HABITAT SELECTION, MOVEMENT PATTERNS, AND DEMOGRAPHY OF COMMON MUSK TURTLES (*STERNOTHERUS ODORATUS*) IN SOUTHWESTERN QUÉBEC

by

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ABSTRACT

I studied the common musk turtle (*Sternotherus odoratus*) at the northern limit of its range at Norway Bay, Québec, from April to October 2006. Common musk turtles are habitat specialists and are selective of their habitats at the study-area and home-range scales. Beaver (*Castor canadensis*) lodges were preferred at the study-area scale. Common musk turtles also preferred beaver lodges, emergent wetlands, aquatic beds with floating and submerged vegetation as well as rocky shores at the home-range scale. At the location scale, common musk turtles chose shallower and cooler sites that contained more logs and submerged vegetation than the sites available at random. There was no significant effect of sex on habitat use at the location scale. There was no significant difference in mean daily movements between the sexes during the active season. However, sex and month probably interact together to influence the mean distance traveled daily by common musk turtles in Norway Bay. Males appeared to move more than females in May, July, and October. Females appeared to move more daily than males in August and September. Neither sex appeared to move more daily in June. However, our small sample size did not allow us to conduct a conclusive analysis. The mean home-range area was 23.9 ha and was not different between sexes. I estimated a density of 4.1 turtles/ha and a sex ratio of 1.7M: 1F. The population includes 59.6% males, 35.8% females, and 4.6% juveniles. Adults ranged from 77 mm to 133 mm in carapace length.

RÉSUMÉ

J'ai étudié la tortue musquée (*Sternotherus odoratus*) à la limite septentrionale de l'aire de distribution à Norway Bay, Québec, d'avril à octobre 2006. Les tortues musquées sont spécialistes et préfèrent certains habitats à l'échelle de l'aire d'étude et à l'échelle du domaine vital. Les huttes de castor (*Castor canadensis*) ont été préférées à l'échelle de l'aire d'étude tandis que les tortues musquées ont préféré les huttes de castor, les milieux humides émergents, les lits aquatiques avec de la végétation immergée et flottante ainsi que les berges rocheuses à l'échelle du domaine vital. À l'échelle de la localisation, les tortues musquées ont choisi des sites moins profonds et plus froids avec une plus grande quantité de billots immergés et de végétation immergée que ce qui était disponible aléatoirement. À cette échelle, il n'y avait pas d'effet significatif du sexe sur l'utilisation de l'habitat. Il n'y avait pas de différence significative entre les mouvements journaliers moyens des mâles et des femelles durant la saison active. Toutefois, le sexe et le mois semblent interagir pour influencer les mouvements journaliers moyens des tortues musquées à Norway Bay. Les mouvements journaliers des mâles semblaient plus grands que ceux des femelles en mai, juillet et octobre tandis que les mouvements journaliers des femelles semblaient plus grands que ceux des mâles en août et septembre. Les mouvements journaliers des deux sexes semblaient équivalents pour le mois de juin. Par contre, la taille de l'échantillon utilisé ne permettait pas d'effectuer une analyse concluante. La superficie moyenne des domaines vitaux était de 23,9 ha et ne différait pas selon le sexe. J'ai estimé une densité de 4,1 tortues/ha ainsi qu'un ratio des sexes de 1,7M : 1F. La population comprend 59,6% de mâles, 35,8% de femelles et 4,6% de juvéniles. La longueur de la carapace des adultes se situait entre 77mm et 133 mm.

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CHAPTER ONE

GENERAL INTRODUCTION

Decline of reptile populations worldwide constitutes a conservation crisis (Gibbons et al. 2000). These declines are attributed to habitat loss and degradation, environmental pollution, introduction of invasive species, diseases, global climate change, and overexploitation (Gibbons et al. 2000). Loss, degradation, and fragmentation of wetland habitats can induce abnormal population structure (Dodd 1990; Reese and Welsh 1998) or even lead to population decline and extinction of aquatic turtles (Gibbons et al. 2000). However, sustainability can be achieved by having management plans that are specific to species and populations (Gibbons et al. 2000).

Both the Species at Risk Act (S.A.R.A.) in Canada and the Endangered Species Act (E.S.A.) in the US require respective governments to designate the critical habitat of species listed under these acts. Critical habitat is defined as specific areas within the geographical area occupied by a species and containing physical and/or biological features essential to its conservation. Furthermore, the important impact of habitat loss on biodiversity decline (Wilcove et al. 1998) stresses the importance of identification and protection of used and critical habitats in management and conservation plans (Harvey and Weatherhead 2006). Habitat selection studies permit fulfillment of this conservation goal for particular populations, but also provide knowledge on the process followed by animals in selecting habitats. Knowledge of the process allows predictions on how animals will use habitats at other locations (Harvey and Weatherhead 2006).

Turtles are long-lived (Gibbons 1987; Congdon et al. 1994) with life-history traits that make recovery from decline difficult (Congdon et al. 1994). Long-term monitoring is usually required to assess adequately turtle populations because adverse situations can sometimes occur over long periods before the effects on a population become detectable (Russell 1999). Rigorous estimates of demographic parameters can provide information about different aspects of a population (Madsen and Shine 1993; Brown and Weatherhead 1999) and help in creating management and conservation plans for long-lived species (Heppell et al. 1999) such as turtles.

During the past decades, several studies on turtles in Canada have provided relevant information for the management and conservation of turtle populations at the northern limit of their range. There is information on the Blanding's turtle (*Emydoidea blandingii*) (Herman et al. 1995; Standing et al. 1999; McMaster and Herman 2000; McNeill et al. 2000; Mockford et al. 2005), the wood turtle (*Clemmys insculpta*) (Quinn and Tate 1991; Walde 1998; Arvisais et al. 2002; Trochu 2003; Walde et al. 2003; Arvisais et al. 2004; Saumure 2004), the snapping turtle (*Chelydra serpentina*) (Brown and Brooks 1993; Bobyn and Brooks 1994; Petitt et al. 1995), the spotted turtle (*Clemmys guttata*) (Litzgus and Brooks 1998; 2000; Haxton and Berrill 2001), the painted turtle (*Chrysemys picta*) (Lefevre and Brooks 1995), the map turtle (*Graptemys geographica*) (Daigle et al. 1994) as well as the spiny softshell turtle (*Apalone spinifera*) (Daigle et al. 2002; Galois et al. 2002). However, despite the status of the common musk turtle (*Sternotherus odoratus*) as a threatened species in Canada (COSEWIC 2002), the ecology of only one Canadian population has been studied (Edmonds and Brooks 1996; Edmonds 1998). Furthermore, despite the lack of information and its northern situation, no study has ever been conducted on the most northern population of this species located in southwestern Québec.

While a few studies have described habitat use by common musk turtles in different parts of the species' range (Ernst 1986; Ernst et al. 1994; Edmonds 1998), studies describing habitat use by common musk turtles in Canada are rare (Chabot and St-Hilaire 1991; Edmonds 1998). Generally, the common musk turtle is described as an omnivorous, bottom-dwelling, and highly aquatic species inhabiting littoral zones and shallow waterways (Ford and Moll 2004) like rivers, lakes, streams, ponds, canals, and swamps with slow current and soft bottom (Ernst et al. 1994; Conant and Collins 1998). The musk turtle ranges from Texas to Lake Michigan and from Southern Ontario and Québec to the Atlantic coast (Figure 1.1). The available information on habitats selected by common musk turtles remains largely qualitative.

Several other aspects of the ecology of common musk turtle have been studied. These studies have taken place in several states and provinces, including Virginia (Mitchell 1988; Holinka et al. 2003; Smar and Chambers 2003), southeastern Pennsylvania (Ernst 1986), Missouri (Ford and Moll 2004), Indiana (Evermann and Clark 1916; Clark et al. 2001; Ewert 2005), Ohio (Conant 1951), Michigan (Risley 1933; Lagler 1941; Williams 1952), Oklahoma (Mahmoud 1967, 1968 and 1969), Florida (Berry 1975, Iverson 1977; Bancroft et al. 1983; Meshaka 1988;

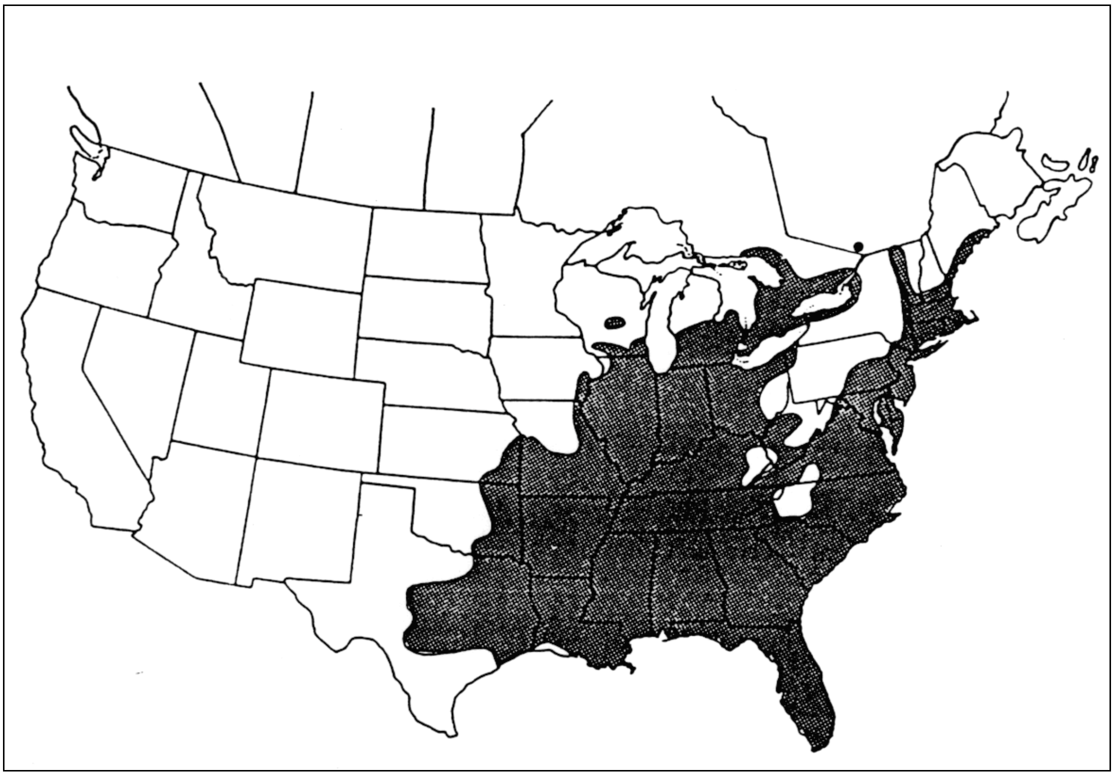

Figure 1.1: Overall range of the common musk turtle (Source: Edmonds 2002).

Aresco 2005), Alabama (McPherson and Marion 1981*a*, 1981*b*; Dodd 1989), Illinois (Tucker and Lamer 2005), South Carolina (Gibbons et al. 1983), and Ontario (Edmonds and Brooks 1996). The different aspects of common musk turtle ecology that were documented include daily cycle of activity (Mahmoud 1969, Bancroft et al. 1983; Ernst 1986), annual cycle of activity (Risley 1933; Conant 1951; Mahmoud 1969; Ernst 1986), temperature relationships (Hutchison et al. 1966; Mahmoud 1969; Ernst 1986), food and feeding behaviour (Risley 1933, Mahmoud 1968; Ernst and Barbour 1972; Berry 1975; Bancroft et al. 1983; Ernst 1986; Ford and Moll 2004), growth (Sergeev 1937; Mahmoud 1969; Ernst 1986; Edmonds 1998), longevity (Ernst 1986), reproduction (Evermann and Clark 1916; Risley 1938; Lagler 1941; Edgren 1942, 1956; Tinkle 1961; Mahmoud 1967; Gibbons 1970*a*; Ernst and Barbour 1972; Iverson 1977; Moll 1979; McPherson and Marion 1981*a*, 1981b, 1983; Mitchell 1985*a*, 1985*b*; Ernst 1986; Mendonça 1987; Meshaka 1988; Clark et al. 2001; Tucker and Lamer 2005; Ewert 2005), population dynamics (Risley 1933; Tinkle 1961; Mahmoud 1967, 1969; Gibbons 1970*b*; McPherson and Marion 1981a; Ernst 1986; Holinka et al. 2003; Swannack and Rose 2003), movements (Williams 1952; Ernst 1968; Gibbons et al. 1983 ; Smar and Chambers 2005; Andres and Chambers 2006), predation and injuries (Ernst 1986), and ectoparasites (Wilson and Friddle 1950 ; Edgren et al. 1953; Neill and Allen 1954; Proctor 1958; Dixon 1960; Belusz and Reed 1969; Ernst 1986; Ryan and Lambert 2005).

Despite numerous studies focusing on the ecology of common musk turtles, very few studies have been conducted on northern populations (Lindsay 1965; Edmonds and Brooks 1996; Edmonds 1998). For species with large distribution ranges, climatic variation across their range is likely to produce differences in demographic characteristics among populations (Blouin-Demers et al. 2002). Therefore, applying management actions to populations based on information derived from populations located much further south may be risky. Creation of management plans designed to conserve viable populations of a species across its range thus requires information from populations across the range. Our study population at the northern limit of the species' range is located in the southern part of the Outaouais region, along the north shore of the Ottawa River (Bider and Matte 1994), near Norway Bay. Information from this population will fill a knowledge gap important for the conservation of this threatened species (COSEWIC 2002).

This research focused on the most northern known common musk turtle population and its main objectives were to provide information on patterns of habitat use and movements, and demography. I also wanted to provide conservation recommendations useful for the Norway Bay population but which may also be useful for other northern populations.

The first chapter focuses on habitat selection and movement patterns. Specific objectives include the assessment of selection at two spatial scales: selection of a home range within the study area and selection of different habitats within the home range. Another objective is to identify variables influencing selection at the microhabitat scale, also referred to as the location scale. A further objective is to describe mean daily movements during the active season and during the months of May to October. I also want to estimate home range size. Finally, a last objective is to give a set of conservation recommendations and explain what implications the results have for conservation.

The second chapter focuses on the population's demography. Specific objectives are to estimate turtle density and sex ratio and to describe the population structure. Finally, a last objective is to provide conservation recommendations.

