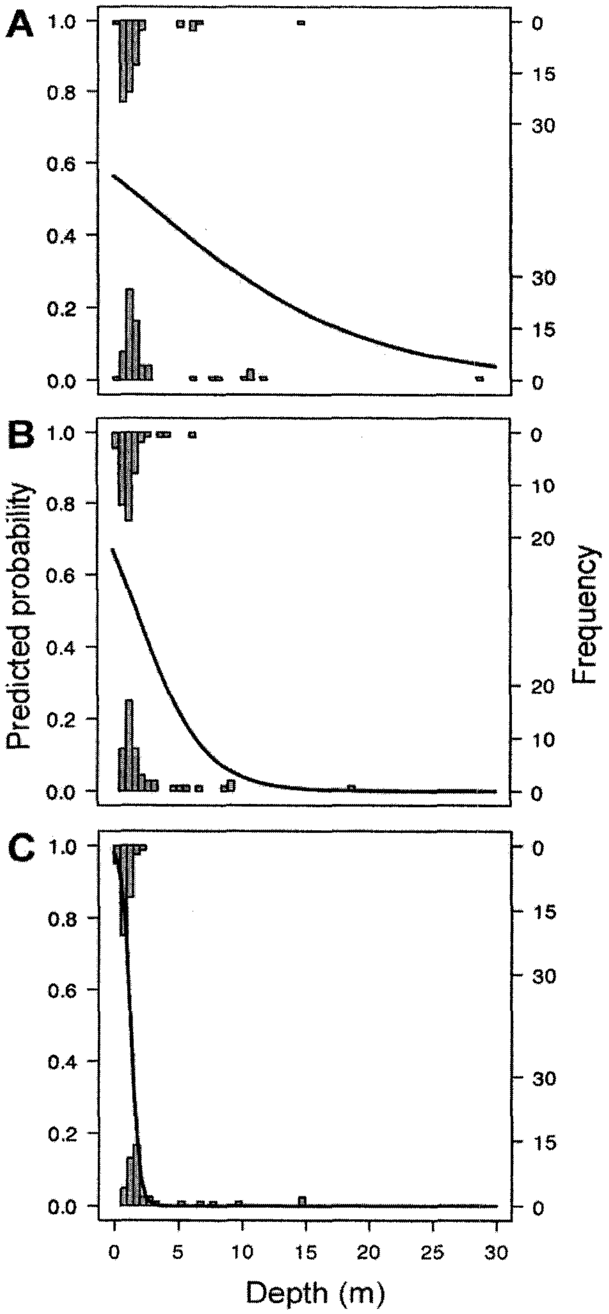

Figure 2-3. Frequency of observed data (histograms) and predicted probability of selection as depth increases for adult female (A), juvenile female (B) and male (C) map turtles (1 = habitat used by turtle, 0 = habitat available) followed by radio-telemetry in the St. Lawrence River, Ontario, Canada.

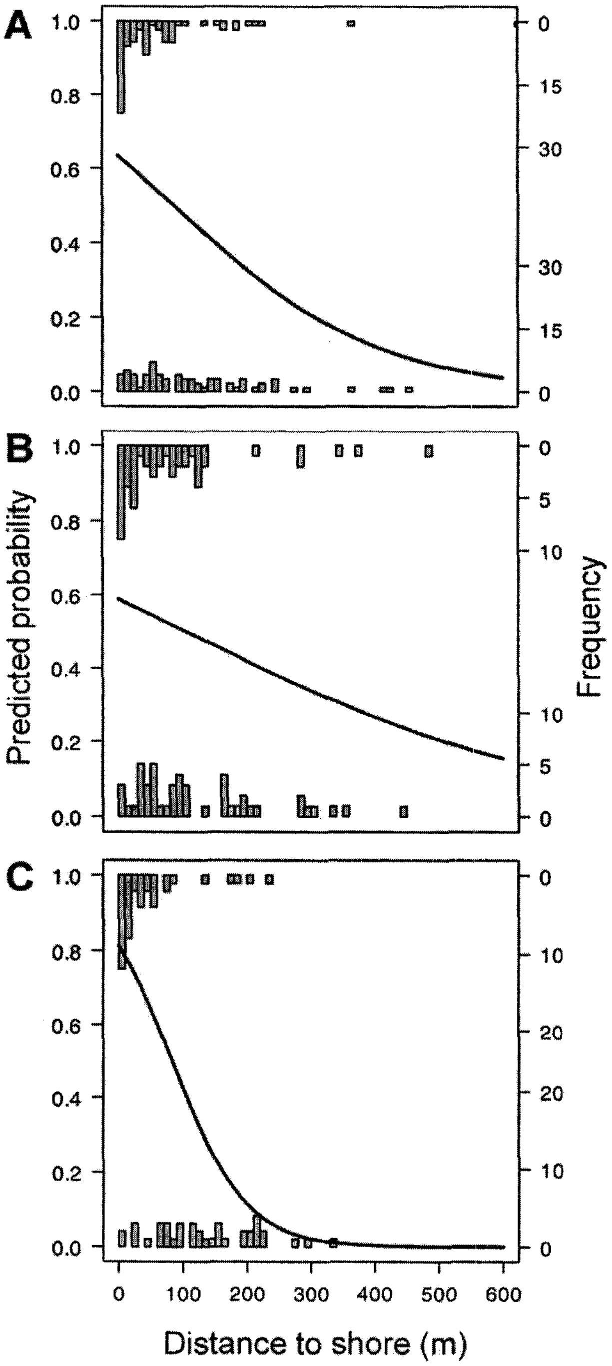

Figure 2-4. Frequency of observed data (histograms) and predicted probability of selection as distance to shore increases for adult female (A), juvenile female (B) and male (C) map turtles (1 =habitat used by turtle, 0 = habitat available) followed by radio-telemetry in the St. Lawrence River, Ontario, Canada.

