Common Musk Turtles (Sternotherus odoratus) select habitats of high thermal quality at the northern extreme of their range

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Abstract. In ectotherms, variation in body temperature (T_b) affects physiological performance and, ultimately, fitness. Therefore, reptiles regulate T_b behaviourally by choosing habitats of optimal temperature. The main goal of this study was to determine the link between patterns of thermoregulation and habitat selection in Common Musk Turtles inhabiting a thermally challenging region. We expected habitat selection to be based on the fulfillment of thermoregulatory requirements, which can be accomplished by selecting thermally superior habitats. From early May to late August 2007, we tracked 22 Common Musk Turtles with temperature-sensitive radio-transmitters and collected daily T_b profiles with automated radio-telemetry data loggers. In addition, temperature data loggers were placed in the study area to measure the range of environmental operative temperatures (T_e) available to musk turtles. The habitats with the highest thermal quality were aquatic habitats with surface cover (i.e., lily pads, macrophytes, etc.) followed by shallow water. As expected, musk turtles used habitats non-randomly and had a strong preference for thermally superior habitats. This is consistent with the typical aquatic basking behaviour observed in musk turtles, suggesting that there is a strong link between thermal quality of habitats and habitat selection, even in this almost entirely aquatic turtle.

Keywords: aquatic basking, home range, radio-telemetry, reptile, temperature, thermoregulation, stinkpot.

Introduction

All physiological processes depend on body temperature (T_b) . Therefore, in ectotherms such as reptiles, variation in T_b affects physiological performance and, ultimately, fitness (Huey and Kingsolver, 1989). Consequently, reptiles depend on behavioural thermoregulation to maintain T_b in a range allowing optimal performance (Cowles and Bogert, 1944; Huey and Kingsolver, 1989). Inevitably, reptiles depend on the range of temperature provided by the physical environment and, as a result, behavioural regulation of T_b is achieved by choosing habitats of optimal temperature (Huey et al., 1989). In fact, the obligation to maintain T_b within an optimal range to maximize physiological performance seems to be a major driving factor in habitat selection for many terrestrial reptiles (Huey, 1991). It is doubtful that the elevated T_b achieved by basking on land can significantly improve performance for freshwater turtles during critical activities in water. Due to the high thermal conductivity of water, turtle T_b rapidly reaches thermal equilibrium with water after basking has ceased (Ben-Ezra et al., 2008). Since a turtle must remain in the aquatic environment for extended periods when foraging or attempting to mate, the performance potential of elevated T_b achieved by basking would rapidly be lost. Thus, we should expect aquatic turtles to exploit the warmest aquatic habitats for activity. Our general goal was to determine the link between patterns of thermoregulation and habitat use in Common Musk Turtles (*Sternotherus odoratus*), a species that rarely basks.

Thermoregulation should be more tightly linked to fitness in environmental extremes than in more moderate thermal environments (Huey, 1974; Shine and Madsen, 1996). In north temperate regions, for instance, thermoregulation can be particularly challenging (Blouin-Demers and Weatherhead, 2001). Therefore, there should be a particularly tight link between thermoregulation and thermal quality of the environment in regions where thermoregulation is challenging. Our objective was to determine if thermal quality affects habitat use by

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musk turtles in a thermally challenging environment. First, we quantified the thermal quality of habitats available to musk turtles in the study area. Musk turtles are highly aquatic and have rarely been observed performing "aerial basking" typical of most freshwater turtles. Instead, musk turtles have been observed basking while floating at the surface of the water under or amongst aquatic vegetation (Ernst, 1986). Therefore, we expected aquatic habitats containing surface cover (emergent aquatic vegetation such as lily pads or floating macrophytes) to be of higher thermal quality than other aquatic habitats devoid of such cover. Second, we examined whether musk turtles preferentially use habitats of high thermal quality at the homerange scale.