CHAPTER TWO

HABITAT SELECTION AND MOVEMENT PATTERNS OF COMMON MUSK TURTLES (*STERNOTHERUS ODORATUS*) IN SOUTHWESTERN QUÉBEC: IMPLICATIONS FOR CONSERVATION

Introduction

The worldwide decline of reptile populations represents a conservation crisis and its causes include habitat loss, fragmentation and degradation, environmental pollution, introduction of invasive species, diseases, global climate change, and overexploitation (Gibbons et al. 2000). Declines and extinctions of aquatic turtles are at the forefront of reptile conservation concerns (Buhlmann and Gibbons 1997; Gibbons et al. 2000) and are induced by habitat loss, degradation, and fragmentation (Gibbons et al. 2000). The key to sustainability is to have management plans that are specific to species and populations (Gibbons et al. 2000). Determining the type and amount of space needed by organisms throughout their life cycle is an essential step for the identification of essential habitats. Knowledge of movement patterns is also essential in understanding animal ecology and life history (Swingland and Greenwood 1983; Gregory et al. 1987; Gibbons et al. 1990). Therefore, an understanding of habitat use and movements by a species is especially important in designing conservation plans (Litzgus and Mousseau 2004) and making management recommendations.

There is little information on habitat selection and movement patterns of the common musk turtle (*Sternotherus odoratus*), a species listed as threatened in Canada (COSEWIC 2002). While the common musk turtle is widespread in eastern and central United States, it can only be found in two Canadian provinces where it is concentrated in southeastern Ontario and southwestern Québec (Figure 1.1). This very aquatic species has disappeared from most of the southern half of its range and is thought to be vulnerable to mortality from outboard motors, shoreline development, and anthropogenic activity (Edmonds 2002). Several studies have associated this species with shallow waters (Mahmoud 1969; Edmonds 1998), slow currents, and soft substrates (Mahmoud 1969; Cook 1984; Chabot and St-Hilaire 1991; Edmonds 1998; Edmonds 2002). An attempt was made to study responses of the common musk turtle to habitat features at multiple spatial scales in north-central Indiana (Rizkalla and Swihart 2006) but it was not successful due to the species' relative rarity in Indiana. Despite these studies, information on habitat use by common musk turtles is still largely qualitative. Such knowledge would help define critical habitats legally, which is an important part of the protection process in Canada. Furthermore, information on which habitats are used, preferred, and avoided by the common musk turtle would be novel and, as such, useful for any populations throughout the range.

Habitat selection can occur at four spatial scales or orders of selection (Johnson 1980). First order selection is the distribution range of a species (Johnson 1980). An animal can also select a home range within the landscape (second order), then select different habitats within that home range (third order), and finally select particular items within habitats (fourth order) (Johnson 1980). Animals are believed to select habitats which promote long-term reproductive fitness (Orians and Wittenberger 1991; Rettie and Messier 2000). Selection patterns at the first and second orders are thought to be more important for fitness and are considered stronger than selection patterns at finer scales (third and fourth orders) (Rettie and McLoughlin 1999).

Habitat selection is a hierarchical process because what is available at a certain scale depends on what is used at another scale. However, the process is not necessarily congruent across spatial scales because selection pressures as well as limiting factors can vary with scale (McLoughlin et al. 2002). Therefore, a habitat selected at a certain scale is not automatically selected at another (Morin et al. 2005). A multi-scale approach permits description of the elements reflecting all the needs of the species and allows for sound management and conservation decisions (Litzgus and Mousseau 2004; Morin et al. 2005).

While many studies conducted mostly in the southern part of the species' range have documented common musk turtle movements (Williams 1952; Gould 1959; Mahmoud 1969; Ernst 1986; Mitchell 1988; Holinka et al. 2003; Smar and Chambers 2005; Andres and Chambers 2006), the great majority have focused on homing behaviour and site fidelity only. Furthermore, with one exception (Williams 1952), these studies recorded distance traveled by common musk turtles between relocations but did not record them as daily movements. Hence, little is known about the mean distances traveled per day by musk turtles. Information on daily and seasonal movements can further help to identify critical habitats (Arvisais et al. 2002). Determining the space required by animals throughout their lifetime can help to protect viable populations through design of conservation plans (Eubanks et al. 2003; Litzgus and Mousseau 2004). However, few studies have produced reliable estimates of home range size for common musk turtles (Mahmoud 1969; Ernst 1986; Edmonds 1998).

The purpose of this study is to describe habitat selection as well as movement patterns of common musk turtles at Norway Bay, Québec. With respect to habitat selection, the following questions were addressed: (1) Do common musk turtles select their habitats at the second order (landscape scale) and third order (home range scale) of selection? (2) Which variables influence habitat selection at the fourth order (location scale)? The third and fourth objectives were, respectively, to document daily and seasonal movements of common musk turtles and to estimate the mean home range size in this population. Finally, the last objective was to provide a set of management recommendations.

Methods

Study area

The study site had an area of 166.9 ha and was located on the north shore of the Ottawa River, approximately 3.5 km southeast of Norway Bay, Québec (Canada) (45º29'15''N, 76º23'15''O) (Figure 2.1). The study area included several shallow bays with slow currents, and abundant vegetation including species of submerged, floating and emergent aquatic plants. Permanent or seasonal human habitation in the area is rare but camping, fishing and boating occur frequently.

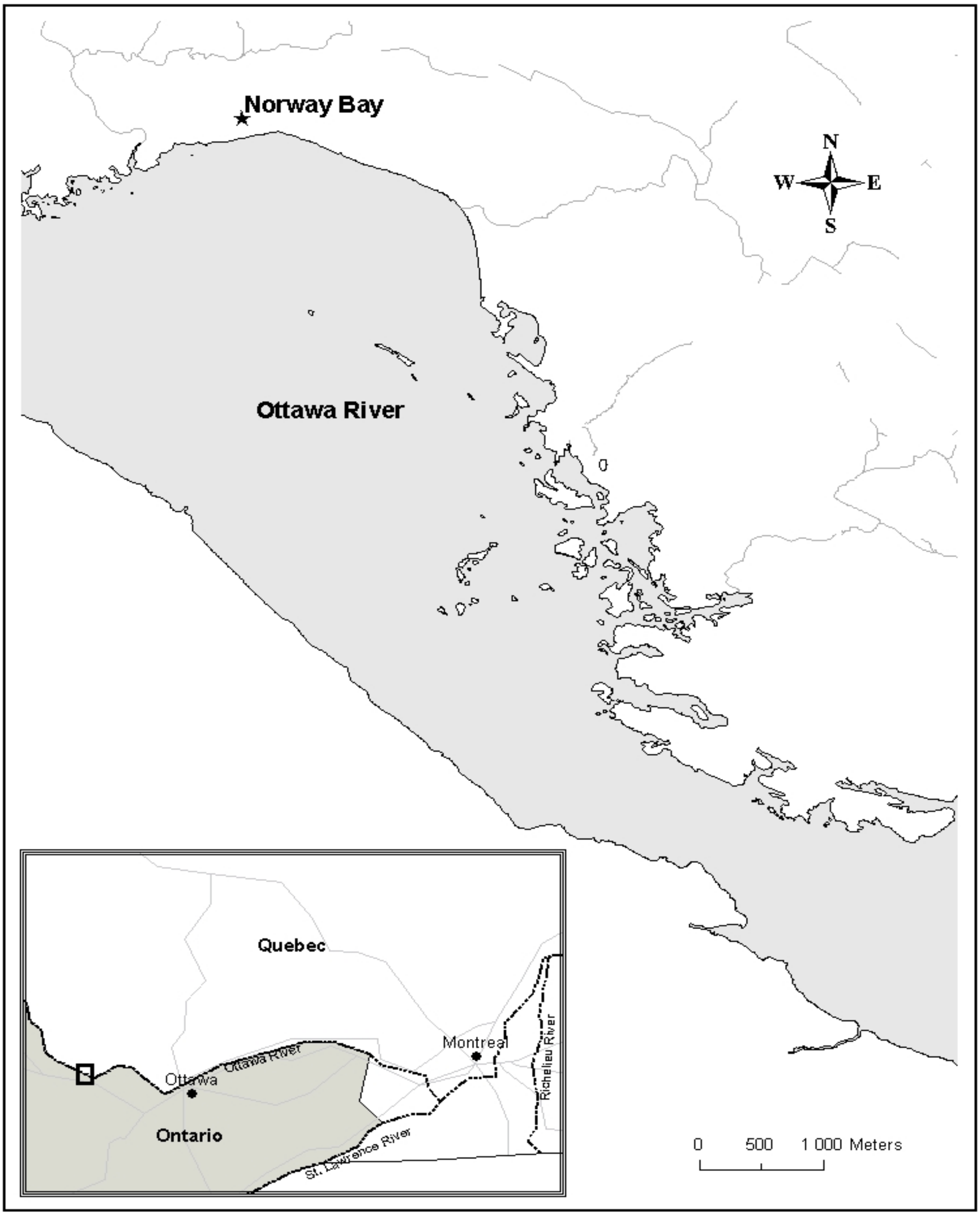

Figure 2.1: Study area at Norway Bay, Québec.

Capture

Musk turtles were captured by hand, dip-nets, and double funnel traps with leaders. In total, 29 radio-transmitters were put on adult turtles during the active season. During the first weeks of field work, 25 radio-transmitters were attached to adult turtles (13 males and 12 females). Transmitters were either of 6 g (Model SB-2F, eight months battery life, Holohil Systems) or 12 g (Model SI-2F, 12 months battery life, Holohil Systems) depending on the mass of the individuals. To compensate for losses of more than half of the transmitters, new units were placed on four turtles in early September. The transmitters were affixed to the turtles' carapace using stainless steel bolts drilled in the posterior edge of the carapace and secured with stainless steel nuts. Turtles equipped with a transmitter were initially captured in different bays of the study area to prevent the sampling of a subpopulation only. Handling of the turtles and use of telemetry was approved by the McGill University Animal Care Committee – Animal Use Protocol 5159 (Appendix A).

Radio-telemetry

Radio-telemetry locations were obtained from early May to late October 2006. Two telemetry locations were obtained for every period of 10 or 11 days: once during the day and once after sunset to distribute the sampling effort around the circadian cycle of the common musk turtle. A visual observation was attempted at each location but was not always possible. The location precision was approximately 5 m. UTM coordinates (NAD 83 datum) were recorded from a GPS (Etrex, Garmin).

Habitat cover map

Habitat types within the Norway Bay study area were delineated according to a modified version of the Cowardin Classification for wetlands and deepwater habitats (Cowardin *et al.* 1979). This classification system is based on vegetation and substrate characteristics of a riverine system. Some original habitat classes of the Cowardin Classification were used without modification while other classes were modified and some were added to make a total of ten habitat types (Table 2.1). The five original categories included emergent wetland (LEWT), rock bottom (LRB), rocky shore (LRS), unconsolidated bottom (LUB), and unconsolidated shore (LUS). The three modified classes included aquatic bed with submerged and floating vegetation (LABF), aquatic bed with submerged vegetation (LABI) and aquatic bed with emergent vegetation only (LEWE) and constitute modifications of an original class called aquatic bed (Cowardin et al. 1979). Modifications to the original classification were made to assess how different types of aquatic vegetation found in aquatic beds influenced macrohabitat selection. The clear spatial separation of these types in the study area supports the modifications. Finally, two additional habitat classes were created because they were abundant in the study area or frequently used while not fitting in the existing categories. These additional categories are beaver lodges (CABA) and cattail (*Typha* sp.) patch (TYPHA).

The study area was delineated with a minimum convex polygon (MCP) (Mohr 1947) encompassing all 661 telemetry locations recorded during the field season. Habitats were classified within this 166.9 ha study area by deliniating each habitat patch with GPS fixes. Afterwards, the habitat map was created by applying the fixes on a 1:3000-scale aerial photograph taken in 2000 (Photocartothèque Québécoise, Charlesbourg, Québec) using GIS tools (ArcView, version 2.0) (Environmental Systems Research Institute, Inc. 1998). The heterogeneity of the area was apparent from a total of 189 polygons (mean (± SE) area: 1.23 ± 0.45 ha) (Table 2.1).

Habitat description

Habitat features potentially important for feeding, hiding, breeding, and thermoregulation were measured or estimated at radio-telemetry locations. Habitat variables were dichotomous (presence/absence), categorical, or continuous (Table 2.2). Habitat variables were also either structural or vegetation-related. A first group of variables focused on water depth and temperature, and substrate depth as well as particle size. Different structures were also assessed at each site. Submerged logs and substrate mounds were counted while the presence or absence of beaver (*Castor canadensis*) lodges, muskrat (*Ondatra zibethicus*) lodges, and shore were noted. A second group focused on the abundance of aquatic vegetation. Percentages of open water and of submerged, floating, emergent, and shrubby vegetation were estimated using five classes of abundance. To control for the possibility that a turtle could move

Table 2.1: Habitat classification scheme (based upon Cowardin et al. 1979) used to create a habitat map analyzed at the second and third orders of selection for common musk turtles (*Sternotherus odoratus*) at Norway Bay, Québec.

Vegetation Type [a]	Vegetation criteria	Substrate criteria	Other criteria	Number of polygons	Area (ha)
CABA	-	-	presence of beaver lodge	30	0.6
LABF	submerged and floating plants	-	-	31	11.5
LABI	submerged plants only	-	-	21	44.4
LEWE	emergent plants only	-	-	3	0.5
LEWT	erect, rooted, hydrophytes	-	-	36	37.1
LRB	cover < 30%	cover of stones, boulders or bedrock ≥ 75%	-	12	15.7
LRS	cover < 30%	cover of stones, boulders or bedrock ≥ 75%	possibility of exposition and flood	38	5.5
LUB	cover < 30%	cover of stones, boulders or bedrock ≥ 75%	-	7	31.5
LUS	cover < 30%	cover of stones, boulders or bedrock ≥ 75%	possibility of exposition and flood	3	0.7
TYPHA	≥ 90 % cattails	-	-	8	19.3

[a]: Habitat types are as follows: CABA: beaver lodge; LABF: aquatic bed with submerged and floating vegetation only; LABI: aquatic bed with submerged vegetation only; LEWE: aquatic bed with emergent vegetation only; LEWT: emergent wetland; LRB: rock bottom; LRS: rocky shore; LUB: unconsolidated bottom; LUS: unconsolidated shore; TYPHA: cattail (*Typha* sp.) patch.