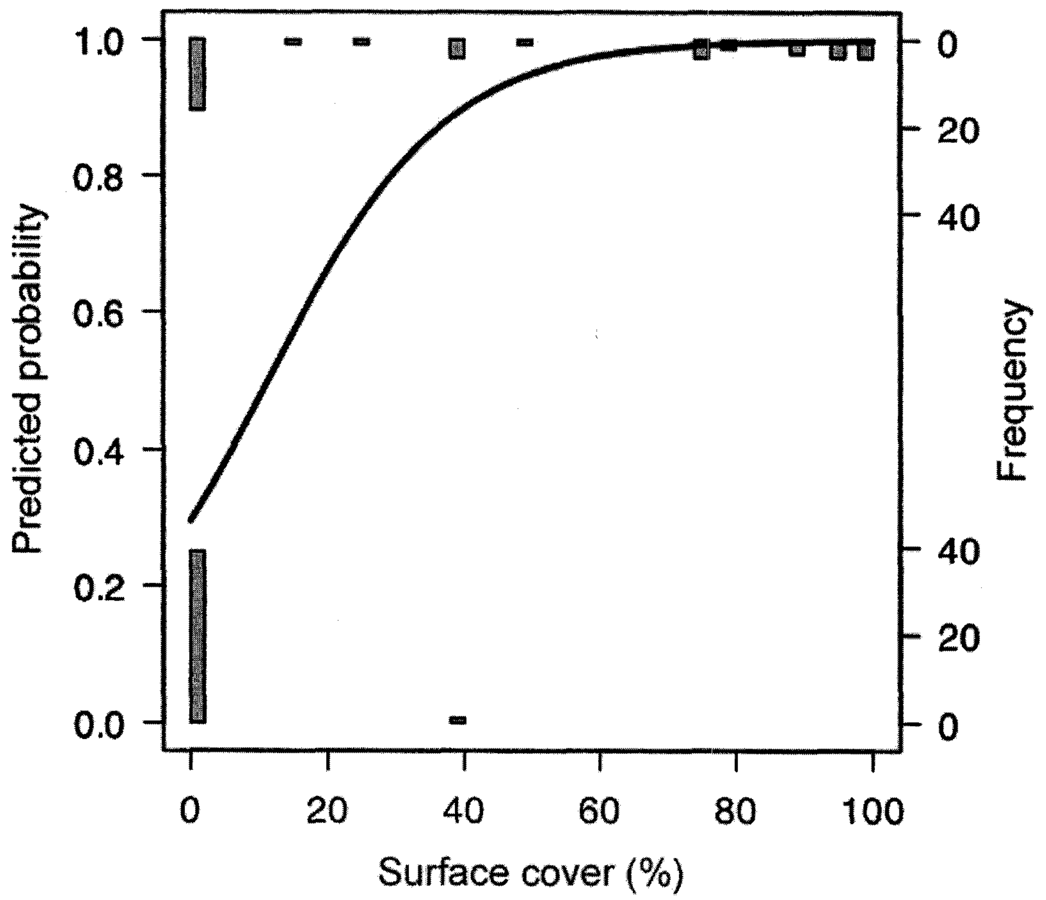

Figure 2-5. Frequency of observed data (histograms) and predicted probability of selection as surface cover increases for male map turtles (1 = habitat used by turtle, 0 = habitat available) in the St. Lawrence River, Ontario, Canada.

APPENDIX I

Preliminary demographic information for a northern population of the common map turtle (*Graptemys geographica*) in St. Lawrence Islands National Park.

INTRODUCTION

The monitoring of populations is essential in wildlife conservation. Assessing changes in local populations is fundamental to understanding the dynamics of such populations over time (Beebee and Griffiths 2005), which allows the effective management of declining species (Boersma et al. 2001). Population estimates for example, provide a basis to which future counts can be compared, enabling the assessment of the variability and trends in population size. Tracking population size through time is also the only way to assess the efficacy of our recovery actions. Monitoring may also help reveal the causes of decline. Due to the apparent decline of most reptiles and amphibians, rigorous field studies examining distribution, abundance, status, and population trends of herpetofauna are critical (Gibbons et al. 2000). Turtles are subject to many anthropogenic stresses that threaten their persistence. Reasons for their decline include habitat loss, pollution, introduced species, disease, unsustainable use, and climate change (Gibbons et al. 2000). These threats can lead to abnormal population structures (Dodd 1990) as well as population declines or extinctions (Gibbons et al. 2000). Without prior knowledge on the population, the demographic response of turtle populations exposed to such threats cannot be interpreted.

Little information exists on the demography and population trends of the common map turtle (*Graptemys geographica*), a species listed as special concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). In Canada, the distribution of map turtles is restricted to southern Ontario and southwestern Québec. Very few studies have been done in the northern part of the range (Gordon and MacCullogh 1980, Flaherty 1982, Daigle et al. 1994). Research along the margin of a range is important to ensure conservation since it has been found that populations along the periphery can persist better than those at the core (Channell and Lomolio 2000). The general goal of this appendix is to give an initial population size estimate and demographic information on a northern population of common map turtles (*Graptemys geographica*) in St. Lawrence Islands National Park.

A preliminary population size estimate for this site will be beneficial to assess changes in the population over time using long-term monitoring programs. Such an estimate is thus an important basis for future monitoring in the park and provides information necessary for recovery actions taken at the regional scale. Preliminary demographic traits such as mortality, nesting occurrences, and sex ratio will also be examined in this population. These demographic characters are important in understanding changes in populations. For example, sex ratio can influence certain aspects of population dynamics such as reproductive output, time spent searching for mates, and intrasexual competition (Gibbons 1990).

METHODS

Study site and study animals

I conducted this study from May to September in both 2005 and 2006 on the St. Lawrence River between Mallorytown and Rockport, Ontario, Canada. The study site covered an area of approximately 11 km x 4 km and surrounded Grenadier Island, one of St. Lawrence Islands National Park's largest islands.