Materials and methods

Study area and study animals

From May to August 2007, we studied a population of Common Musk Turtles (Sternotherus odoratus) in the St. Lawrence River, Ontario, Canada. The study area was 3.8 by 1.1 km along the southeastern shore of Grenadier Island. Musk turtles were captured by hand and 22 adult musk turtles (13 females and 9 males) were fitted with temperaturesensitive radio-transmitters (Model SB-2T, 6.4 g, battery life of 12 months at 20°C, Holohil Systems Inc., Carp, Ontario). We attached the transmitters to the rear of the carapace with stainless steel wire threaded through two small holes drilled in the marginal scutes. The mass of the transmitter never exceeded 5% of the mass of the turtle bearing it. Turtles were located every two days. Upon location, the individual's position was recorded on a detailed map of the study area, from which we later retrieved the Universal Transverse Mercator (datum NAD83) coordinates using ArcMAP 9.2 (Environmental Systems Research Institute, Redlands, California).

Body temperatures

 T_b were acquired via the pulse rate of the transmitters. Because musk turtles are small and almost entirely aquatic and because of the high heat conductivity of water, we considered externally measured T_b (via the temperature-sensitive radio-transmitters) to be close approximations of internal T_b . T_b were recorded every 3 minutes with two automated radio-telemetry data loggers (SRX 400, Lotek Engineering Inc., Newmarket, Ontario). Musk turtles used an area larger than what could be scanned constantly. Therefore, we regularly moved the data loggers to maximize the number of turtles within recording range. Transmitter pulse rates were converted to temperatures by fitting a polynomial equation to the calibration points (provided by the manufacturer) for each transmitter.

Thermal preference

We did not measure preferred body temperature (T_{set}) ourselves, but the published values for freshwater turtles indicate that T_{set} seems a conserved trait (see Annex of Picard, 2008). Therefore, we used the mean T_{set} (central 50% of T_b selected in a gradient) documented in 8 studies of temperate turtles that had a sample size of >10 individuals (*Trachemys scripta* and *Terrapene ornata* Gatten, 1974; *Clemmys guttata* and *Chrysemys picta* Graham and Hutchison, 1979; *Chelydra serpentina* Schuett and Gatten, 1980; Williamson et al., 1989; and Knight et al., 1990; *Pseudemys nelsoni* Nebeker and Bury, 2000; *Chrysemys picta* Edwards and Blouin-Demers, 2007; *Graptemys geographica* Ben-Ezra et al., 2008).

Environmental operative temperatures

Environmental operative temperatures (Te) represent the range of T_b an ectotherm could achieve in the field. Because musk turtles are small and almost exclusively aquatic and because water has very high temperature conductivity, we assumed that Te were the same as water temperatures. There have been reports of Common Musk Turtles basking out of water. In our study, however, all radio-tracked turtles were found underwater (495 observations) with the exception of a nesting female. As a result, we considered water temperature a reliable estimate of Te. To record water temperature, we placed temperature data loggers (Thermochron iButton DS1921; Dallas Semiconductor, Sunnyvale, California) at 8 locations in the study area to represent the range of Te available to musk turtles at all times. Two sets of 3 data loggers were each attached to a floated rope and sunk to be at three depths (0.5 m, 1 m, and 2 m) in open water at representative locations. In addition, 2 data loggers were placed at the water surface under vegetation (lily pads and macrophytes) to mimic the aquatic basking of musk turtles (Ernst, 1986). In total, we thus had two sets of 4 data loggers that recorded water temperature in the study area every 120 minutes for the duration of the active season. As determined by high-resolution digital aerial orthoimagery and nautical charts, the study site was composed of 61.8% deepwater habitat (>2 m), 32.9% intermediate-water habitat (1-2 m), and 4.24% shallow-water habitat (0-1 m). In addition, 0.85% of the water had surface cover. We used these proportions to weigh Te by habitat availability.