Table 2.2: Structural and vegetation-related variables used in the analysis of microhabitat selection by common musk turtles at Norway Bay, Québec.

Variable	Description
Structural	
BEAVER	Presence or absence of beaver lodges
LOGS	Number of submerged logs (> 10 cm in diameter)
MUSKRAT	Presence of absence of muskrat lodges
SHORE	Presence (1) or absence (0) of shore
SUBDEPTH	Substrate depth (cm)
SUBS	Substrate particle size [a]
WDEPTH	Water depth (cm)
WTEMP	Water temperature (° C)
Vegetation	
FRWATER	Percentage of open water [b]
SVEG	Percentage of submerged vegetation [b]
FVEG	Percentage of floating vegetation [b]
EVEG	Percentage of emergent vegetation [b]
SHVEG	Percentage of shrubby vegetation from [b]

[a]: 1: clay/loam/small debris (smaller than 1 mm), 2: sand (greater than 1 mm and smaller than 3 mm), 3: gravel (greater than 3 mm and smaller than 65 mm) and 4: rock (greater than 65 mm).

[b]: none: (0%), low (1% - 25%), medium-low (26 - 50%), medium-high (51 - 75%), and high (≥ 76%), coded as midpoint of category.

slightly from its original location because of the disturbance caused by researchers, variables were measured at three different points 4.5 meters from the location itself and along three axes (120 º, 240 º and 360 º). This distance was used because it represented the length of the canoes and permitted stability during the experiments. This method also ensured that sites were sampled thoroughly despite water turbidity. Estimations of categorical variables at each site were recorded as the mode of the three measures (parcels) whereas means of the three measures (parcels) were calculated for continuous variables. While the variables were measured or estimated by one team at a telemetry location site, the same procedure was followed at the same time at a random site by another team. Random locations were determined by moving a randomly determined distance (10 to 60 m, determined by rolling a six-sided dice and multiplying by 10) in a randomly determined direction (120°, 240° or 360°, determined by rolling the dice and attributing each direction to two numbers on the dice) from each turtle location characterized.

Statistical analyses

The "Animal movements" function in Hawth's Analysis Tools for ArcGIS version 2.0 (Beyer 2004) was used in ArcView version 8.2 (Environmental Systems Research Institute, Inc. 2002) to calculate the 100% minimum convex polygon (MCP) (Mohr 1947) delineating the study area. This method assumes that these resources are equally accessible to all the animals although this may not always be the case (Garshelis 2000). This assumption was considered to have been met in this study considering the short period of time needed for a turtle to cross the study area (approximately a week from north to south). Hence, habitat in the study area was considered available for every turtle at the second order of selection in the sense that each turtle had the possibility to position its home range anywhere in that area.

The "Animal movements" extension version 2.0 (Hooge and Eichenlaub 2000) was used in ArcView version 2.0 (Environmental Systems Research Institute, Inc. 1998) to calculate 95% minimum convex polygons (Mohr 1047) delineating individual home ranges. This method was chosen for its objectivity and its frequent use in habitat selection studies (Row and Blouin-Demers 2006). It permits the removal of 5% of locations which add the most area to the home range (Mohr 1947).

It can also remove observations associated with extreme (unusual) events such as nesting (Jewell 1966). Because home range studies should always attempt to maximize the number of locations used in the analysis (Goldingay and Kavanagh 1993), only individuals that were followed successfully throughout the field season were included in the analysis of home range sizes. Terrestrial habitats were excluded from home ranges and were considered unavailable to turtles.

At the study area-scale (second order selection), the availability of each habitat type in the study area was compared to the proportion of these habitats found within individual home ranges. At the home range-scale (third order), the availability of each habitat type within individual home ranges was compared to the proportion of radio-telemetry locations occurring in each habitat type for each turtle. The Aebischer method (Aebischer et al. 1993) was used to analyze habitat selection at the second and third orders and these analyses were performed using an extension in Excel (Smith 2003). This method consists of a compositional analysis testing for non-random habitat use. Log-ratios of used and available habitat proportions are calculated and a MANOVA is used to test for non-random selection at each scale (Aebischer et al. 1993). When non-random use occurs, a matrix of paired t-tests is constructed with differences in log-ratios between habitat types. This method permits ranking with respect to each other and comparison of where the preferences lie (Aebischer et al. 1993). Since *P*-values associated with habitat selection studies are frequently unreliable because of small sample sizes and non-normal data distributions which produce inflated α levels, randomizations (Manly 1991) with 2500 iterations were used to test the hypothesis of random habitat use (Pendleton et al. 1998). Because numbers of relocations differed among animals, their coefficients were weighted in proportion to their respective number of relocations by multiplying the square root of the number of relocations by their relative use of each habitat as suggested by Granfors (1996). Thus, animals with fewer observations and less precise estimates of parameter coefficients did not disproportionately affect the mean value of estimated coefficients (Alldredge et al. 1998; Thomas and Taylor 2006). Individuals were the sampling units at both spatial scales.

Each location site was compared to its associated random site using paired logistic regressions (Hosmer and Lemeshow 1989; Compton et al. 2002) to determine the main habitat characteristics enabling distinction between available and used sites (Compton et al. 2002). Matched-pairs logistic regressions are more appropriate and more powerful than standard logistic regressions to analyze paired data (Hosmer and Lemeshow 1989) because they examine use *vs* availability at the same time and place, not against all times as in discriminant analysis and non-paired logistic regressions nor against all places as in fixed home range models (Compton et al. 2002). Hence, paired logistic regressions appear to come closer to modeling the choices made by animals with limited mobility (Compton et al. 2002). Explanatory variables used in the paired logistic regressions were first tested for correlation and multicolinearity. When either one or both of these situations occurred, the correlation between each variable involved and the dependent variable was determined with a Pearson correlation coefficient. Only the variable with the strongest correlation to the dependent variable was included in the analysis. A Pearson's coefficient of correlation of $r \geq 0.60$ was used to identify correlated pairs of variables from which one was excluded from the analysis. Potential models were then tested with Akaike's Information Criterion (Burnham and Anderson 1998). The model with the minimum AICc was considered the best. The addition of interaction terms to the model allowed to test the effect of sex on the model and to test for interactions between explanatory variables. Linearity of the final model was tested using design variables based on the quartiles of each variable (Hosmer and Lemeshow 2000).

Average daily movements were obtained by taking the straight line distance between two consecutive radio-telemetry locations and dividing by the number of days elapsed between relocations. Repeated measures ANOVAs were used to compare average daily movements throughout the study between sexes and to test the effects of sex and month on the mean daily movements traveled. Movement data were all log-transformed to achieve normality. An ANOVA was also used to compare home range size between sexes.

Version 9.1 of the program SAS (SAS Institute Inc. 2003) was used to perform the paired logistic regressions and to calculate correlations between variables and to test the linearity of the model. Version 13.0 of SPSS (SPSS Inc. 2005) was used to perform the repeated measures ANOVAs. In all cases, a significance level of 0.05 was used to reject the null hypothesis.

Results

Radio-telemetry

A total of 661 telemetry locations were recorded over the course of the study. One turtle fitted with a transmitter was killed by a terrestrial predator in September. Due to several losses of transmitters, only eight males and four females were followed successfully through the field season. These 12 turtles were located from 28 to 37 times each (mean = 34.0 locations, S.E. = 0.83) for a total of 406 turtle locations. Only these individuals were included in the analyses of habitat selection at both the study area and home range scales and for the estimation of home range size. Aquatic beds with emergent vegetation only (LEWE) and unconsolidated shores (LUS) were both rare and seldom used. Therefore, they were respectively merged with emergent wetlands and unconsolidated bottoms to produce two habitat types categorized as emergent wetland (LEWT) and unconsolidated substrate (LUS) (Figure 2.2). Overall, 12% of locations occurred in CABA, 16% in LABF, 5% in LABI, 54% in LEWT, 12% in LRS, and 1% in LUS. No locations occurred in LRB or TYPHA. Habitat descriptions of 560 pairs of sites were used in the matched-pairs logistic regression. The first two analyses on movements included only individuals that were followed successfully through the field season. However, the last analysis included the monthly means of individuals that were relocated at least 5 times per month.

Macrohabitat selection

At the second order of selection, habitat use was non-random (Wilk's λ = 0.0414, X^2 = 38.2106, df = 7, randomized P = 0.003). Beaver lodges, aquatic beds with submerged and floating vegetation, emergent wetlands, and unconsolidated substrates were used more than predicted while rocky shores were used according to their availability and aquatic beds with submerged vegetation only, rock bottoms and cattail patches were used less than their availability (Table 2.3; Figure 2.3). Beaver lodges were significantly preferred over all the other habitat types (Table 2.4).

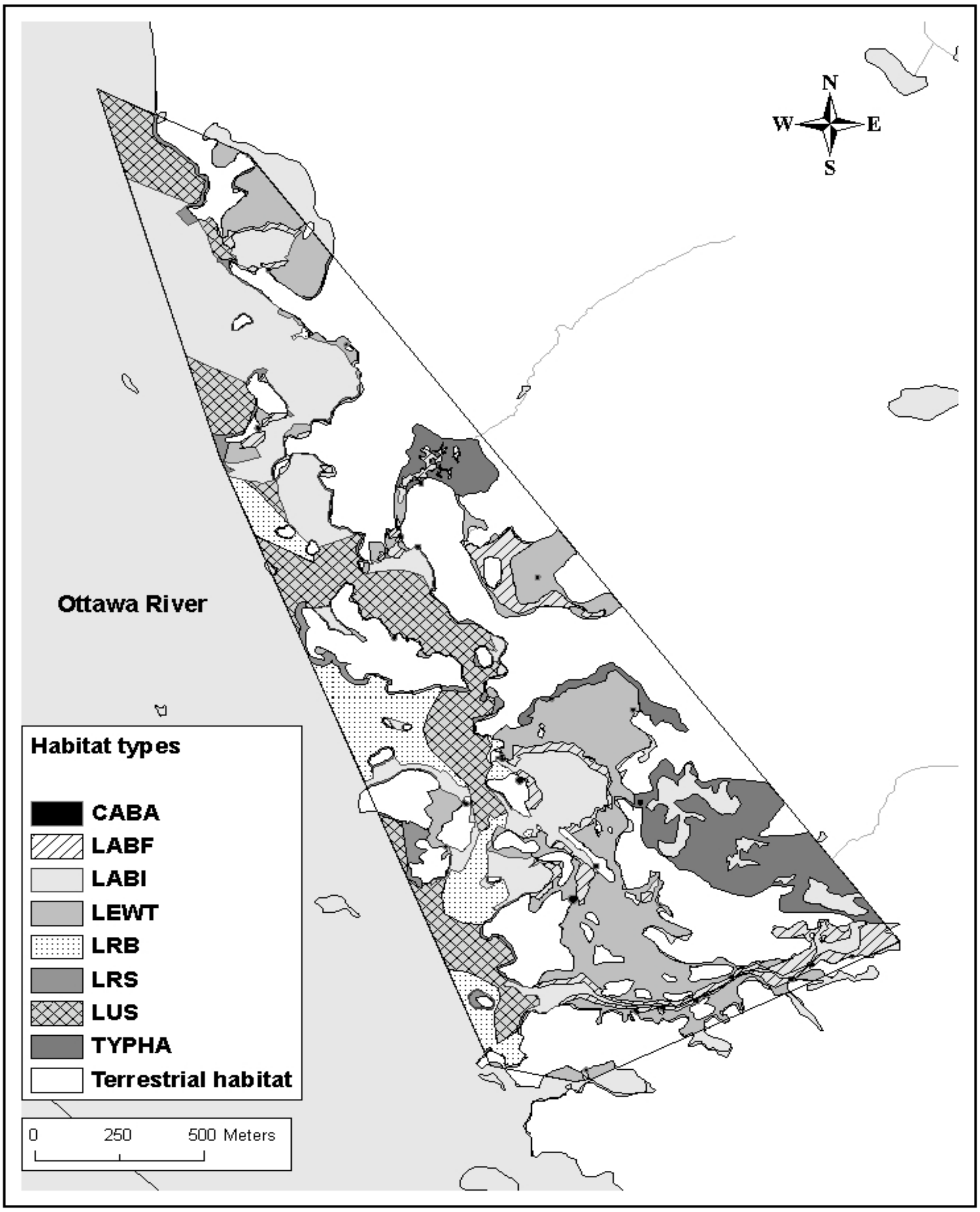

Figure 2.2: Vegetation map created for the study of habitat selection of the common musk turtle (*Sternotherus odoratus*) at Norway Bay, Québec. Habitat types are as follows: CABA: Beaver lodge; LABF: aquatic bed with submerged and floating vegetation; LABI: aquatic bed with submerged vegetation only; LEWT: emergent wetland; LRB: rock bottom; LRS: rocky shore; LUS: unconsolidated substrate; and TYPHA: cattail (*Typha* sp.) patch.

Table 2.3: Mean (± SE) percentages of habitats available to and used by *Sternotherus odoratus* (N = 12) at the study area scale and the home range scale at Norway Bay, Québec, in 2006.

Habitat [a]	% study area [b]	% home ranges ± SE	% locations ± SE
CABA	0.4	0.8 ± 0.1	11.3 ± 2.2
LABF	6.9	10.7 ± 2.0	17.2 ± 4.0
LABI	26.6	23.6 ± 4.2	4.9 ± 1.5
LEWT	22.5	32.4 ± 5.1	53.2 ± 2.9
LRB	9.4	1.4 ± 0.4	0 [c]
LRS	3.3	3.3 ± 0.6	12.1 ± 2.5
LUS	19.2	25.2 ± 4.0	1.2 ± 0.6
TYPHA	11.6	2.7 ± 0.8	0 [c]

[a]: Habitat types are as follows: CABA: beaver lodge; LABF: aquatic bed with submerged and floating vegetation only; LABI: aquatic bed with submerged vegetation only; LEWT: emergent wetland; LRB: rock bottom; LRS: rocky shore; LUB: unconsolidated bottom; LUS: unconsolidated shore; TYPHA: cattail (*Typha* sp.) patch.

[b]: No variance is associated with these percentages because available habitat is constant for all animals at this scale.

[c]: No variance is associated with these percentages because no locations were recorded in these habitats at this scale.