I captured turtles using basking traps, snorkeling near areas of aggregation, scuba diving, and using a dip net directly from a boat. All individuals captured were brought back to the park lab on the mainland and new individuals were marked with a hand-held high-speed drill. I drilled 3-mm holes into the marginal scutes of the carapace (excluding marginal scutes attached to the bridge). Using different combinations of holes, each individual received a unique marking code. Individuals recaptured could then be easily identified and were only brought back to the lab once a year for measurements. All turtles were measured with forestry calipers to the nearest 1mm for carapace length, carapace width, plastron length, and carapace height. I weighed turtles in a bucket to the nearest 5 g with a spring scale. Sex was determined by size, carapace shape, and preanal tail length. Any injuries or scars were noted for each individual.

Population Estimate and Sex Ratio

The population size and sex ratio were estimated for individuals in this portion of the St. Lawrence River from the mark recapture data. Both an operational and an overall sex ratio were calculated. An operational sex ratio is the relative proportion of sexually mature males and females while an overall sex ratio is the proportion of all identifiable males and females, regardless of sexual maturity.

The population estimate was calculated using a Lincoln-Petersen model ($N= ((n_1 + 1)(n_2 + 1) / (m + 1)) -1$) where n_1 represents the total number of animals captured on the first visit, n_2 the total number of animals captured on the second visit, and m is the number of animals captured on the first visit that were then recaptured on the second visit. Although this model typically assumes that the population is closed to additions and deletions, this assumption can be weakened and a modification of the model has often been used for completely open populations (Pollock 1991, Lunn et al. 1997). In addition, other assumptions of the model were met. First, since hatchling turtles were not included in our sample, there were no births. Second, no loss of marks occurred between samples since the turtles are permanently marked with drill hole codes along the margins of the carapace. Last, in accordance with another major assumption, there is no evidence to suggest that marked and unmarked turtles differ in their vulnerability to capture.

Statistical Analyses

I performed statistical analyses with JMP version 5.0.1 (SAS Institute 2002). All means are reported ± 1 SE and I accepted significance of tests at $\alpha = 0.05$.

RESULTS

Population Estimate

Overall during the length of the study, a total of 346 map turtles were captured (plus 297 recaptures). Basking traps were the most successful method of capture, resulting in 451 of the total captures, while snorkeling was the second most successful, yielding 104 individuals (Fig A1-1). In 2006, 27% of individuals caught were recaptures of marked individuals from 2005. Figure A1-2 shows the number of new and recaptured individuals caught in both years. Using the Lincoln-Peterson method, the population estimate for map turtles within the designated study site is 572 (95% confidence interval = 502-668).

Sex Ratio

The overall sex ratio (female : male) in the population is female biased (2:1) and statistically different from 1:1 ($\chi^2 = 60.1$, $p < 0.0001$). The operational sex ratio (mature females : mature males) is also female biased (2:1) and statistically different from 1:1 ($\chi^2 = 85.3$, $p < 0.0001$). Ream and Ream (1966) found that sampling methods were responsible for at least some unbalanced sex ratios in turtles, including a female bias when using basking traps. Since this method of capture was my most successful, I looked at the sampling bias of this method by examining the number of individuals in four groups: unsexed juveniles (carapace length (CL) < 7cm), juvenile female (CL < 20cm), adult female (CL> 20cm) and adult males (CL>7cm) caught in basking traps compared to the total captured by other methods. There was a significant difference in the basking traps compared to the other method of captures ($\chi^2 = 20.6$, $p< 0.0001$) with the basking traps capturing a larger proportion of adult females. However, since the sex ratio was still female biased (1.4:1) when only examining captures from the other methods ($\chi^2 = 4.5$, $p = 0.03$), this suggests the female bias is real, although somewhat exaggerated by the capture methods employed.

Nesting Occurrences

Of the 396 adult females captured, 85 were gravid upon capture (22 in 2005, 63 in 2006) all from May to July with most caught in June. All females with transmitters double clutched and nested at the same site both times. Using radio-telemetry, these nesting sites were identified. The most utilized nesting site was on a sandy embankment of a privately owned lot (n = 5). Communication was established with the local landowner to emphasize the importance of the site and help create public awareness. Other nesting sites included a private golf course (n = 2), sandy lots on the north shore of Tar Island (n = 2) and mud banks in the far back arm of one of the bays (n = 2). Many females were observed basking at all of these sites. Although map turtles were occasionally seen nesting by the side of the highway that runs along the river, only 1 of our 12 females equipped with transmitters was found nesting at this site. Several map turtle nests were also found on Squaw Island, an island owned by Parks Canada.

Injuries and Mortalities

Several turtles were found with severe gashes through their carapace. These gashes most likely resulted from encounters with boat propellers. Two adult females recaptured in 2006 had recent propeller scars. Other turtles harbored older scars, often leaving them with deformed carapaces. A total of 11.3% of all turtles captured showed obvious signs of propeller injuries. Of these, 85% were adult females. This is bound to be an underestimate of injury rates because the most serious collisions would kill the turtles and these carcasses would be unlikely to be recovered.

Mortality rates in 2005 were very high (n = 16) due to drowning of individuals in commercial fishing traps in one of the bays. This bay is highly utilized by map turtles, especially by gravid females in the weeks prior to nesting. The bay was the area with the highest capture rate (30% of all captures). Based on the 2005 telemetry data, the Ministry of Natural Resources (MNR) imposed date restrictions on commercial fishing within the bay for 2006. All fishing traps were pulled from the water on May 1st, coinciding with the beginning of movements of turtles into that area the previous year. The removal of the fishing traps resulted in avoiding any further mortality due to these traps in 2006. Only 2 mortalities were noted in 2006, both apparently from natural causes: one male died at his hibernation site and one female was preyed upon, possibly by a raccoon. However, due to the situation in 2005, the overall mortality rate is still quite high, representing 5.5% of the individuals captured.