Indices of thermoregulation

In accordance with Hertz et al. (1993), we measured the accuracy of T_b and the thermal quality of each habitat using the mean deviations of T_b from T_{set} (d_b) and of T_e from T_{set} (d_e). We used the mean monthly d_e and the proportion of T_e within T_{set} ($d_e = 0$) to quantify the thermal quality of each habitat. Following Blouin-Demers and Weatherhead (2001), we measured the effectiveness of thermoregulation with $d_e - d_b$. We also calculated the thermal exploitation index

(Ex) of Christian and Weavers (1996), which represents the amount of time a reptile spends with T_b within T_{set} expressed as a percentage of the amount of time when T_e indicated that it was possible to achieve T_b within T_{set} .

Home ranges and habitat use

We calculated minimum convex polygon (MCP) home ranges for each individual tracked throughout the whole active season (Hayne, 1949). Considering that musk turtles are highly aquatic, we excluded all land from the home range estimations. MCP home ranges were calculated in ArcMAP 9.2 (Envrionmental Systems Research Institute, Redlands, California) with the Hawth's Analysis Tools extension. Following Row and Blouin-Demers (2006a), we used kernel density estimators (Worton, 1989) to examine habitat use within the home range. Using the Animal Movement extension for ArcView 3.0 (Environmental Systems Research Institute, Redlands, California), we adjusted the smoothing factor (h) for each individual until the area of the 95% kernel (excluding land) was the same size as the MCP home range (Row and Blouin-Demers, 2006a).

We characterized macrohabitat types in the study area with high-resolution digital aerial orthoimagery from New York State GIS Clearinghouse. In addition, we used a nautical chart layer (1:25000 scale) from Fisheries and Oceans Canada to classify depth in three categories: shallow water (<1 m), intermediate water (1-2 m), and deep water (>2 m). Finally, we used photographs taken at the end of each month at every area where musk turtles were located, cross-referenced with hand drawn surface cover maps, to create a surface cover layer for each month (May to August). For the purpose of this study, we defined surface cover as sparse (i.e., open reeds) and dense (i.e., matted marshes, cattails) aquatic emergent vegetation that is present throughout the entire study season combined with seasonally emergent aquatic vegetation (i.e., lily pads). The total area of surface cover was deducted from the different water depth areas to obtain four habitat types: deep water, intermediate water, shallow water, and cover.

To determine habitat selection at the macrohabitat scale, we compared the habitat composition within the 95% and the 50% kernel home ranges of each individual to the habitat composition of the study area. To quantify habitat use and availability, we determined the proportion of surface cover (SCOVER), shallow water (SHALLOW), intermediate water (INTER), and deep water (DEEP) in the 95% kernel, the 50% kernel, and the study area. The proportions of these four habitat types sum to one. Following Aitchinson (1986), we used log-ratio transformations to remove this linear dependency. We used a compositional analysis to examine which habitats were preferred by musk turtles at the two intensity levels (95% and 50% kernel) (Aebischer et al., 1993).

Statistical analyses

The compositional analysis was conducted using Resource Selection (Leban, University of Idaho, Moscow, Idaho). All other statistical analyses were conducted on JMP version 5.0.1 (Statistical Analysis Systems, Cary, North Carolina) and R (R Development Core Team, R Foundation for Statistical Computing, Vienna, Austria). All assumptions of normality and homogeneity of variance were met and verified by examining scatter plots. We report all means \pm one standard error and we accepted significance of tests at $\alpha = 0.05$.

Results

From May to August 2007, we measured 29 406 body temperatures (T_b) from 13 female and 9 male musk turtles. These observations were condensed to 10 725 hourly mean T_b values that were used as the basis for all analyses.

Thermal preference

In total, 14 thermal preference measurements of 7 species of turtles were used to estimate T_{set} for *Sternotherus odoratus*. Averaged across all studies, the mean 75% and 25% quartiles of the distribution of selected T_b in a thermal gradient were 28.02 \pm 0.78°C and 24.4 \pm 0.98°C, respectively, and were used as the estimate of T_{set} .