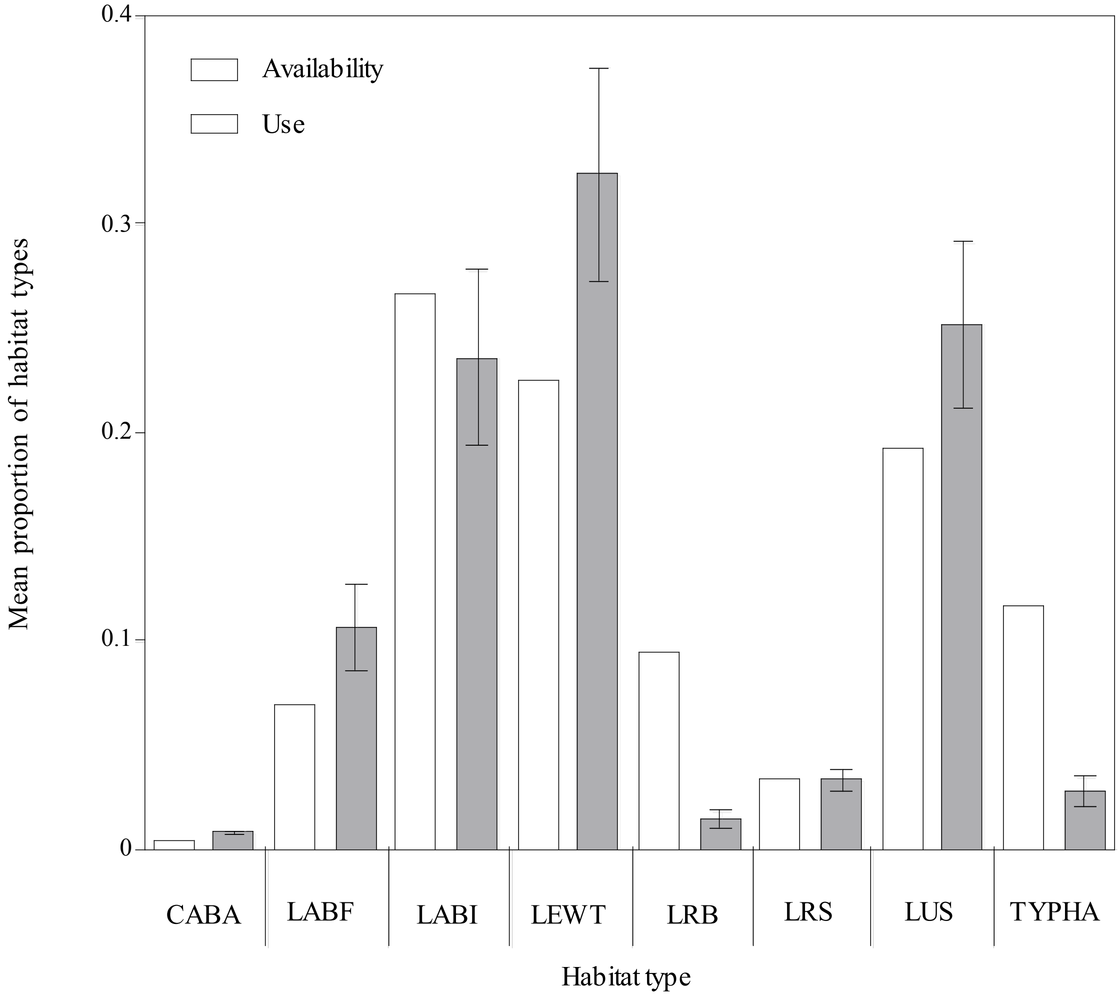

Figure 2.3: Mean proportion of habitat types (CABA: Beaver lodge; LABF: aquatic bed with submerged and floating vegetation; LABI: aquatic bed with submerged vegetation only; LEWT: emergent wetland; LRB: rock bottom; LRS: rocky shore; LUS: unconsolidated substrate; and TYPHA: cattail (*Typha* sp.) patch) in study area (availability) against their proportion in common musk turtle home ranges (use). Standard errors are shown for habitat use only because available habitat is constant for all animals at this scale. Plotted data for use are population means, but statistical analyses were performed on paired data of availability and use for each turtle.

Table 2.4: Habitat preference by *Sternotherus odoratus* (N = 12) at Norway Bay, Québec, in 2006. Habitat types are as follows: CABA: Beaver lodge; LABF: aquatic bed with submerged and floating vegetation; LABI: aquatic bed with submerged vegetation only; LEWT: emergent wetland; LRB: rock bottom; LRS: rocky shore; LUS: unconsolidated substrate; and TYPHA: cattail (*Typha* sp.) patch.

Order of selection	Preferred ↔ Avoided [a]	Statistics		
		λ	X^2	P [d]
Second	CABA>>>LABF>LEWT>LUS>LABI>LRS>>>TYPHA>LRB	0.0414[b]	38.22	0.003
Third	CABA>LEWT>LABF>LRS>>>LABI>>>LUS>LRB>TYPHA	0.0077[c]	58.46	< 0.001

[a]: The symbol “>” indicates a preference for a habitat over another while the symbol “>>>” indicates a significant preference for a habitat over another.

[b]: Wilk’s lambda.

[c]: Weighted mean lambda.

[d]: Randomized *P* value.

At the third order of selection (home range scale), habitat use was also non-random (weighted mean $\lambda = 0.0077$, $\chi^2 = 58.4806$, df = 7, randomized $P < 0.001$). A weighted mean lambda was produced instead of a Wilk's lambda due to the lack of telemetry locations in several habitat types. At this scale, beaver lodges, aquatic beds with submerged and floating vegetation, emergent wetlands, and rocky shores were used more than expected and preferred over the four other categories (Table 2.4; Figure 2.4).

Microhabitat selection

Correlations between explanatory variables (multicolinearity) indicated that three pairs of factors were highly correlated. The presence of a beaver lodge was highly correlated to the number of submerged logs ($r = 0.76$) and so was the type of substrate to the presence or absence of shore ($r = 0.68$) and the percent of open water to abundance of floating vegetation ($r = -0.68$) and to the abundance of emergent vegetation ($r = -0.62$). In these cases, the presence of a beaver lodge, the type of substrate, the abundance of floating vegetation and the abundance of emergent vegetation were excluded from the analysis because the strength of their correlation with the dependent variable was lower than that of the other member of their respective pair.

Because I had many explanatory variables, I ran separate univariate tests for each of them and eliminated variables that were clearly non-significant (> 0.25). Due to the difficulty to achieve normality by transforming the data, Kolmogorov-Smirnov tests were used. These univariate tests revealed that the abundance of shrubby vegetation ($P = 0.867$), the number of substrate mounds ($P = 0.959$) and the presence or absence of a muskrat lodge ($P = 1.000$) clearly did not reveal a difference between used and available sites and were therefore excluded from the analysis. Therefore, only water depth, substrate depth, water temperature, the percent of free water, the abundance of submerged vegetation, the number of submerged logs and the presence or absence of shore were included in the analysis. The model with the lowest AICc included four variables significantly showing the difference between available and used sites: the number of submerged logs ($P < 0.0001$), the abundance of submerged

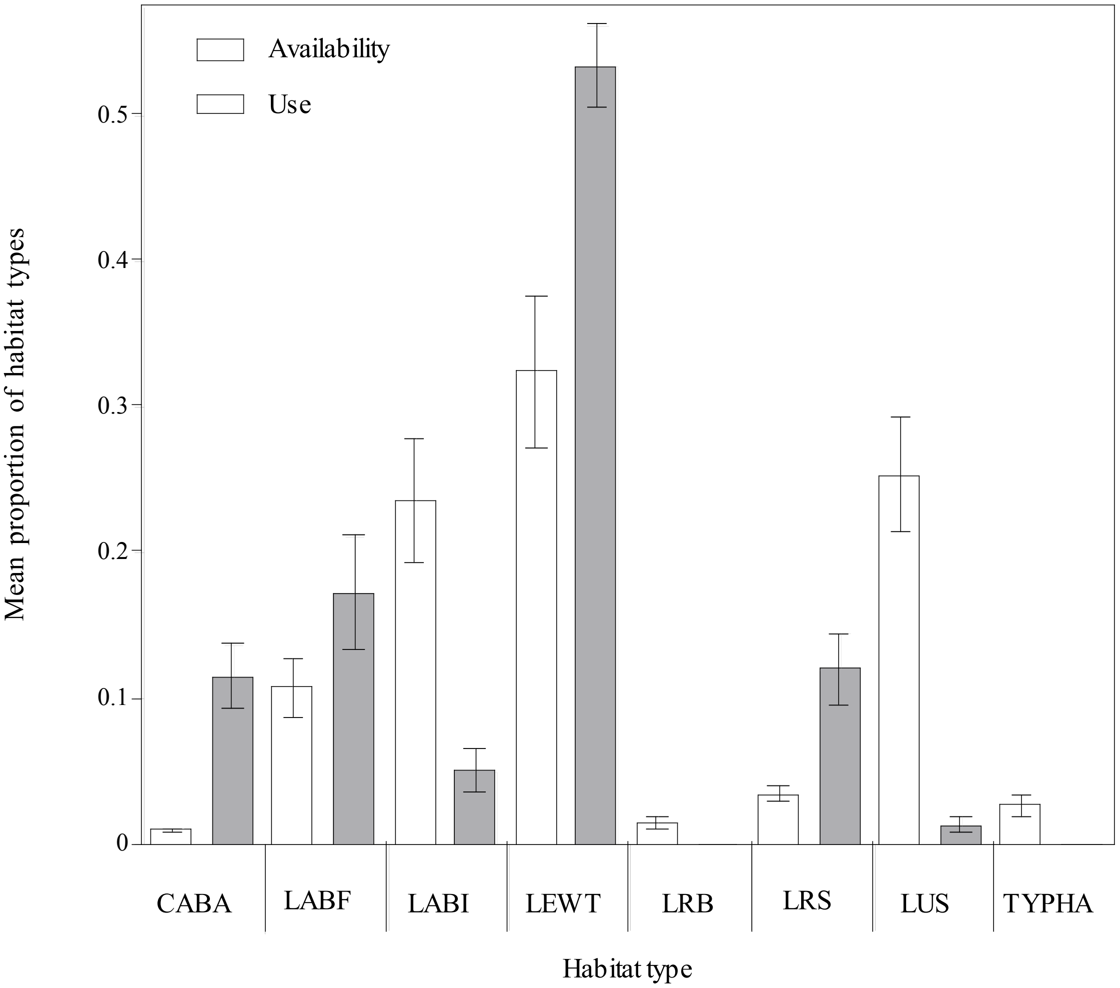

Figure 2.4: Mean proportion of habitat types (CABA: Beaver lodge; LABF: aquatic bed with submerged and floating vegetation; LABI: aquatic bed with submerged vegetation only; LEWT: emergent wetland; LRB: rock bottom; LRS: rocky shore; LUS: unconsolidated substrate; and TYPHA: cattail (*Typha* sp.) patch) in common musk turtle home ranges (availability) against the proportion of locations in each habitat type (use). Standard errors are shown. Plotted data are population means, but statistical analyses were performed on paired data of availability and use for each individual.

vegetation (*P*< 0.0001), water depth (*P*= 0.0045), and water temperature (*P*= 0.0265). No interactions among these variables contributed significantly to the model, nor was there any interaction with sex. The best model was significant but explained only a small portion of the variation ($R^2 = 0.0058$, Log-likelihood= 86, $P < 0.0001$).

The odds ratios (Table 2.5) indicate that musk turtles show a preference for sites including several submerged logs: every 5 additional logs found at a site increases the probability of selection by 10 %. Musk turtles also demonstrated a preference for shallower sites as an increase of 50 cm in water depth decreases probability of selection by 10 %. An increase in 8° C in water temperature results in a decrease of 10 % in selection. Finally, an increase of the abundance of submerged vegetation by 25 % increases the probability of selection by approximately 12 %.

Movements

Mean distances traveled daily during the active season by the 12 common musk turtles ranged from as little as 0.1 m to 1000 m. Only turtles with at least 5 locations per month were included in the movement analyses. Differences between mean distances traveled daily by these three males (38.0 ± 5.6 m/day) and three females (36.6 ± 8.9 m/day) through the active season were not significant (F = 0.358, R^2= 0.08, df = 1, *P* = 0.582). The power of this analysis (0.05) was lower than the 0.8 usually required (Thomas 1997). A power analysis indicated that a minimum of 2498 turtles per sex with 30 locations per turtle would have been necessary to detect differences in mean daily distance moved between sexes. Thus, it is reasonable to assume that there is no real difference between mean daily distances traveled by males and females throughout the active season.

Sex and month did not interact significantly to have an effect on the mean monthly distance traveled daily by the 3 males and the 3 females (F = 0.750, R^2 = 0.09, df = 5, *P* = 0.587) (Figure 2.5). However, the power of this analysis (0.19) is lower than the required 0.8 and a minimum of 5 relocations per month of 10 turtles of each sex would be required to detect a significant interaction of sex and month on the daily mean distance traveled per month. Therefore, it suggests that sex and month probably interact significantly to affect mean distance traveled daily.

Table 2.5: Paired logistic regression model that best explains microhabitat selection across all *Sternotherus odoratus* (N = 29) at Norway Bay, Québec, in 2006. Variables are as follows: LOGS: number of logs, WDEPTH: water depth, SVEG: abundance of submerged vegetation, and WTEMP: water temperature.