DISCUSSION

Sex Ratio

The St. Lawrence map turtle population was found to be female-biased (2:1). Unbalanced sex ratios in turtle populations occur naturally, but several factors could also be driving the observed differences in this study population. Gibbons (1990) suggested that in sexually size-dimorphic species, such as in the genera *Graptemys*, the sex ratio should actually be biased in the direction of the earlier-maturing sex, the males. When this bias is not apparent, other possible influencing factors should be examined such as sampling bias. Sampling bias has been responsible for at least some unbalanced sex ratios in previous studies (Ream and Ream 1966, Gibbons 1990). Several capture methods were used throughout this study, but basking traps were by far the most successful. A female bias was found in the capture sample from basking traps that may lead to an overestimation of the actual number of females present in the population. A possible explanation for the sex bias with basking traps may be related to the locality of the traps. These traps were moved regularly throughout the season in accordance with shifts in areas of high basking. Although males were commonly seen basking at these sites with females, they were also often observed on logs and branches in shallow water, away from the main aggregation sites. Hence, a difference in microhabitat selection could have influenced the success of sampling.

Another factor producing a female-biased ratio could be temperature sex-determination. Environmental influences have an important effect on the hatchling sex ratio in map turtles (Vogt and Bull 1984). The population from the Vogt and Bull (1984) study was also female-biased and a possible explanation was that turtles preferred to nest in open areas created by dredging operations. Although I cannot compare my hatchling ratio to that of the adult population, it is interesting to note that females in the St. Lawrence population also often selected nest sites in artificial environments such as the open sand pits of golf courses, gardens, and the roadside. According to Vogt and Bull (1984), these open sites have more sunlight, hence warmer soil and produce a female biased clutch.

Sex-specific rates of mortality could also lead to an unbalanced sex ratio. However, mortality rates over the course of my study appeared to be greater in females (14 females, 4 males) but it may be that male carcasses were missed more often due to their small size. Nonetheless, the overall female bias is typical of most North American turtle populations (Ernst and Barbour 1972), such as a neighbouring map turtle population in Québec (Gordon and MacCullogh 1980). Furthermore, since the female bias in this population remained when basking trap captures were removed from the analysis, it is likely that this population is truly female biased.

Mortalities

Boat propeller scars were frequently observed on adult females, but very rarely on males. Since males are half the size of adult females, it is probable that they would not survive the extent of such injuries. It is likely that some individuals, both male and female, do not survive these accidents. In fact, propeller accidents are a known cause of mortality in turtles (Horne et al. 2003). Another possibility to explain why few males harbour injuries is a difference in habitat use. In my first chapter, I found that adult females moved more than males and swam longer distances. This increased travel leads them to cross the boat channel more often than males. In addition, in chapter two I found that adult females used deeper water more than males, again demonstrating greater use of the boat channel and hence, greater risk of boat encounters. It should be noted that the two largest communal hibernation sites for these turtles are found directly within the small boat channel, leaving both sexes equally vulnerable to traffic when surfacing to breathe at these sites in the spring and fall.

A relatively large proportion of map turtles died in commercial fishing traps during this study. Freshwater turtle mortalities due to fishing traps have been reported elsewhere (Michaletz and Sullivan 2002, Horne et al. 2003, Barko et al. 2004). Since these traps (i.e. fyke nets) are completely submerged, turtles are unable to reach the surface to breathe and consequently drown. The number of freshwater turtles affected by commercial fishing traps is unknown. Although a short-term solution was devised in my study area with the MNR's date restrictions, this does not resolve the situation in other areas along the river or provide sufficient long-term management. No research has evaluated the amount of turtle by-catch in freshwater systems as we have seen in marine ecosystems (e.g. Pinedo and Polacheck 2004, Shiode et al. 2005, Gilman et al. 2006). Turtle excluder devices have been used in marine systems (Crowder et al. 1995, Epperly and Teas 2002) but the applicability and efficiency of these devices in freshwater river systems have never been determined. In addition to the needed continued research, present management implication should at least involve setting these nets so that the top portion is above water, providing breathing room for turtles.

The long-term effect of these mortalities in the St. Lawrence River is unknown. Because turtles are long-lived, slow growing, experience late sexual maturity, and have high rates of mortality of eggs and hatchlings (Gibbons 1987), they are very sensitive to even slight increases in adult mortality rates (Brooks et al. 1991, Congdon et al. 1993, Gibbs and Shriver 2002). As little as 2-3% additive annual adult mortality on a turtle population is likely to cause a decline (Gibbs and Shriver, 2002). The high rate of mortality observed in this study is therefore a cause of serious concern for the population and highlights the importance of continued monitoring at this site.

Conservation Implications

The population estimate from this study is an important foundation for future monitoring in the area. An advantage of this study population is that it is situated in part within one of Canada's National Parks; St. Lawrence Islands National Park. Parks have the unique opportunity to conduct long-term monitoring projects in protected areas. Their role is therefore invaluable in collecting long-term data. Many species which are thought to be declining have not been monitored over a long period of time, making short-term changes in the population difficult to assess critically (Gibbons et al. 2000). Gathering long-term data on these turtles is therefore an essential part of their successful recovery.