Thermal quality of habitats

Due to technical difficulties, we lack Te measurements for May. As a result, all analyses including Te measurements use data from June, July, and August only. A total of 8344 Te measurements were collected from 8 locations. These were condensed to 4401 measurements representing the 4 habitat types. Mean Te never reached T_{set} in any month, suggesting that the habitat of musk turtles in Ontario is thermally challenging. The deep water habitat was the coldest and the least variable throughout the day (table 1). In fact, the lower bound of T_{set} (24.4°C) was reached only once in deep water (representing 0.05% of observations), suggesting that deep water could serve as a permanent refuge from high temperatures. The surface cover habitat provided the highest T_e in every month (table 1) and was the habitat with the highest thermal quality (lowest d_e, $3.21 \pm$ 0.43°C). Deep water had the lowest thermal

Table 1. Monthly mean (± 1 SE), maximum, and minimum operative environmental temperatures (T_e) recorded in the four main habitats available to Common Musk Turtles in the St. Lawrence River, Ontario, Canada. Monthly mean (± 1 SE) and maximum deviations of environmental temperatures from the preferred body temperature range (d_e).

Habitat	Te			de		
	Mean	Maximum	Minimum	Mean	Maximum	% = 0
June						
Shallow (<1 m)	18.94 ± 0.09	25.5	13.0	5.5 ± 0.09	11.4	0.8
1-2 m	17.40 ± 0.07	21.0	12.0	6.7 ± 0.07	12.4	0.0
Deep $(>2 m)$	16.44 ± 0.07	19.0	11.5	8.0 ± 0.07	12.9	0.0
Surface cover	21.62 ± 0.12	30.0	13.5	3.2 ± 0.10	10.9	18.9
July						
Shallow (<1 m)	22.11 ± 0.08	28.0	17.5	2.5 ± 0.07	6.9	17.1
1-2 m	20.44 ± 0.06	25.0	17.5	4.0 ± 0.06	6.9	0.9
Deep $(>2 m)$	19.57 ± 0.05	22.5	17.0	4.8 ± 0.05	7.4	0.0
Surface cover	23.56 ± 0.16	37.5	15.5	2.7 ± 0.08	9.5	19.9
August						
Shallow (<1 m)	23.44 ± 0.09	28.5	17.0	1.5 ± 0.07	7.4	37.1
1-2 m	22.73 ± 0.04	25.5	19.0	1.7 ± 0.04	5.4	9.1
Deep $(>2 m)$	22.14 ± 0.03	25.0	20.5	2.3 ± 0.03	3.9	0.1
Surface cover	23.15 ± 0.19	38.5	13.5	3.3 ± 0.11	10.9	21.2

quality (5.16 \pm 3.07°C). In general, the thermal quality (low d_e) of habitats increased during the study period. The surface cover habitat had the highest quality in June and July, but the lowest in August. In fact, d_e = 0 in June could only be reached in the habitat with surface cover (18.9% compared to near 0% for the other habitats). In July, however, surface cover habitats were closely followed by shallow habitats in terms of thermal quality, and were surpassed in August (d_e = 0 for 37.1% of time in shallow habitats).

Patterns of body temperature

A repeated measures two-way ANOVA indicated that T_b varied significantly between months ($F_{3,32} = 37.61$, P < 0.0001) and sex ($F_{1,32} = 4.94$, P = 0.031). The interaction between sex and month was not significant ($F_{3,32} = 1.95$, P = 0.13). On average, females had T_b 1.6°C higher than males (mean = 25.37 ± 0.48 °C for females and 23.77 ± 0.55 °C for males). The difference between the sexes appeared most marked in May (2.86°C) when females are carrying eggs, although the interaction was not statistically significant (fig. 1). Mean monthly T_b was lowest in May ($20.69 \pm$



Figure 1. Mean $(\pm SE)$ monthly body temperatures of male and female Common Musk Turtles in the St. Lawrence River, Ontario, Canada.