Variable	Coefficient	Odds ratio	Odds ratio (95% confidence intervals)
LOGS	0.01950	1.020	(1.013, 1.027)
WDEPTH	- 0.00217	0.998	(0.997, 0.999)
SVEG	0.11154	1.118	(1.067, 1.172)
WTEMP	- 0.01199	0.988	(0.997, 0.999)

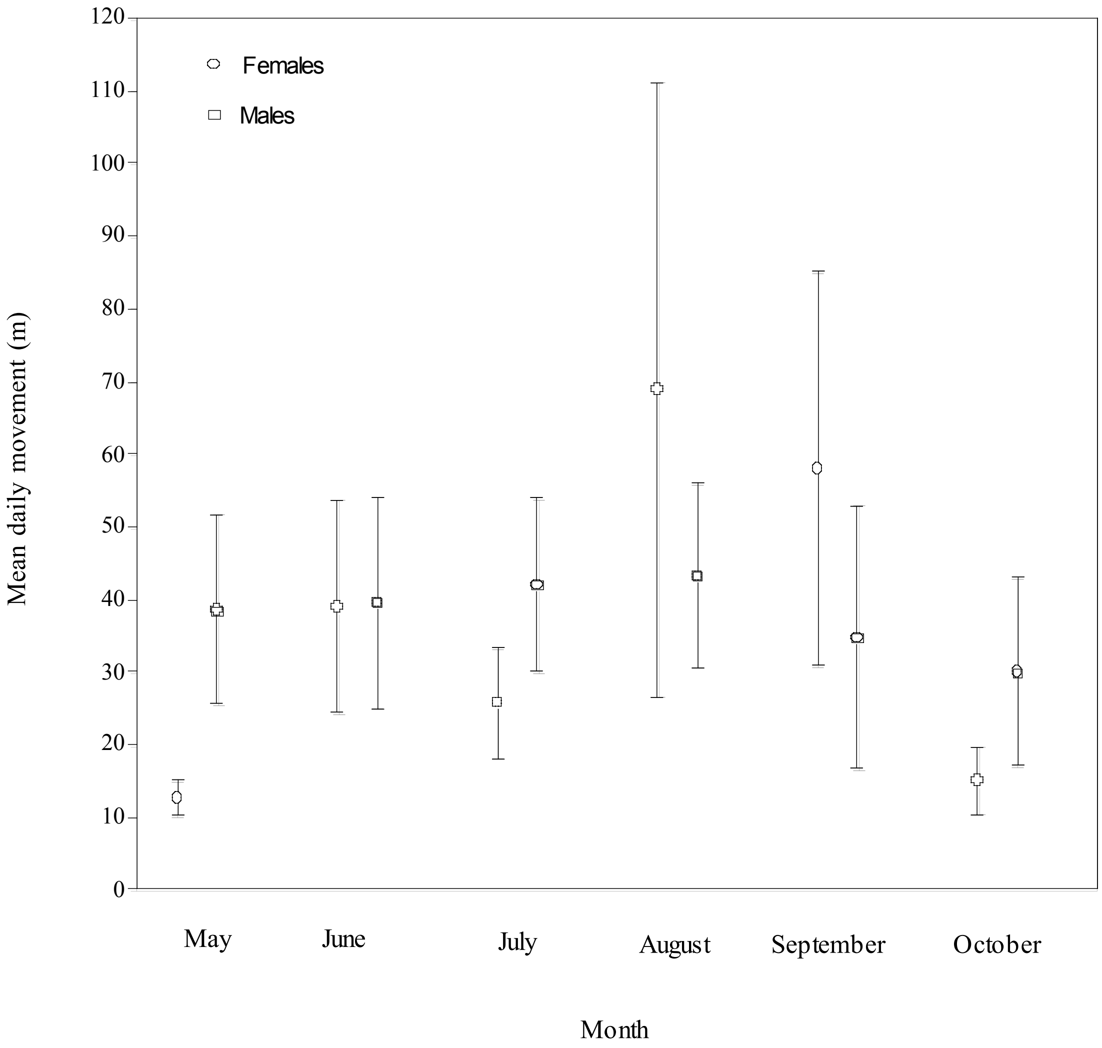

Figure 2.5: Mean daily movement per month of male (N = 3) and female (N = 3) *Sternotherus odoratus* at Norway Bay, Québec, from May to October 2006.

Due to a small sample size, we were not able to test for monthly differences on the daily distance traveled by each sex. However, the 3 males included in the analysis appear to move more daily compared to females in May (females: 12.7 ± 2.4 m and males: 38.7 ± 13.1 m), July (females: 25.8 ± 7.6 m and males: 42.0 ± 11.9 m), and October (females: 15.0 ± 4.7 m and males: 30.0 ± 13.0 m). However, the females appear to move more daily compared to males in August (females: 68.9 ± 42.4 m and males: 43.3 ± 12.7 m) and September (females: 58.0 ± 27.0 m and males: 34.7 ± 18.1 m). Neither sex appears to move more than the other in June (females: 39.1 ± 14.7 m and males: 39.6 ± 14.5 m). Finally, the amplitude of daily distance moved by the 3 males included in the analysis seems to be smaller compared to females (Figure 2.5). Nevertheless, our small sample size does not permit a conclusive analysis.

Home range size

The difference in mean home range size between males (25.4 ± 6.7 ha) and females (20.9 ± 5.2 ha) was not significant ($F= 0.194$, $R^2= 0.019$, $df= 1$, $P= 0.669$) (Figure 2.6). The power of this analysis was determined to be 0.08, well below the required power of 0.8. A retrospective power analysis has demonstrated that at least 143 turtles of each sex would have been required to detect a difference between male and female home ranges. Thus, there is probably no significant difference in home range size between male and female common musk turtles at Norway Bay.

Discussion

As predicted by the hierarchical model of habitat selection, common musk turtles use both scales of macrohabitat as well as microhabitats selectively. Habitat selection was relatively consistent across the three spatial scales studied. The three most preferred habitat types were the same at both macrohabitat scales. At the location scale, musk turtles preferred shallow sites with numerous submerged logs, abundant submerged vegetation, and slightly cooler water temperature. Therefore, musk turtles can be described as habitat specialists.

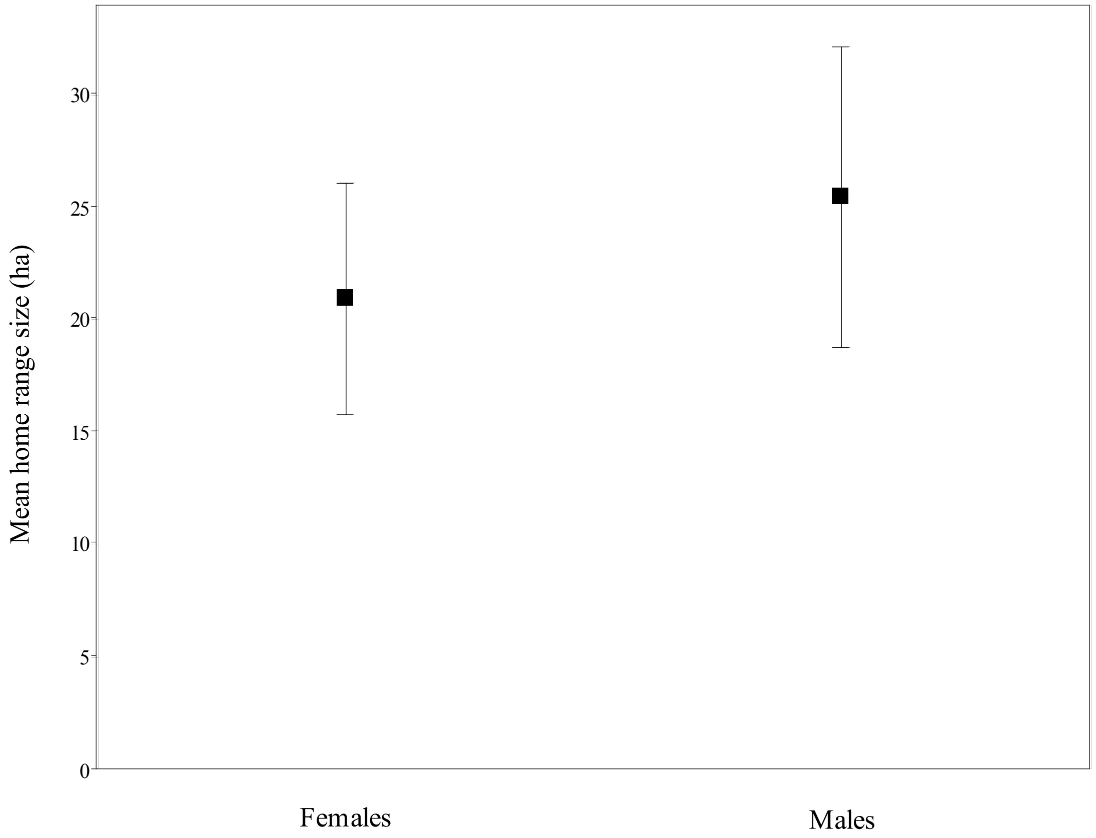

Figure 2.6: Mean home range sizes of female (N = 4) and male (N = 8) *Sternotherus odoratus* at Norway Bay, Québec, in 2006.

Macrohabitat selection

Despite the presence of beavers in all lodges used by common musk turtles, these habitats may offer several advantages. The abundance of wooden debris found in these habitats provides good potential for protection against both aquatic and terrestrial predators of common musk turtles. Beaver lodges were used by males and females throughout the active season but several aggregations including individuals of both sexes occurred during the months of September and October. These gatherings may be associated with fall mating. Previous studies (Risley 1933; Ernst et al. 1994) have documented the use of muskrat lodges as nesting sites and Ernst et al. (1994) observed female common musk turtles laying eggs under logs and stumps. Therefore, beaver lodges may be used as egg-laying sites by females. While the two smallest common musk turtles (maximum carapace lengths of 31 and 33 mm) captured during the field season were found in a beaver lodge, these habitats seem to be used by all size classes.

Common musk turtles prefer habitats filled with aquatic vegetation (Cahn 1937) and are usually found in shallow waters with slow currents (Cook 1984). In the study area, emergent wetlands and aquatic beds with floating and submerged vegetation were primarily characterized by abundance of vegetation, but also by shallow water and softer substrates. At Norway Bay, these habitats mostly occurred in the back sections of bays where the current was weak or absent. Back-bay segments in wetlands have been observed to have greater vegetative cover, more structural complexity, and lower levels of water movement as well as being more prone to high water temperatures (Trebitz et al. 2005). Such habitats may provide important advantages for common musk turtles, including great potential for foraging, protection, and thermoregulation. Good opportunities for foraging may explain the selection of aquatic beds because common musk turtles forage while walking on the substrate searching for prey by probing with their heads into the soft substrate and rotting vegetation (Edmonds 2002). The abundance of aquatic vegetation usually associated with emergent wetlands and aquatic beds at Norway Bay also greatly decreased the probability of visually locating turtles and it is reasonable to assume that floating, submerged, and emergent vegetation represent good protection for them while they carry on their activities. The potentially higher temperatures of these habitats may also attract common musk turtles seeking to increase their body temperature. Generally, basking occurs in shallow water where common musk turtles rest on the substrate with only the top of the carapace emerging from the water or they float at the surface in aquatic vegetation (Ernst et al. 1994).

Rocky shores were used intensively by common musk turtles, but almost exclusively during the pre-hibernation period (late August, September and October). While small sample size prevents me from testing for seasonal differences in habitat selection, the preference for this habitat over the other four types throughout the active season demonstrates its importance. Reasons for the choice of such habitats are still vague. While more turtles occupied rocky shores during the last two months of the active season, other common musk turtles were found elsewhere in aquatic beds. Turtles occupying either habitat type during the pre-hibernation period have stayed in the same habitat type to hibernate. These results raise the question of what drives the change of habitat at this time. Since diet may explain habitat choice of chelonians (Plummer and Farrar 1981; Hart 1983) and because common musk turtle diet differs between sexes (Bancroft et al. 1983; Ford and Moll 2004) and between seasons (Mahmoud 1968; Bancroft et al. 1983; Ford and Moll 2004), it is possible that some seasonal differences in habitat selection could occur at Norway Bay and be linked to diet change. Mating may also induce changes in habitat use during the pre-hibernation period. Spring and fall represent the peak mating periods for common musk turtles when they congregate at hibernation sites (Risley 1933; McPherson and Marion 1981*b*; Mendonça 1987). Hence, fall gatherings may explain the mass displacements observed in late August and early September. Several gatherings were observed at rocky shores and a beaver lodge in the principal hibernation area in September and October, while one mating was witnessed in late September. These observations support the potential for fall mating of common musk turtles suggested by Risley (1938) and McPherson and Marion (1981*a*) and observed by Evermann and Clark (1916) and McPherson and Marion (1981*a*). However, because major gatherings of turtles were observed in spring but occurred in other habitats away from the principal hibernation area (aquatic beds), it is possible that both diet and mating may influence the selection of habitats during the prehibernation period.

At Norway Bay, unconsolidated substrates were usually found in deeper habitats with higher currents and were mostly constituted of sand. Common musk turtles are usually found in shallow waters with slow or no current (Cook 1984); the absence or rarity of the vegetation in the deeper habitat types does not make them suitable for common musk turtles. Hence, the notable use of unconsolidated substrates at the second order of selection demands an explanation. In the study area, unconsolidated substrates occupy large areas and these habitats are mostly found between the main prehibernation area and the sectors used by common musk turtles during the summer. As a result, unconsolidated substrates are included in the home ranges of most turtles. Hence, the shape of the study area, the method used to estimate home range size as well as the fragmentation of the study area resulted in the inclusion of a significant amount of unconsolidated substrate in the home ranges. Nevertheless, they were clearly used less than expected at the third order measure of selection.

Aquatic beds with submerged vegetation were only used slightly less than expected at the study-area scale but clearly avoided at the home range scale. Deeper waters as well as higher currents in these habitats compared to the other types of aquatic bed could explain this avoidance. Their proximity to other types of aquatic beds that were selected could also explain their relatively important use at the second order of selection. On the other hand, rock beds, cattail patches and aquatic beds with submerged vegetation only were noticeably avoided at both second and third orders of selection compared to other habitat types. Although the common musk turtle had been associated with cattails in a previous study (Edmonds 1998), reasons behind the avoidance of cattail patches at Norway Bay are still unclear. However, these avoided habitats were often found near extensively used ones.

Microhabitat selection

The presence of submerged logs significantly increases selection by musk turtles. Beaver lodges were made of hundreds of submerged logs and 12.3% of all the locations included a beaver lodge. Preference for sites including several logs can then be attributed to the selection of beaver lodges at the macrohabitat scale. Nonetheless, submerged logs not associated with beaver lodges also attract common musk turtles.

More than 72% of the submerged logs not associated with a beaver lodge encountered during the study were found at sites used by turtles. Musk turtles at sites with logs were either buried in the substrate underneath a log, resting between several logs or swimming slowly between or around the logs. These habitat features may provide protection from predators whether the logs are associated with a beaver lodge or lying on the substrate in shallow water.

The significant and positive effect of abundance of submerged vegetation on microhabitat selection may be surprising and the nonsignificant effect of percent of open water may appear inconsistent with the macrohabitat results. However, the preferred types of aquatic beds at both scales of macrohabitat also included submerged vegetation. Therefore, at the location scale, musk turtles appear to use the abundance of submerged vegetation to discriminate between available and used sites in aquatic beds.