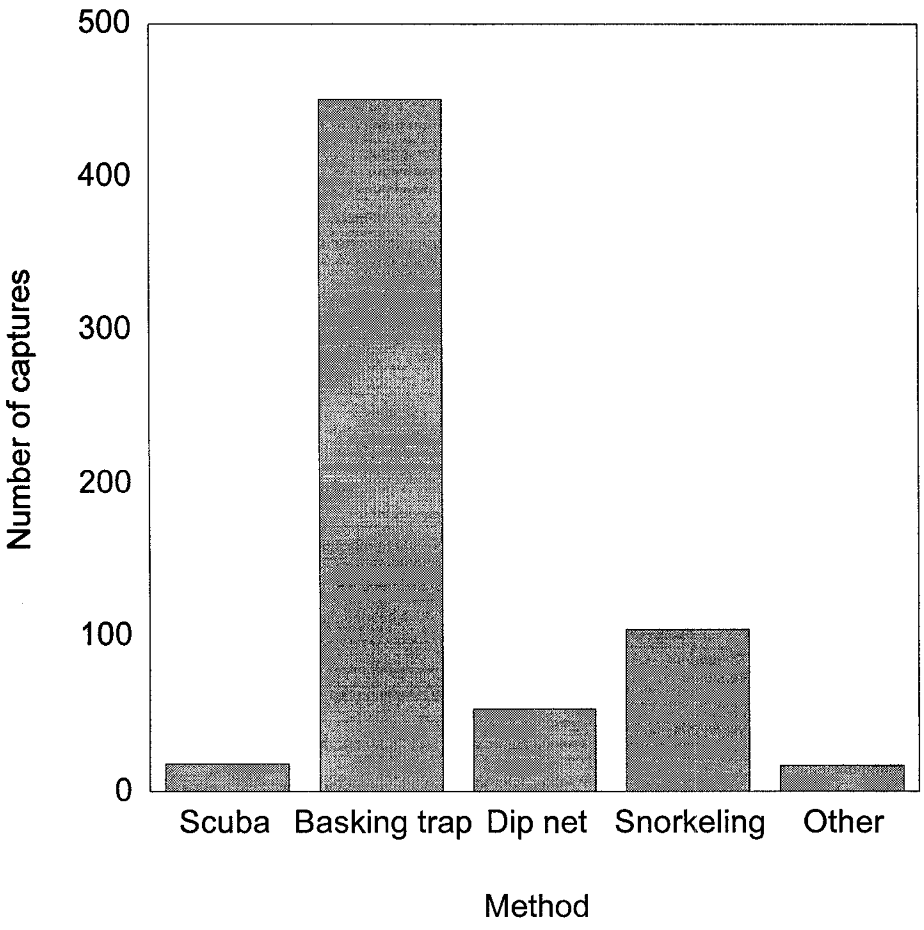

Figure A1-1. Number of map turtles (*Graptemys geographica*) captured by various methods in the St. Lawrence River, Ontario, Canada.

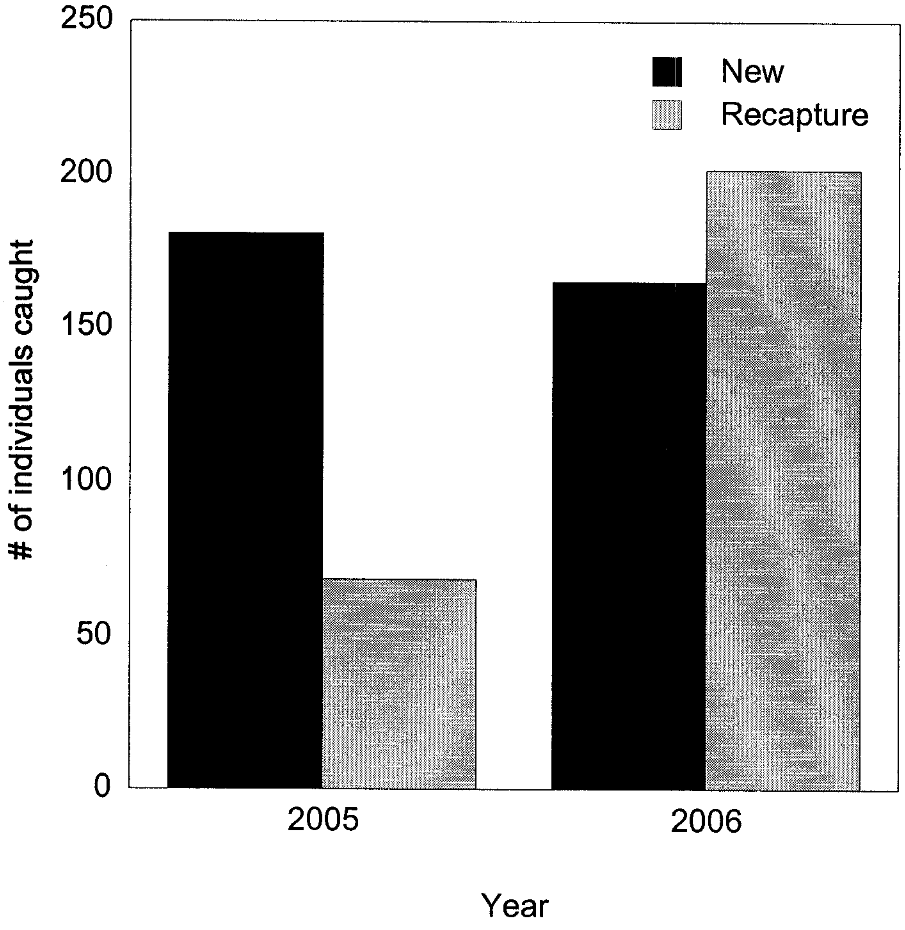

Figure A1-2. Total number of new and recaptured map turtles (*Graptemys geographica*) caught in the St. Lawrence River, Ontario, Canada.

APPENDIX II

A preliminary study of a northern population of stinkpot turtles (*Sternotherus odoratus*) investigating movement patterns in St. Lawrence Islands National Park.

INTRODUCTION

The ecology of the stinkpot, or common musk turtle (*Sternotherus odoratus*), has received remarkably little attention. This small cryptic turtle has a large range from Florida, north to central Ontario, and west to Wisconsin and central Texas (Reynolds and Seidel 1982). The majority of ecological studies have been conducted in the USA, more specifically in Oklahoma (Mahmoud 1969), Florida (Berry 1975), Pennsylvania (Ernst 1986), Virginia (Mitchell 1988), and Alabama (Dodd 1989). To date, there has only been a single in-depth study of stinkpots in Canada. This study was conducted along the coast of Georgian Bay (Edmonds and Brooks 1996, Edmonds 1998). Of all these studies, only a few have examined spatial ecology (Mahmoud 1969, Ernst 1986, Edmonds 1998).