0.54°C) and reached a peak in August (26.6 \pm 0.48°C), but a Tukey-Kramer HSD test revealed that mean monthly T_b in August was not significantly higher than in June and July.

The distribution of mean hourly T_e was different from the distribution of mean hourly T_b (Kolmogorov-Smirnov test, D = 0.6251, P < 0.0001). T_b fell within the range of T_{set} 47.4% of the time while T_e fell within this range only 10.7% of the time. Musk turtles avoided low

temperatures and maintained body temperatures above the mean T_e .

Monthly plots of mean hourly T_b , maximum hourly T_e , and minimum hourly T_e showed that musk turtles were as warm as they could get during the night for all three months (fig. 2). In June, musk turtles were as warm as their environment permitted throughout the whole day, suggesting that the habitats with the highest temperatures were selected. In July and August, however, the warmest environments were avoided during the day because they were too warm for musk turtles. Furthermore, hourly mean T_b of musk turtles generally fell within the range of T_{set} throughout the whole day (fig. 2).

Indices of thermoregulation

The mean d_b across all individuals was $1.91 \pm 0.18^{\circ}$ C and the mean d_e (weighted by habitat availability) was $4.5 \pm 0.46^{\circ}$ C. Therefore, the average value of d_e – d_b (effectiveness of thermoregulation) for all individuals was $2.59 \pm 0.18^{\circ}$ C. The difference between d_e and d_b was most pronounced early in the season and decreased throughout the active season resulting in higher thermoregulation effectiveness in June than in July and August ($F_{2,32} = 313.4$, P < 0.0001, fig. 3). In June, musk turtles were on average 6.56° C closer to T_{set} than what was available, compared to 1.1° C in August (fig. 3). There was no significant difference between the sexes ($F_{1,32} = 1.34$, P = 0.255).

Ex averaged across all individuals was $44.2 \pm 2.56\%$. The proportion of T_b above T_{set} was $41.4 \pm 2.14\%$ and the proportion of T_b below T_{set} was $14.3 \pm 0.51\%$. A repeated measures two-way ANOVA indicated that the proportions of Ex did not differ between the sexes ($F_{1,31} = 0.074$, P = 0.787) or months ($F_{2,31} = 2.074$, P = 0.143, fig. 4). This pattern indicates that, throughout the active season, musk turtles chose habitats that permitted them to maintain T_b equal or above T_{set} more often than below.



Figure 2. Maximum and minimum mean hourly environmental temperatures and hourly mean body temperature of Common Musk Turtles in the St. Lawrence River, Ontario, Canada for (A) June, (B) July, and (C) August. The preferred body temperature range is represented by horizontal lines.



Figure 3. Monthly mean $(\pm 1 \text{ SE})$ deviations of field body temperatures from the preferred body temperature range (d_b), deviations of operative temperatures from the preferred body temperature range (d_e), and thermoregulation effectiveness (d_e - d_b) for Common Musk Turtles in the St. Lawrence River, Ontario, Canada.



Figure 4. Mean (± 1 SE) thermal exploitation indices (time spent with body temperatures (T_b) within, above, or below the preferred body temperature range (T_{set})) for Common Musk Turtles in the St. Lawrence River, Ontario, Canada.

Home range and macrohabitat selection

Aquatic home range size for the 13 females and 9 males that were followed for the whole active season was variable, ranging from 0.622 ha to 22.11 ha with a mean of 6.63 ± 1.1 ha. Home



Figure 5. Mean percentage $(\pm 1 \text{ SE})$ of the four habitat types within the 50% and 95% kernel home ranges and the available habitat for Common Musk Turtles in the St. Lawrence River, Ontario, Canada.

range size did not vary by sex ($t_{20} = 1.519$, P = 0.14). In both kernel intensities, musk turtles selected shallow water, intermediate water, and habitats with surface cover more than they were available and deep water less than it was available (fig. 5). Habitat types were used nonrandomly at both the 95% kernel ($\chi_3^2 = 50.08$, P < 0.0001) and the 50% kernel ($\chi_3^2 = 86.63$, P < 0.0001) scale. The same habitat preference trend was observed at both intensity levels (table 2). The ranking from most to least preferred is SCOVER > SHALLOW > INTER > DEEP. For both kernel densities, all pairs are significantly different (table 2).