As ectotherms, common musk turtles regulate their body temperature by choosing environments of appropriate temperature. A *post hoc* Kolmogorov-Smirnov test revealed that water temperature was significantly cooler in sites with a beaver lodge (17.3 ± 0.9 ºC) compared to sites without a lodge (21.5 ± 0.2 ºC) ($Z = 2.556$, $P < 0.001$). A second *post hoc* analysis indicated that telemetry locations without a beaver lodge (21.9 ± 0.3 ºC) were not significantly warmer ($Z = 1.227$, $P = 0.098$) than random sites without a lodge (21.2 ± 0.3 ºC). Aestivation in soft substrates and muskrat lodges by musk turtles has been observed when water temperatures rise above 25 ºC in Pennsylvania (Ernst 1986), but was not observed at Norway Bay although the water temperature did rise to 36 ºC in July. However, during hot summer days, the use of these habitat features could be used to reduce their body temperature and keep it in the thermal activity range of 10 ºC to 34 ºC (Mahmoud 1967). Body temperatures could thus be maintained within an optimal range that maximizes performance and fitness (Christian and Tracy 1981; Huey and Kingsolver 1989) while the common musk turtles could still use back-bay segments nearby which are more prone to high water temperatures (Trebitz et al. 2005). However, these cooler environments could constitute sites of low thermal quality for the musk turtles during the spring and prehibernation periods. Therefore, other habitat characteristics should compensate that decrease in thermal quality.

Common musk turtles tend to follow shorelines and avoid crossing open bodies of water (Williams 1952). However, Smar and Chambers (2005) found that open water as deep as 3 m did not constrain their movements in a lake in Virginia. At Norway Bay, the deepest location was 2.25 m and the mean water depth at which musk turtles were located was 0.43 m. Musk turtles appeared to prefer shallow sites while still able to use relatively deeper habitats. Shallow sites in the study area were mostly found in bays and close to shores and may therefore provide protection and thermoregulation advantages with more abundant vegetation, slower currents, and warmer temperatures.

This model does not show strong predictive power. This may be a consequence of common musk turtles selecting different microhabitat features depending upon their activity (e.g., foraging and thermoregulating) or their reproductive state (e.g., mating individuals and gravid females). Stratification by activity and/or reproductive state could presumably increase the predictive power of this model (Compton et al. 2002).

Movements

Movements associated with breeding, basking, mating, hiding, and dormancy result from changing environmental, demographic, and physiological conditions (Gibbons et al. 1990; Moll and Moll 2004). While musk turtles are known to return to their initial site of capture (Williams 1952; Ernst 1986; Mitchell 1988; Holinka et al. 2003), indicating limited movement (Mahmoud 1969; Holinka et al. 2003), the longest distance traveled in one day by a turtle at Norway Bay was 1000 m. Such lengthy travel in a short period has not been reported for musk turtles.

In numerous turtles, movements of males are generally longer and occur more often during the mating season than those of females (Gibbons 1986), and studies focusing on movements and home ranges of *S. odoratus* in Oklahoma and Virginia have observed males to move longer distances than females (Mahmoud 1969; Andres and Chambers 2006). Sexual differences in movement are usually attributed to different reproductive strategies (Ernst 1986). Males tend to maximize their individual reproductive success by maximizing the number of eggs they are able to fertilize.

Hence, increased movement should increase chances for copulation with several females and maximize fertilizations (Ernst 1986) as more extensive movements increase possibilities of mating (Morreale et al. 1984; Parker 1984). However, equivalent distances traveled by both sexes at Norway Bay over the course of the study could be a result of spring and fall gatherings. These biannual aggregations may decrease the benefit for males to travel farther and more frequently as they have access to several females ready to mate in a relatively confined area.

An interaction between sex and month that would influence the mean daily distance moved by common musk turtles seemed probable. Distances traveled in May, especially by females, were relatively short. Spring gatherings can explain the short distances traveled. Although no mating event was observed in spring, turtle gatherings were observed to lead to spring mating in Connecticut (Finneran 1948). Several turtles with transmitters as well as others stayed grouped for a while in a relatively small sector before dispersing in June and early July. Greater distances traveled by females in late June compared to distances traveled in May may be attributed to breeding (Tinkle 1961) as Lindsay (1965) observed nesting of common musk turtles in late June and July in Ontario. Long distances traveled by females in August and by males in September coincided with the return of common musk turtles to prehibernation areas. Longer distances traveled by males in October may be a result of their increased activity for fall mating as a mating event was observed in late September. Smaller distances traveled during September and October by both sexes could be a result of fall gatherings possibly for mating and due to cooler water temperatures during these months.

Home range size

At Norway Bay, there is no difference in home range size of male and female common musk turtles. However, males in Ontario had larger home ranges (Edmonds 1998). As for movements, sexual differences in home range size in turtles are often attributed to differential reproductive strategies (Ernst 1986). Males could possibly tend to maximize their individual reproductive success by maximizing the number of eggs they are able to fertilize. Therefore, larger home ranges increase their possibilities of mating (Morreale et al. 1984; Parker 1984). Despite spring and fall gatherings, males may travel further than females in order to mate with unrelated females (Alcock 1998). However, the spring and fall gatherings observed in the study area could decrease the importance of long travels by males to fertilize a lot of females.

The estimated home range sizes of both males and females at Norway Bay were larger than the majority of those recorded from southern populations which were never larger than a few hectares (Mahmoud 1969; Ernst 1986). Aquatic turtles tend to occupy discrete home ranges and exhibit site fidelity (Schubauer et al. 1990). The common musk turtle is no exception and in the United States these turtles tend to return to their initial site of capture (Williams 1952; Ernst 1986; Mitchell 1988; Holinka et al. 2003) indicating limited movement and thus a possible definitive activity range (Mahmoud 1969; Holinka et al. 2003). However, habitat fragmentation may explain large home ranges (Edmonds 1998). Dispersed areas that are needed by common musk turtles to forage and mate can result in larger home ranges encompassing all those needed components. In fact, habitats used by common musk turtles in the study area are large, but not always continuous. Furthermore, habitats used by common musk turtles outside of the study area were sometimes isolated from other big patches of suitable habitat. Hence, the large home ranges observed at Norway Bay may have resulted from habitat fragmentation. Our northern location may also influence home range size because such habitats are generally less productive (Harestad and Bunnell 1979). Turtles would then have to travel more to acquire all the resources that they need.

Yet another possible explanation for the differences in home range size with latitude could be the cost of longer movements. While known common musk turtle populations in Canada are found in rivers, several populations in the United States occupy small lakes (Wade and Gifford 1964; Lindsay 1965; Mitchell 1988; Dodd 1989), and ponds (Cagle 1942; McPherson and Marion 1981*b*; Ernst 1986). In those populations, large home ranges may include movements on land. Hence, the large ranges observed in Québec may be due to the lower risks and lower costs of travelling long distances in water than on land (increased predation and energy expenditure and decreased foraging time).

Implications for conservation

Protection efforts for the common musk turtles should be concentrated on habitats used by turtles throughout their annual cycle. Therefore, habitat protection efforts for the common musk turtle should focus on shallow waters filled with aquatic vegetation, especially zones with an abundance of floating and emergent vegetation. Habitats encompassing potential refuges (sites with several submerged logs) as well as gathering spaces (beaver lodges and rocky shores) should also be protected. Maintenance of corridors between such habitat patches should also be a major concern even if habitats found in these corridors seem avoided.

There is still no information about nesting sites in the area. The location and description of nest sites is critical for the protection of musk turtles at Norway Bay. Common musk turtle females are known to share nesting sites (Ernst et al. 1994) and this makes the identification and localization of these habitats particularly crucial. Radio-telemetry studies focusing on nesting sites could greatly help in providing the necessary knowledge to protect these sites.

The common musk turtles followed by telemetry used a total area of 166.9 ha. However, it is possible that turtles could use areas upstream or downstream since the boundaries of the population are still unknown. Nonetheless, individuals followed throughout the study required approximately 24 ha to complete their annual activity cycle. Therefore, this information should be considered in future conservation plans in order to protect habitats as well as viable populations, especially at Norway Bay.

A future objective should be to apply results from this study to identify other suitable habitats for *S. odoratus* in the broader region as well as the province and other sectors of the range. Since common musk turtles select their habitats at both landscape and home range scales, aerial and satellite imagery and field work could be used to identify appropriate sectors.

CHAPTER THREE

DEMOGRAPHY OF COMMON MUSK TURTLES (*STERNOTHERUS ODORATUS*) IN SOUTHWESTERN QUÉBEC: IMPLICATIONS FOR CONSERVATION

Introduction

Turtles are long-lived (Gibbons 1987; Congdon et al. 1993) with life-history traits (e.g., late sexual maturity and low reproductive success) that make recovery from decline difficult (Congdon et al. 1994). Monitoring, managing, and conserving long-lived species can represent special challenges (Heppell et al. 1999). Long-term monitoring is usually required to assess adequately turtle population trends because there can be a long lag between adverse situations and declines (Russell 1999). Demographic characteristics of several species vary noticeably across their range (Gregory and Larsen 1996) and the vulnerability of endangered species can be affected by synchronous variation among conspecific populations (Weatherhead et al. 2002). Rigorous estimates of demographic parameters can provide information about different aspects of a population (Madsen and Shine 1993; Brown and Weatherhead 1999) and help create management and conservation plans for populations of long-lived species (Heppell et al. 1999) such as turtles.

Recent studies on the demography of turtles have been conducted with the goal of providing quantitative data to inform conservation and management agencies (Litzgus and Mousseau 2004; Marchand and Litvaitis 2004; Daigle and Jutras 2005; Verdon and Donnelly 2005; Pike 2006). The structure and natural history of populations of the common musk turtle, a species ranging from the southeastern United States to southwestern Québec (Canada), have been well studied in the southern part of its range (Mitchell 1988; Holinka et al. 2003; Smar and Chambers 2003; Ernst 1986; Ford and Moll 2004; Clark et al. 2001; Risley 1933; Williams 1952; Oklahoma; Mahmoud 1969; Dodd 1989). However, only one study has been conducted on a northern population (Edmonds and Brooks 1996; Edmonds 1998).

Since the common musk turtle was designated as threatened in 2002 (COSEWIC), no study has focused on the demography of common musk turtle populations found in Canada near the northern limit of its range. Data from such northern populations are required to make more informed conservation and management decisions.

Life-history traits are known to vary with latitude within a species (Iverson and Smith 1993; Iverson et al. 1993; Cardillo 2002) because climatic variation occurring across a species' range is likely to result in disparities in demographic characteristics (Blouin-Demers et al. 2002). Therefore, while some extrapolations could be made based on other studied populations of common musk turtles throughout the range, those extrapolations are risky when populations live under different climatic and ecological regimes. Knowledge of population characteristics including turtle density, sex ratio, and population structure will give basic information that will be crucial in enlightening future management decisions of common musk turtle populations in the northern part of the range.

Turtle density can vary with resource availability (Ernst et al. 1994), habitat quality, and presence of predatory fish (Ernst 1986; Congdon et al. 1986). A wide variety of common musk turtle population densities have been documented in both riverine and lacustrine habitats throughout their range with values falling within 7.5-700/ha (Mahmoud 1969; Ernst 1986; Mitchell 1988; Dodd 1989; Holinka et al. 2003). The estimation of common musk turtle density at Norway Bay is clearly a first step in providing essential information concerning its population status.

In natural populations of turtles, the sex ratio is often found to differ significantly from 1:1 (Gibbons 1990; Smith and Iverson 2002; Gibbs and Steen 2005; Aresco 2005). Through the common musk turtle's range, the sex ratio was found to vary from male-biased (Ernst 1986; Edmonds and Brooks 1996; Holinka et al. 2003; Aresco 2005; Smar and Chambers 2005), to even (Mahmoud 1969; Mitchell 1988), to female-biased (Risley 1933; Dodd 1989). While the ratio of males to females in turtles may have a considerable impact on reproductive success (Tinkle 1961), estimation of the sex ratio of the Norway Bay population may help identify a trend for sex ratios in northern populations. Because turtles are long-lived, grow slowly, mature late, and have low recruitment (Harding 1991) they are vulnerable to environmental change (Congdon et al. 1993). Hence, quantitative information on the population structure is necessary to understand the status of a population. Knowledge of the relative proportions of juveniles, adult males, and adult females in the population are crucial in revealing recruitment (Congdon et al. 1993) and the proportion of a common musk turtle population that can potentially reproduce.

The specific objectives of this study are: (1) to estimate turtle density, (2) to calculate sex ratio, and (3) to determine the population structure. A last objective is to provide a set of management recommendations.

Methods

Study area

The study was conducted on the north shore of the Ottawa River, approximately 3.5 km southeast of Norway Bay, Québec (Canada) (45º29'15''N, 76º23'15''O). The study site consisted of a total area of 71.7 ha and it included several bays with shallow waters, slow currents, and abundant aquatic vegetation.

Data collection

Fieldwork was conducted from the end of April to the end of October 2006. Mark-recapture was used to estimate the number of turtles in the study area. A total of four sectors (Figure 3.1) were chosen to conduct this part of the study while other sectors were excluded for logistical reasons: some were difficult to access and some were too distant for the equipment available. Visits consisted of actively searching for turtles after sunset for a period of three hours. This technique involved slow movement in a canoe in the littoral zones as well as any sector where the water depth permitted fairly good visibility of the substrate. Million candle power lamps plugged to 12 volt batteries lit the water to see the turtles. Favourable weather conditions were needed to ensure that visibility through the water was optimal. The same amount of sampling effort was expended in each sector throughout the field season. A total of four sampling sessions occurred from: 1) 24-30 April; 2) 1 May to 30 June; 3) 1 July to 31 August; and 4) 1 September to 31 October. All four sectors were visited equally at least 3 times during the first week of field work, 4 times during period 2, 3 times during period 3, and once during period 4 for a total of at least 10 active searches in each sector. No mark-recapture event occurred in late September and October due to weather that produced very poor visibility. However, opportunistic captures occurred while conducting radio-telemetry and other aspects of the study.

Most of the common musk turtles were captured by hand and/or with a dip-net from a canoe. In fact, only 3 turtles were caught in a double funnel trap with a leader during the first days of fieldwork. All captured turtles were individually marked by notching marginal scutes of the carapace (Cagle 1939). Secondary sexual characteristics were used to determine sex. A male could be recognized by his smaller plastron, thicker and longer tail, and the presence of two small patches of tuberculate scales on each hind leg (Risley 1930; 1933; Reynolds and Seidel 1982). However, this method only permitted identification of adult males (Holinka et al. 2003). Records of mean size at maturity of females from a population in Ontario (Edmonds 1998) were used to identify adult females: a female was considered sexually mature when her carapace length exceeded 81 mm. Individuals < 81 mm were considered to be juveniles. Maximum length of the carapace was measured in a straight line with a calliper to the nearest mm. Turtles were released at their site of capture after manipulations which usually lasted approximately 10 minutes.