Stinkpot turtles are listed as threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Little is known about this declining species, making research essential to provide accurate information to improve recovery planning and guide management actions (Boersma et al. 2001, Tear et al. 2005). Spatial ecology provides information on the interaction between an individual and its environment, which can aid recovery. Home ranges, for example, are used in conservation to delineate areas that need to be protected by estimating the size and shape of the area used by an animal (Murphy and Noon 1992, Linnell et al. 2004). Habitat loss is a primary threat to most species at risk and examining movement patterns help reveal important portions of a species' habitat such as hibernation and nesting sites. These areas can then be protected to help in the recovery of the species. In this appendix, I present preliminary data on the spatial ecology of a northern population of *S. odoratus* in the St. Lawrence River. I examine movement patterns and home ranges for this population. I also examine preliminary demographic information on the population to help guide local management of the species as well as to provide a basis for future studies in the area.

METHODS

Study Area

I conducted this study from May to September 2006 on the St. Lawrence River near Mallorytown, Ontario, Canada in the Thousand Islands Ecosystem. The study site was located on the north side of Grenadier Island, one of St. Lawrence Islands National Park's largest islands.

Radio-telemetry and data collection

Stinkpots were often found floating beneath lily pad leaves. They were most often caught by hand (Fig A2-1). Stinkpots are highly aquatic and rarely seen basking out of the water. Instead, most basking occurrences occur while floating among aquatic vegetation (Ernst and Barbour 1972). I also captured some turtles with a dip net and by snorkeling. All individuals captured were brought back to the lab for processing. Depending on size, turtles were marked with a unique combination using either holes or notches in the marginal scutes (excluding marginal scutes attached to the bridge). Whenever possible, holes were used as the marking method since they last longer than notches. However, due to the domed shape of the carapace and small size of this turtle, this was not possible in small individuals. A hand-held high-speed drill was used to make the holes, while a triangular file was used for the notches. All turtles were measured to the nearest 1 mm for carapace length, carapace width, plastron length, and carapace height with forestry calipers. I weighed turtles to the nearest 5 g with a spring scale. Sex was determined by tail length and width as well as the presence of a blunt scale at the tip of males' tails. Any injuries or scars were noted for each individual.

Nine of the stinkpots captured (3 males, 6 females) were fitted with radio-transmitters (Holohil SB-2FT 6 g battery life of 12 mo). Transmitters were attached with stainless steel trolling wire tied through holes in the rear marginal scutes of the carapace. I used marine silicone to cover wire and transmitter edges to aid in adhesion and to seal any openings between shell and transmitter where vegetation could snag. Transmitters (including wire) represented at most 5% of the turtle's body mass. Transmitters were removed from the turtles at the end of the study.

Turtles were released at their site of capture the following day and tracked every 3-5 days using a telemetry receiver (Teletonics, Mesa AZ) and a directional antenna. At each location, I recorded the turtle's location on a map and later retrieved the associated Universal Transverse Mercator coordinates (datum NAD83) in ArcMAP (ESRI 2000a). I noted the behaviour (swimming, basking, immobile underwater, or burrowed) of the turtle when located. A few habitat characteristics were also noted; distance from shore (m), depth (m), and the percentage of surface cover at each location.

Because stinkpots are thought to be crepuscular or nocturnal (Mahmoud 1969, Ernst and Barbour 1972, Smith and Iverson 2004), I tracked 3 females and 2 males for 4 consecutive days at the beginning of the season to confirm such activity patterns. Incorporating biological traits, such as diel activity patterns, is important for accurate sampling and accuracy (Kernohan et al. 2001). Ignoring nocturnal movements if they occur could bias location estimates by missing activity patterns at this time. These individuals were tracked 3-4 times over the course of the day from 8h00 to 23h00 to determine if diurnal sampling would be sufficient.

Movement Patterns

I derived movement statistics from 8 turtles (5 females and 3 males) located a total of 163 times. All these individuals were tracked regularly throughout a whole active season (June, July, and August). I used the recorded UTM coordinates to measure distances moved per day in ArcView 3.2 (ESRI 2000b) equipped with the Animal Movements Extension 2.0 (Hooge and Eichenlaub 2000). Movements were measured as straight-line distances between relocations. Any straight-line movements crossing land were modified to represent the shortest distance in water between points since stinkpots are very rarely found on land. I averaged distances moved for each individual before analyses. I examined the effect of sex and body size (carapace length) on the mean distance moved per day.

Home Ranges

I estimated the aquatic home range (excluding all land) of each individual with the minimum convex polygon method (MCP). MCPs are the most commonly used method to estimate animal home ranges (Powell 2000). Although it is often stated that MCPs tends to incorporate large areas that are never used by the animal (Powell 2000), MCP has been found to be an accurate measure for home range size in reptiles (Row and Blouin-Demers 2006). I calculated MCPs using Hawth's Tools (Beyer 2004), an animal movement extension for ArcMAP 9.0 (ESRI 2000a).

Statistical Analyses

I performed statistical analyses with JMP version 5.0.1 (SAS Institute 2002). Transformations were performed on some variables to meet the assumptions of homogeneity of variance and of normality. All means are reported ± 1 SE and I accepted significance of tests at $\alpha = 0.05$.

RESULTS

Demography

A total of 56 stinkpots (33 females, 21 males, and 2 juveniles) were captured during the course of the year. The sex ratio (female : male) was 1:0.6 and was not significantly different from 1:1 ($\chi^2 = 2.6$, $p = 0.10$). Of the 33 females captured, 6 were gravid, including 3 with transmitters. All gravid females were captured in June and July. Although no turtles were observed nesting, all gravid females with transmitters moved to a bay that has an old gravel pit and a beaver lodge. Exact nesting sites remain unknown but it is likely that nesting occurred in the vicinity of this bay. Most individuals used this same bay as a hibernation site.