Discussion

Thermal quality and patterns of thermoregulation

Musk turtles in our study area were exposed to an environment that was thermally challenging throughout the active season. In fact, mean monthly T_e never reached the lower bound of T_{set} and mean hourly T_e only reached the lower bound of T_{set} in habitats with surface cover, and only for a few hours during the afternoon. The Common Musk Turtles (Sternotherus odoratus) select habitats of high thermal quality

Table 2. Matrices of *t*-values and associated *p*-values comparing between-pairs of habitat types in the 50% and 95% kernel home ranges for Common Musk Turtles (n = 23) in the St. Lawrence River, Ontario, Canada. Preference rankings are in order of most (1) to least (4) preferred.

Habitat type	Value	SCOVER	SHALLOW	INTER	DEEP	Rank
50% kernel	t value		8 6306	5 3 5 7 7	30.0513	1
SCOVER	<i>p</i> -value		<0.0001*	< 0.0001*	< 0.0001*	1
SHALLOW	<i>t</i> -value <i>p</i> -value			2.1051 0.0469*	27.1176 <0.0001*	2
INTER	<i>t</i> -value <i>p</i> -value				17.8647 <0.0001*	3
DEEP	<i>t</i> -value <i>p</i> -value					4
95% Kernel						
SCOVER	<i>t</i> -value <i>p</i> -value		5.5034 <0.0001*	9.7149 <0.0001 [*]	12.8717 <0.0001*	1
SHALLOW	<i>t</i> -value <i>p</i> -value			2.6883 0.0134 [*]	11.8223 <0.0001*	2
INTER	<i>t</i> -value <i>p</i> -value				12.4602 <0.0001*	3
DEEP	<i>t</i> -value <i>p</i> -value					4

*denotes significant difference.

environment was especially challenging in June, when T_{set} could only be reached in habitats with surface cover. As a result, habitats with surface cover provided superior thermoregulation opportunities, especially early in the season. Early active season (late May-June) is a critical time for turtles coming out of hibernation, especially for pre-nesting females (Krawchuk and Brooks, 1998). Thus, we expected a strong selection for surface cover early in the season. Surface cover became less critical to thermoregulation as the season progressed because the water warmed. Nevertheless, most of the available habitat was deep water and this habitat never reached preferred temperatures. In July and August, surface cover habitat had similar thermal quality to shallow water. Accordingly, the highest percentages of Te falling within Tset were observed in habitats with surface cover and shallow water.

Despite poor environmental thermal quality, musk turtles were able to maintain their T_b within the preferred range most of the study period, indicating that they are effective thermoregulators. The daily T_b profile in June indicated that musk turtles were as warm as their environment permitted throughout the day. The profiles for July and August indicated that turtles kept a relatively constant T_b throughout the day.

Compared to other reptiles for which quantitative thermoregulation indices have been calculated, musk turtles can be categorized as moderate thermoregulators. To our knowledge, only one other study has applied quantitative indices of thermoregulation to describe the thermal ecology of a turtle (Edwards and Blouin-Demers, 2007). Compared to the painted turtle (Chrysemys picta) population studied by Edwards and Blouin-Demers (2007) at the same latitude, musk turtles displayed very similar effectiveness of thermoregulation. Musk turtles had a mean effectiveness of thermoregulation value of 2.59°C and exploited the thermal environment 44.2% of the time, whereas values calculated for painted turtles were 2.4°C and 42%, respectively (Edwards and BlouinDemers, 2007). Musk turtles and painted turtles seem to use different basking strategies. Musk turtles are mostly found at the water surface ("aquatic basking") while painted turtles bask above water ("aerial basking") (Ernst et al., 1994). We did not record any "aerial basking" by musk turtles, whereas Edwards and Blouin-Demers (2007) observed painted turtles basking out of water more than twice as much as at the water surface. As such, our findings suggest that both basking strategies can be equally effective.