Statistical analysis

The number of common musk turtles in the study area was estimated using the POPAN formulation (Schwarz and Arnason 1996) of the Jolly-Seber method (Jolly 1965; Seber 1965) in the program MARK (White and Burnham 1999). Two analyses were conducted; one looking at all the common musk turtles as a homogeneous group and a second examining males and females separately. Three different models were considered in both analyses and each model differed with respect to the number of free parameters included. Each group of every analysis had their respective catchability and number of individuals, but they could either differ or not in the number of parameters associated with survival and dilution rate. Hence, the different models represented different situations that could occur in the population (i.e. survival and dilution were either constant or different with time and group). The preferred models were the ones with the lowest AIC values for each analysis because they best explained the data with a minimum of free parameters (Burnham and Anderson 1998). The overall sex ratio of the population and the sex ratio of size classes broken down by 10 mm of carapace length were calculated using Chi-Square goodness-of-fit tests. Version 13.0 of SPSS (SPSS Inc. 2005) was used for the Chi-Square tests.

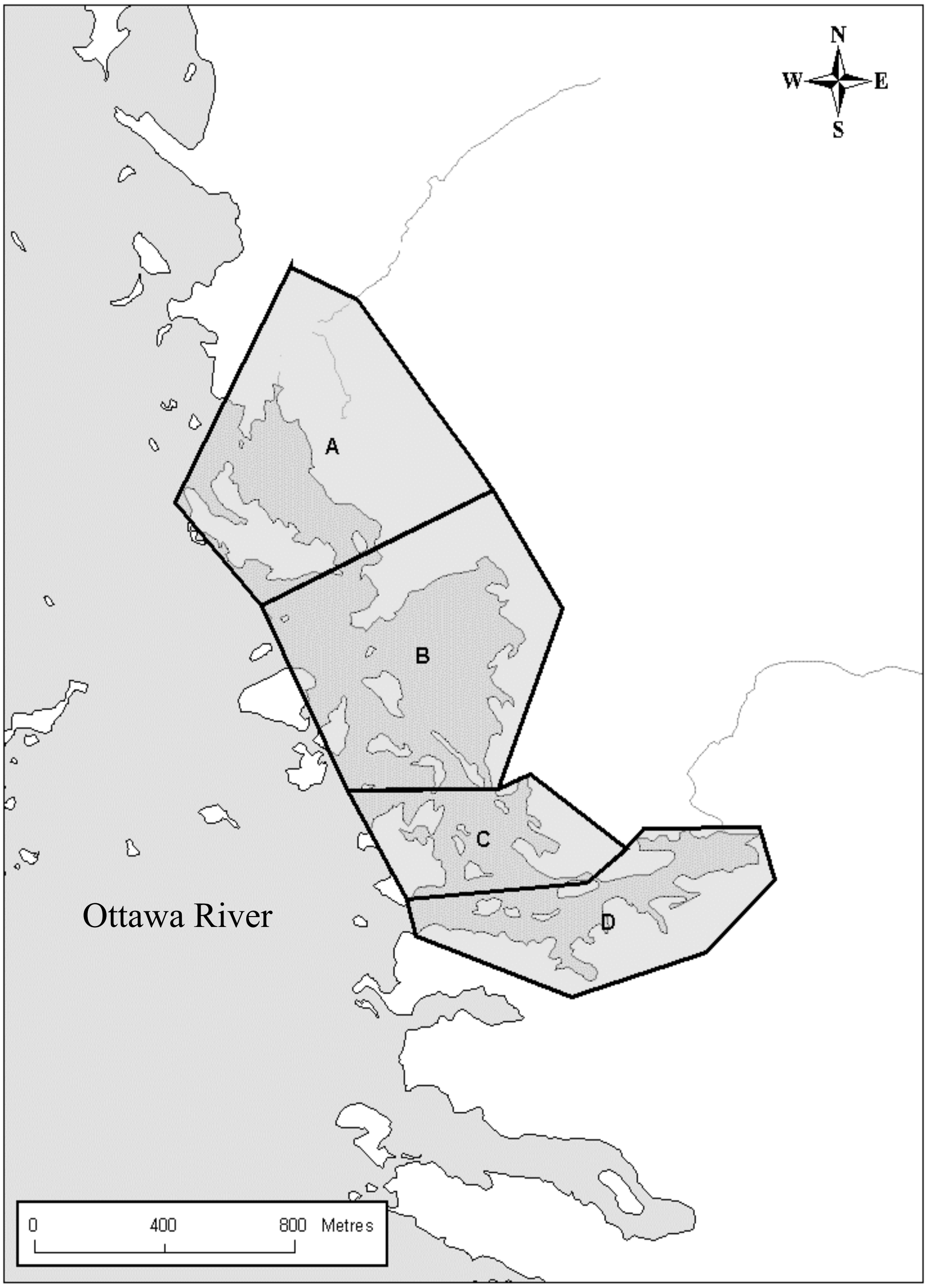

Figure 3.1: Sectors A, B, C, and D of the study area in Norway Bay, Québec.

Throughout the study, significance levels of 0.05 were used to reject null hypotheses.

Results

Altogether, 109 individual musk turtles were captured from 29 April to 26 October. In total, 17 recaptures of 15 different turtles were made for a total of 126 captures. Three females and 10 males were captured twice while two males were captured three times. Overall, the preferred model estimated the number of individuals in the study area, regardless of sex, to be 295 turtles (95% confidence intervals (C.I.): 206, 467). The preferred model looking at males and females separately gave the estimated number of individuals in each group to be 146 males (95% C.I.: 103, 235) and 149 females (95% C.I.: 72, 402) for a total of 295 turtles. This model included survival rates that differed according to time but that were not different between males and females (Table 3.1; Table 3.2). Based on this first analysis, the musk turtle density of the Norway Bay population is 4.1 turtles/ha (95% C.I.: 2.9 turtles/ha, 6.5 turtles/ha).

The 109 individuals that were captured included 65 (59.6%) males, 39 (35.8%) females, and 5 (4.6%) juveniles. Thus, the overall male to female ratio in the study area including only the 104 adults was 1.7:1 and differed significantly from 1:1 (χ^2= 6.5, df= 1, P = 0.011). However, when estimated for each size class, sex ratio was only significantly different from equality and biased towards males for the size class of 91-100 mm of carapace length with 3M: 1F (males: 12, females: 4, χ^2= 4.00, df= 1, P= 0.046) (Table 3.3 and Figure 3.2). Adult males ranged from 77 and to 133 mm in carapace length whereas for adult females carapace length ranged from 83 to 128 mm. Juveniles ranged from 33 to 68 mm (Figure 3.3).

Discussion

Population density

The density of 4.1 turtles/ha at Norway Bay falls lower than the reported range

Table 3.1: Jolly-Seber results for all models tested in analyses by global population (captured turtles of both sexes) and by sex (adult males and adult females) of *Sternotherus odoratus* at Norway Bay, Québec, in 2006. The AIC criteria, their respective weight, the model likelihood and the numbers of parameters are shown for each model.

Analysis	Model	AICc	AICc Weight	Model Likelihood	No. of Param.
Population	{p(*), phi(t), pent(t)} [a]	147.4944	0.7813	1.0000	8
(N=109)	{p(*), phi(*), pent(t)}	150.9252	0.14055	0.1799	6
	{p(t), phi(t), pent(t)}	152.0989	0.07816	0.1000	11
By sex	{p(g), phi (t), pent(g*t)} [a]	163.0902	0.49919	1.0000	13
Males: N=65	{p(g), phi (t), pent (t)}	163.1498	0.48453	0.9706	10
Females: N=39	{p(g), phi(g*t), pent(g*t)}	163.937	0.01627	0.0326	16

[a] indicates the preferred model for each analysis.

Table 3.2: Jolly-Seber results for analyses by global population (captured turtles of both sexes) and by sex (adult males and adult females) of *Sternotherus odoratus* of Norway Bay, Québec, in 2006. The number of individuals per group in the study area, their catchability, their survival, and their dilution rate (turtles entering the population) are estimated. Confidence intervals of 95% are shown in parentheses. No results are shown for the fourth sampling period because the program cannot estimate catchability, survivability, and dilution rates for the last sampling session of an experiment.

Group	Population size	Catchability	Sampling occasion	Survival	Dilution rate
Population	295	0.23	1	1.00 (0.99, 1.00)	0.54 (0.34, 0.73)
	(206, 467)	(0.13, 0.37)	2	0.79 (0.66, 0.88)	0.05 (0.00, 0.65)
			3	0.99 (0.01, 0.99)	$0.10e^{-02}$ ($0.14e^{-17}$, 0.10)
Females	149	0.18	1	1.00 (1.00, 1.00)	0.73 (0.48, 0.89)
	(72, 402)	(0.06, 0.43)	2	0.75 (0.67, 0.82)	$0.95e^{-08}$ (-0.05^{e-04}, 0.50^{e-04})
			3	1.00 (0.01, 1.00)	$0.37e^{-11}$ (0.75^{e-04}, 0.66^{e-04})
Males	146	0.29	1	1.00 (1.00, 1.00)	0.37 (0.17, 0.64)
	(103, 235)	(0.17, 0.44)	2	0.75 (0.67, 0.82)	0.08 (0.01, 0.39)
			3	1.00 (0.01, 1.00)	0.07 (0.01, 0.44)

Table 3.3: Sex ratios of the *Sternotherus odoratus* population at Norway Bay, Québec, in 2006 broken into size classes of maximum carapace length. Chi-Squares analysis tests for deviations from a ratio of 1:1.

Size class	N	Ratio (m:f)	X^2 ($X^2_{0.05}$ = 3.84)	P
71-80	2	NA	NA	NA
81-90	14	2.5	2.571	0.109
91-100	16	3.0	4.000	0.046 *
101-110	28	1.6	1.286	0.257
111-120	36	1.1	0.111	0.739
121-130	7	NA	NA	NA
> 130	1	NA	NA	NA

* Sex ratio is significantly male biased.

'NA' indicates that sex ratio could not be estimated due to a lack of females or a sample size that is too small.

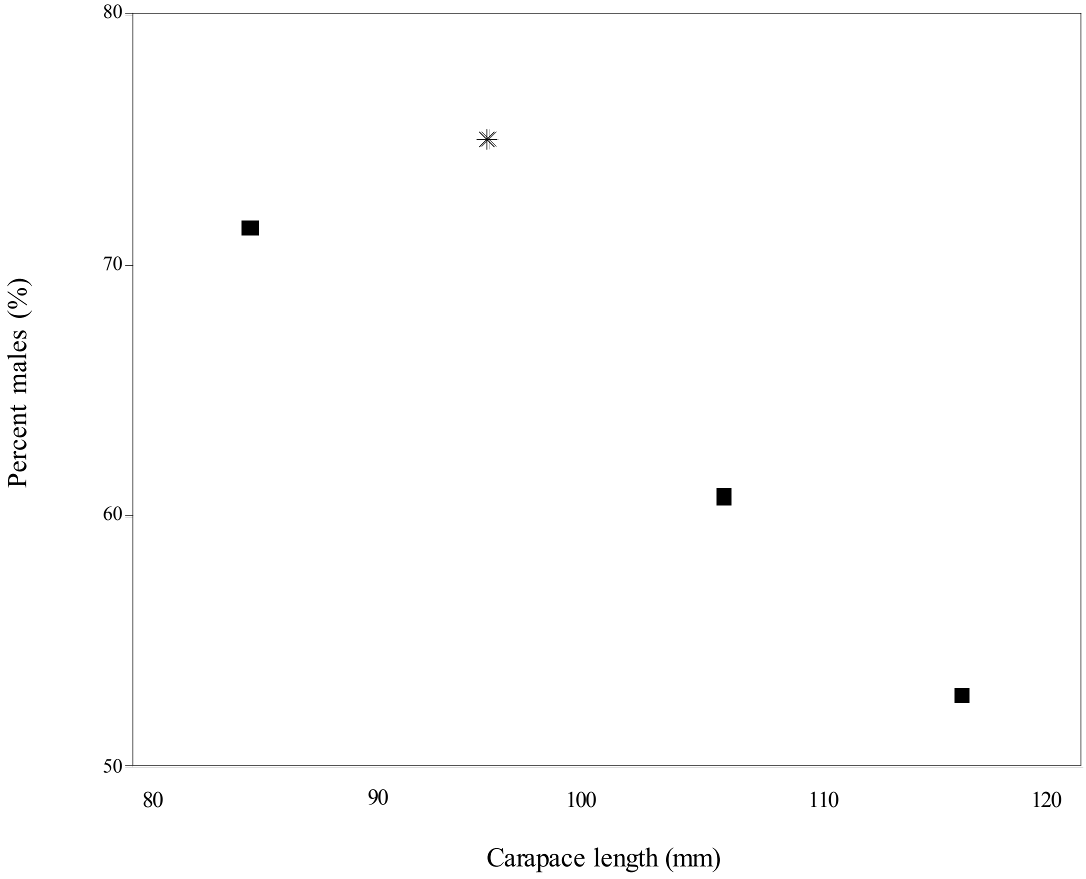

Figure 3.2: Sex ratios of *Sternotherus odoratus* (N = 109) at Norway Bay, Québec, in 2006 broken into size classes of maximum carapace length. Unbiased sex ratios are represented by squares and the biased sex ratio is represented by an asterisk. Sex ratios for size classes of 71-80 mm and > 130 mm were impossible to calculate due to a lack of females.