Stinkpots were burrowed in the mud the majority of the time (44%) and only once was an individual observed during aerial basking (Fig A2-2). Stinkpots were nearly always in less than 1 m (mean = 0.7 ± 0.03 m) of water except once at their hibernation sites where depths reached nearly 3 m. Turtles were usually found close to shore (mean = 5.0 ± 0.3 m) with the exception of a single individual located once 25 m from shore. Not surprisingly, surface cover was used significantly less in May ($F_{4,177}$=18.6, $p < 0.001$) than in other months due to lack of emergent vegetation at this time of year. During the rest of the season (June-September), turtles tracked were found under surface cover such as lily pads, duckweed, and cattails 88% of the time.

Diel activity pattern

Three individuals made single long distance moves over the course of the four days when activity patterns were examined. These long moves occurred when individuals traveled from one bay to another. All other movements were short; individuals stayed within the small bay of their previous location. The three long movements occurred overnight between 21h00 and 8h00. This evidence suggests that stinkpots are most active during the night. However, due to the rarity of these moves and the evidence that individuals typically stay in one area for a prolonged time afterwards, I did not feel that I needed to track turtles at night to document their movements.

Movements and Home Range

I used an ANCOVA to determine if the mean distance moved per day was related to body size and sex. No significant interaction was found between sex and body size ($R^2 = 0.21$, $F_{3,4} = 0.62$, $p = 0.47$). I found no significant relationship with body size ($F_{3,4} = 0.34$, $p = 0.59$) or sex ($F_{3,4} = 0.41$, $p = 0.56$). The mean distance moved per day for all stinkpots tracked was 25.64 ± 1.98 m.

Home range size varied greatly between individuals, ranging from 0.08 to 35.1 ha (mean = 6.2 ± 4.2 ha, Table A2-1). Males tended to have larger home ranges but ANOVA revealed no significant effect of sex on home range size (log transformed) ($R^2 = 0.4$, $F_{1,6} = 3.9$, $p = 0.09$).

DISCUSSION

Home Ranges

Stinkpots in the St. Lawrence River appear to have larger home ranges than those in more southern populations. Stinkpots had very small home ranges in Oklahoma (0.024 to 0.14 ha) (Mahmoud 1969), and Pennsylvania (1.75 ha for males and 0.94 ha for females) (Ernst 1986). However, both of these southern studies estimated home range size based on recapture data. Recapture data tend to underestimates home range size (Schubauer et al. 1990) especially for species known to be very cryptic. Using telemetry data dramatically increases the accuracy and detail of movement information, resulting in more biologically accurate information (Garton et al. 2001). To my knowledge, a study by Edmonds (1998) is the only other study that used telemetry to estimate home range size. Home range sizes in the Georgian Bay population were considerably larger than those of the other studies (10.64 ha to 430.01 ha) (Edmonds 1998). The studies conducted in the south focused on populations in small bodies of water (2.4 ha pond in Pennsylvania, 90 m wide shallow river in Okalahoma), while the Canadian studies occurred in a very large lake and river. Hence, the observed increase in home range size in northern populations could be due to sampling method (capture vs. telemetry), habitat types (size of body of water), or a combination of both. In accordance with my results, none of these studies found a significant difference in home range size between the sexes.

Movement Patterns

I found no difference in movement patterns between the sexes and no effect of body size. The mean distance moved was larger in the St. Lawrence River population than in southern populations. Stinkpot turtles in Pennsylvania moved 93.6 m (Ernst 1986) between capture locations while Oklahoma turtles moved 56 m on average (Mahmoud 1969). Again, size of the turtles' habitat could limit how far an individual moves. The St. Lawrence River is one of Canada's largest rivers and my study area is adjacent to the international shipping channel. Since stinkpots prefer shallow, calm waters and rarely venture on land (Ernst and Barbour 1972), the characteristics of the St. Lawrence study site confines these turtles to the shoreline along Grenadier Island. Moving out from this island would bring turtles in the deep and fast waters of the seaway. In addition, since stinkpots are highly vulnerable to desiccation (Ernst 1968) moving to a neighbouring bay overland is unlikely. Hence, the stinkpot turtles in the St. Lawrence must move greater distances along the shoreline to find necessary resources that might otherwise be easily accessible in smaller habitat types such as ponds or small lakes.

Stinkpots were found to be most active during the night, although telemetry locations taken during the day still adequately represent broad spatial patterns. However, studies examining behaviour and activity patterns in this species should take this timing of activity into consideration. A nocturnal or crepuscular diel activity pattern has been suggested by several other authors (Mahmoud 1969, Ernst and Barbour 1972, Smith and Iverson 2004). Although my study provides preliminary evidence of nocturnal activity, it does not determine if movements occur at dusk, dawn, or throughout the night. It would be interesting to study further such activity patterns in a northern population of stinkpots since latitudinal shifts in diel activity appear to exist; stinkpots are primarily nocturnal in Florida but crepuscular in more northern regions such as Indiana (*see* Smith and Iverson

2004). It has been suggested that water temperature influences the daily activity patterns in this species (Ernst 1986) although further studies are needed.

Conclusion

This study is a preliminary investigation into the spatial ecology of stinkpots in the St. Lawrence River. Although sample sizes were small and the study period relatively short, the results provide an important groundwork for further research in the area. There have been very few ecological studies of stinkpots to date and little is known of their behaviour. The designation of this species as threatened highlights the urgency and importance of research to provide essential information on their biology and ensure their successful recovery.

Table A2-1. Home range estimates (ha), number of telemetry relocations and duration of tracking period for female (n = 5) and male (n = 3) stinkpot turtles (*Sternotherus odoratus*) followed by radio-telemetry in the St. Lawrence River, Ontario, Canada.