Habitat selection

As expected, musk turtles used habitats at the home range scale non-randomly: they had a strong preference for thermally superior habitats. Musk turtles strongly preferred shallow aquatic habitats with abundant floating or submerged aquatic vegetation, such as lily pads (Nymphaea odorata and Nuphar variegata), cattails (Typha sp.), and other macrophytes that serve as surface cover. These habitats were mostly found in small bays with shallow water and very slow current. Despite being the dominant habitat within the study area, deep water was clearly avoided during the active season. The fact that musk turtles clearly preferred shallow habitats with surface cover provides evidence that there is a strong link between thermal quality and habitat selection in musk turtles.

In thermally challenging conditions, the link between thermoregulation and habitat selection tends to be strong (Blouin-Demers and Weatherhead, 2002; Row and Blouin-Demers, 2006b, 2006c). Thermoregulatory requirement, however, is certainly not the only factor contributing to habitat selection. Other studies have shown that reptiles tend to select habitats based on other factors, such as foraging requirements (Compton et al., 2002) and predator avoidance (Downes, 2001; Webb and Withing, 2005). Musk turtles have been described as omnivorous generalists, searching for food at the bottom of the water by probing their head into the soft substrate (Mahmoud, 1968; Ernst, 1986) and feeding mostly on algae, leeches, various

mollusks, and insects (Ford and Moll, 2004). The shallow waters in the area, by virtue of their slow current, favour the accumulation of decaying organic matter and thus provide considerable foraging opportunities for musk turtles. Thus, the thermally superior habitats also provide good foraging opportunities. Because even the deep-water areas of the site are not very deep, however, good foraging opportunities are available throughout most of the study area. Thus, foraging alone could not explain habitat selection in musk turtles. As for predator avoidance, musk turtles are very cryptic and are rarely observed out in the open (Ernst, 1986). If we were to speculate on how predation risk varies as a function of habitat, we would guess predation risk to be lower in deep water as predators of adult musk turtles are mostly mammals (raccoons, minks) that are more common in shallow water along the shoreline. Thus, predator avoidance alone could not explain habitat selection patterns in musk turtles either.

Common Musk Turtles have a remarkably vast geographical range and can be found as far south as Florida and as far west as Wisconsin and Texas. We present the first in-depth quantitative study of the thermal ecology of the musk turtle, providing critical information on habitat selection at the home range scale. The present study underlines the importance of protecting natural shoreline habitats used by musk turtles. Natural shorelines possess more emergent and aquatic vegetation than developed shorelines (Radomski and Goeman, 2001), and these habitat configurations are crucial to musk turtles.

In summary, our results support the hypothesis that thermal quality of the environment is a strong driver of habitat selection in reptiles living in thermally challenging environments. Aquatic vegetation is an important structural component affecting habitat selection by musk turtles. Habitats with aquatic vegetation had the highest thermal quality. Selection of these habitats is consistent with the prediction that these thermally superior habitats provide optimal thermoregulation opportunities, especially when the water is cool. Similar quantitative studies looking at habitat selection in relation to thermal quality in the southern part of the range of the species would be needed to determine whether the relationship between habitat selection and thermal quality is less strong in thermally superior environments.

Acknowledgements. We are grateful to E. Ben-Ezra, M.-A. Gravel, V. Juneau, and C. Verly for their able help in the field. Funding for this study was provided by Parks Canada (special thanks to Jeff Leggo for his support of the project), the Natural Sciences and Engineering Research Council of Canada, and the University of Ottawa. Permits were issued by the Ontario Ministry of Natural Resources and our protocol (BL-221) was approved by the University of Ottawa Animal Care Committee.

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Received: April 28, 2010. Accepted: October 5, 2010.