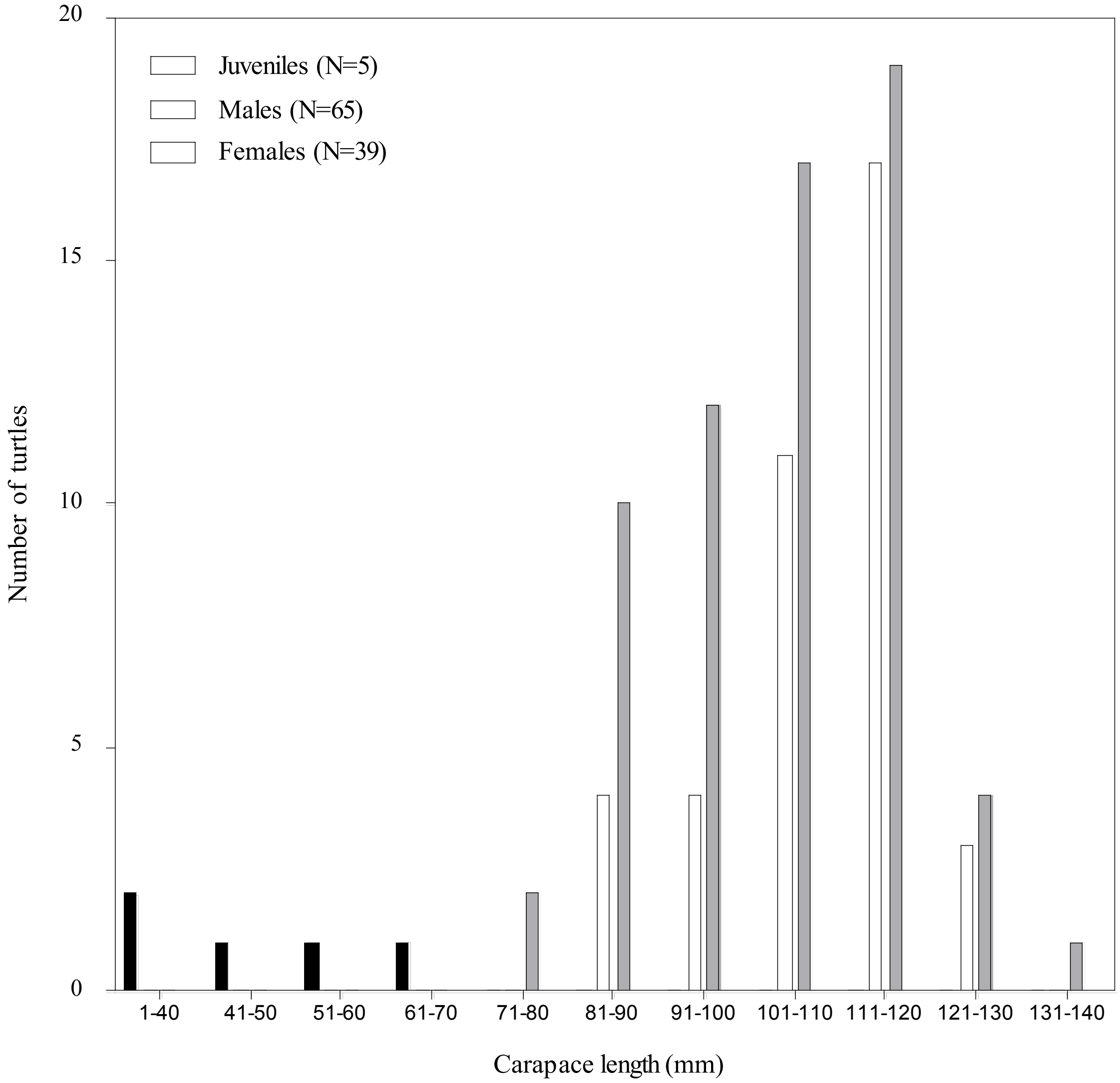

Figure 3.3: Frequency histogram of size classes of *Sternotherus odoratus* at Norway Bay, Québec, in 2006.

of 7.5-700/ha in the literature (Mahmoud 1969; Congdon et al. 1986; Ernst 1986; Mitchell 1988; Dodd 1989; Holinka et al. 2003). A low density estimate could be explained by a sampling technique disregarding one or several groups of turtles (Holinka et al. 2003). The skewed sex ratio could also have contributed to the lower density observed if females were captured less often than males.

Small numbers of fish predators and an abundance of emergent vegetation tend to result in higher turtle densities (Congdon et al. 1986). In the study area, emergent vegetation was relatively abundant. In certain sectors, it formed only a narrow band near the shoreline but elsewhere emergents covered a significant proportion of the bays over a global area of several hectares. Potential fish predators were present and could have negatively influenced the common musk turtle population size (Ernst 1986; Holinka et al. 2003). Raccoons (*Procyon lotor*) were seldom observed, but at least one common musk turtle was killed by a terrestrial predator in September.

Sex ratio

The overall sex ratio estimate of the common musk turtle population was male-biased, with 1.7 males per female. The same kind of male-biased ratios were found in many populations inhabiting the United States (Ernst 1986; Holinka et al. 2003; Smar and Chambers 2005) and Canada (Edmonds and Brooks 1996). Although only the size class of 90-100 mm was significantly male-biased, all classes had a higher number of males.

Because selection is expected to lead to the evolution of a balanced sex ratio (Fisher 1930), deviation from a 1:1 ratio in a natural population requires an explanation. Although uneven sex ratios may exist in natural turtle populations, the skewed overall sex ratio and the variation among classes could be induced by any or a combination of different biological factors (Gibbons 1990) or sampling biases (Ream and Ream 1966; Gibbons 1970*b*; Swannack and Rose 2003). Current hypotheses suggest that several biased ratios observed in turtle populations are the result of sexual differences in behaviour (Ream and Ream 1966; Gibbons 1983, 1990, Dodd 1989, 1997; Edmonds 1998; Ford and Moll 2004), or sampling bias (Edmonds 1998;

Holinka et al. 2003). Hence, correctly estimating the sex ratio of a natural turtle population is complicated by empirical and interpretational traps (Mrosovsky 1994).

Behavioural differences between males and females, such as differential mortality, activity patterns, and habitat use can induce a bias in sex ratio (Ream and Ream 1966; Gibbons 1983, 1990; Dodd 1989, 1997; Edmonds 1998). Edmonds and Brooks (1996) found male common musk turtles to be more abundant in every size class in Ontario, leading them to think that they could survive better and live longer than females. Thus, a lower mortality rate of males was postulated to explain the bias in the sex ratio (Edmonds 1998). However, the model that best supported the analysis of numbers of male and female common musk turtles at Norway Bay included similar survival for both sexes. The male biased sex ratio may also be a result of males being more active than females making them more likely to be captured. A larger mean home range size for males would support this explanation (Mahmoud 1969; Bancroft et al. 1983). At Norway Bay, females did not have smaller home ranges and did not move less compared to males. Differential habitat use may have led to a more extensive sampling of male habitats. The effect of sex on macrohabitat use is still unknown due to small sample size. However, there was no significant effect of sex on microhabitat use by common musk turtles at Norway Bay.

Potential sampling errors include improper sex determination, sampling technique bias, and sample size bias (Gibbons 1970*b*; Swannack and Rose 2003). Although it is possible to determine the sex of young stinkpots without ambiguity within a year of hatching (Swannack and Rose 2003), the juveniles *S. odoratus* at Norway Bay were excluded from the sex ratio analysis to diminish the possibility of errors of sex determination. The male biased sex ratio may be induced by sampling techniques (Ream and Ream 1966; Gibbons 1983, 1990). Trapping methods may favour capturing males versus capturing females. Nonetheless, the use of capture by hand and by dip-net has produced even sex ratios in a painted turtle (*Chrysemys picta*) population in Wisconsin (Ream and Ream 1966). It is also possible that the time of day during which most of the turtles were captured could have an effect. However, Smith and Iverson (2002) found no effect of time of day on the sex ratio of a stinkpot population in Indiana. Finally, a previous study of the musk turtle in Canada found a significant relationship between sex ratio and sample size (Edmonds and Brooks

1996) where smaller sample sizes resulted in biased ratios. However, another study in Indiana found no such relationship (Smith and Iverson 2002).

Population structure

Few studies have clearly documented musk turtle population structure (Ernst 1986; Dodd 1989). In Pennsylvania, the juveniles constituted 30.0% of the population (Ernst 1986) while they represented 16.3% in Alabama (Dodd 1989). The proportion of juveniles of 4.6% estimated at Norway Bay can thus be considered low and is similar to the proportion of 5.4% estimated in Ontario (Edmonds and Brooks 1996). Their small size may have contributed to difficulty in locating and capturing juveniles. Mortality of juveniles may also be higher and that could account for their smaller numbers in the Norway Bay population.

The size distribution of the Norway Bay population includes a broader range of body size for males compared to females. Tinkle (1961) found that body size of common musk turtles follows the common ecological pattern of increasing body size with increasing latitude. Average maximum carapace length of common musk turtles in Norway Bay was greater than the ones recorded from studies in the southern part of the species' range (McPherson et al. 1981*b*; Tinkle 1961; Mitchell 1985*a*; Dodd 1989; Holinka et al. 2003). However, in some studies the absence or low numbers of juveniles and other small turtles may have affected the overall mean carapace length (Holinka et al. 2003). Hence, it is possible that the calculated means are artefacts of sampling techniques. Also, the great majority of previous studies have recorded carapace length as a straight line in the middle of the carapace. This probably results in slightly smaller measured lengths of the turtles. The mean carapace lengths calculated at Loon Island, Ontario (males 103.10 ± 0.59 mm, females 98.69 ± 1.05 mm) (Edmonds and Brooks 1996; Edmonds 1998), are closer to those observed at Norway Bay. Common musk turtles in Norway Bay and Loon Island probably have very similar mean carapace lengths in accordance with the general ecological pattern of increasing body size with increasing latitude (Tinkle 1961). Nevertheless, the published record of the largest maximum carapace length (150 mm) was measured in Virginia (Ewert 2005) indicating that regional variation can alter the latitudinal pattern.

Implications for conservation

At Norway Bay, the high proportion of mature common musk turtles represents a good potential for reproduction. However, stable or growing populations require a fairly large portion of juveniles and sub-adults (Congdon et al. 1993). Therefore, the low estimated proportion of juveniles as well as the lower proportion of mature females compared to mature males constitute threats to population stability. Furthermore, if the low proportion of immatures was correctly estimated, the population seems to be declining. The similar proportion calculated in Ontario by Edmonds and Brooks (1996) could indicate that low recruitment may be a trend in northern populations of common musk turtles. There is still an urgent need to locate, describe, and protect nesting sites to ensure recruitment to this population, especially considering its relatively low recruitment. Intensive radio-telemetry studies should be conducted during the nesting period for consecutive years to achieve this objective. Locating more hatchlings could also permit a more accurate assessment of the status and the demographic composition of populations (Pike 2006). Such studies would also reliably indicate the timing of the nesting period for this northern population of the common musk turtle.

Human activities in the study area were relatively infrequent. Except for a few cottages and occasional fishing, there does not seem to be a real threat from human activity. However, it is necessary to maintain these good conditions to sustain this population. Therefore, short- and long-term monitoring is crucial to create as well as modify management and conservation plans. Adaptive management and conservation decisions based on changes in population structures would be beneficial for the Norway Bay population or any other population.

CONCLUSIONS

The objectives of this study were to describe habitat selection, movement patterns, and demography of common musk turtles in southwestern Québec. These objectives were achieved by determining habitats selected at study-area and home-range scales, identifying habitat features which differentiate used from available sites, estimating daily and monthly distances moved by turtles, calculating turtle density and sex ratio, and describing population structure. Management recommendations concerning habitats, movements, and demography which are useful for this northern population as well as any other population throughout the species' range were also provided.

A habitat selection study focusing on seasonal and sexual differences would complement the current study. However, more radio-tracked common musk turtles from both sexes would be needed. At the location scale, different analyses regarding the type of activity and/or reproductive state may also help in providing models with a greater predictive power. A radio-telemetry study focusing on the nesting sites used by the Norway Bay population would be important to identify and describe these crucial sites.

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APPENDIX A

Guidelines for completing the form are available at www.mcgill.ca/research/compliance/animal/forms

For Office Use Only:
Protocol #: 5159
Approval End Date MAY 31, 2007
Facility Committee: AGR

McGill University
Animal Use Protocol – Research

Title: Étude de la sélection de l'habitat et des paramètres de la première population québécoise de la tortue musquée (Sternotherus odoratus)
(must match the title of the funding source application)

☒ **New Application** ☐ **Renewal of Protocol #** ____ ☐ **Pilot** **Category** *(see section 11)*: C

1. Investigator Data:

Principal Investigator: Rodger Titman **Phone #:** 398-7933
Unit/Department: Natural Resource Sciences **Fax#:** 398-7990
Address: Macdonald Camps **Email:** titman@nrs.mcgill.ca

2. Emergency Contacts: Two people must be designated to handle emergencies.

Name: Rodger Titman **Work #:** 398-7933 **Emergency #:** (514) 457-6480
Name: Pascale Belleau **Work #:** R2-085 **Emergency #:** (819) 568-5589

3. Funding Source:

External ☒	**Internal** ☐	For Office Use Only: ✓ May 11 '06 APPROVED
Source (s): FFQ, PIH, FREP, Service canadien de la faune, Ministère des ressources naturelles et de la faune	**Source (s):** ____	
Peer Reviewed: ☒ YES ☐ NO**	**Peer Reviewed:** ☐ YES ☐ NO**	
Status : ☐ Awarded ☒ Pending	**Status:** ☐ Awarded ☐ Pending	
Funding period: 2006	**Funding period:** ____	

**** All projects that have not been peer reviewed for scientific merit by the funding source require 2 Peer Review Forms to be completed e.g. Projects funded from industrial sources. Peer Review Forms are available at www.mcgill.ca/research/compliance/animal/forms**

Proposed Start Date of Animal Use (d/m/y): 15/04/06 **or ongoing** ☐
Expected Date of Completion of Animal Use (d/m/y): 15/11/06 **or ongoing** ☐

Investigator's Statement: The information in this application is exact and complete. I assure that all care and use of animals in this proposal will be in accordance with the guidelines and policies of the Canadian Council on Animal Care and those of McGill University. I shall request the Animal Care Committee's approval prior to any deviations from this protocol as approved. I understand that this approval is valid for one year and must be approved on an annual basis.

Principal Investigator's signature:	Rodger Titman	**Date:** Jan. 30, 2006

Approved by:

Chair, Facility Animal Care Committee:		**Date:** April 3/06
University Veterinarian:		**Date:** April 13, 2006
Chair, Ethics Subcommittee (as per UACC policy):	—	**Date:** —
Approved Animal Use	**Beginning:** June 1, 2006	**Ending:** MAY 31, 2007

☐ This protocol has been approved with the modifications noted in Section 13.

December 2005

MAI