Frequency ID	Sex	MCP Home Range (ha)	# relocations	Season span
119	F	2.42	20	May 16 - Sept 4
257	F	5.87	23	May 7 - Sept 15
272	F	0.11	18	May 7 - Aug 23
620	F	0.25	20	June 10 – Sept 4
661	F	0.082	20	May 20 - Aug 31
856	M	3.21	20	May 13 – Sept 4
462	M	35.15	23	May 13 – Sept 15
93	M	2.50	19	June 21 – Sept 15

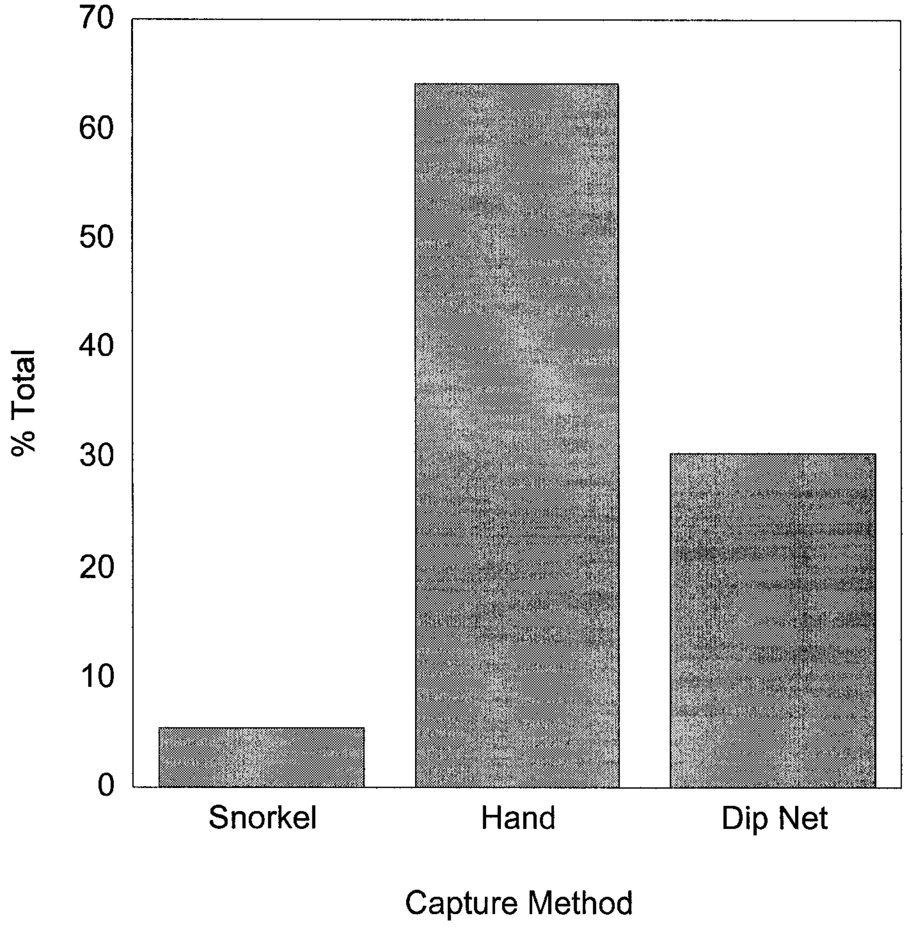

Figure A2-1. Percent of total stinkpots (*Sternotherus odoratus*) (n = 56) caught by various methods in the St. Lawrence River, Ontario, Canada.

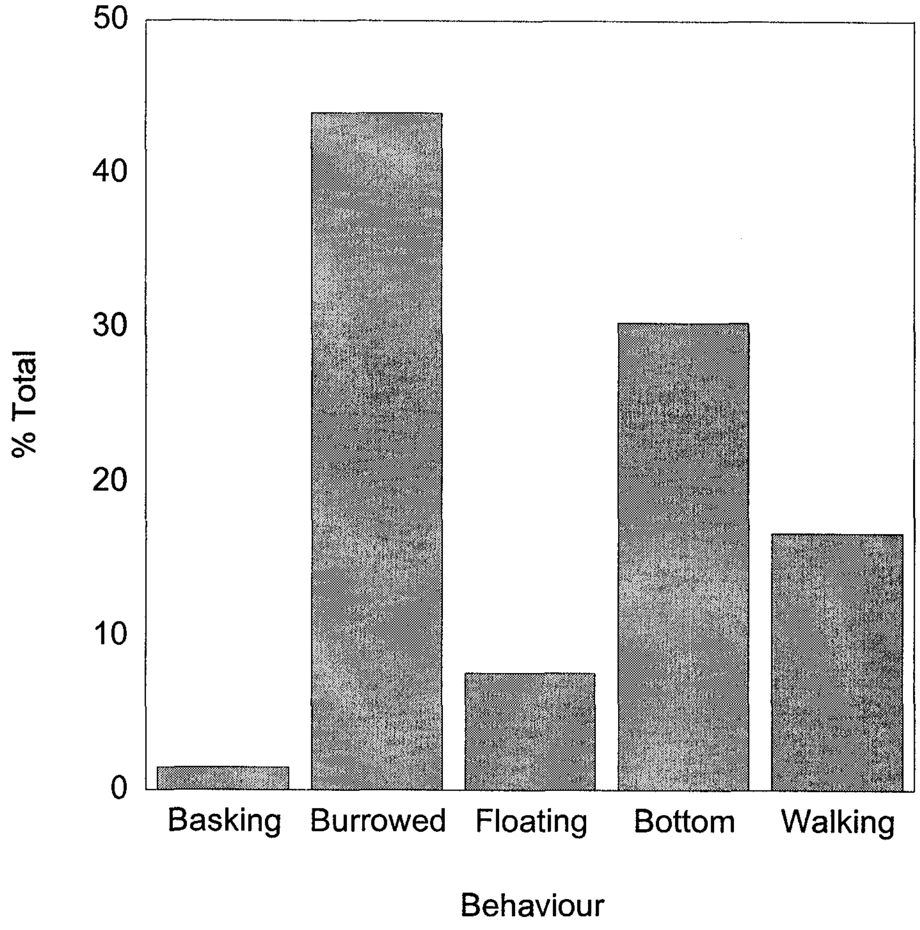

Figure A2-2. Behaviour of stinkpots (*Sternotherus odoratus*) (n = 8) at telemetry locations (n = 66) in the St. Lawrence River, Ontario, Canada.

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