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Long Distance Aquatic Movement and Home-Range Size of an Eastern Mud Turtle, *Kinosternon subrubrum*, Population in the Mid-Atlantic Region of the United States

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ABSTRACT. – **The aquatic movement patterns and home-range size of the Eastern Mud Turtle, *Kinosternon subrubrum*, have received little attention. We radio-tracked 5 adult females and 5 adult males during 2 yrs in the Mid-Atlantic region of the United States. Our mean estimates of home-range size (18.6 ± 23 ha in 2008 and 16.3 ± 16.3 ha in 2009) and maximum aquatic distance traveled (815 ± 455 m in 2008 and 774 ± 331 m in 2009) suggest that *K. subrubrum* is highly adept at movement in aquatic environments.**

Long-distance and sex-specific movement patterns by freshwater turtles are related to nesting, seasonal migration, avoidance of suboptimal habitat conditions, and mate searching by males (reviewed in Gibbons 1986). The only available estimate of home-range size for the highly vagile Eastern Mud Turtle (*Kinosternon subrubrum*) is 0.05 ha (Mahmoud 1969). However, some populations may require an area of up to 69.56 ha to complete key life cycle stages such as nesting and overwintering (Burke and Gibbons 1995). *Kinosternon subrubrum* generally migrates in spring (March through May) from overwintering sites in upland forests to aquatic habitats, where it may spend 6 to 9 mo (Gibbons 1970; Bennett 1972; Scott 1976; Harden et al. 2009). Nesting takes place during March through August (Iverson 1979; Burke et al. 1994; Buhlmann and Gibbons 2001), and females remain buried for up to 29 d near nesting sites at 90 m from the wetland's edge (Burke et al. 1994).

Observations of *K. subrubrum* in terrestrial environments are well documented (reviewed in Gibbons 1983). Nonetheless, aquatic behavior in this bottom-dwelling species has not been examined thoroughly in the field. Consequently, some investigators consider the aquatic movement and, in turn, home-range size of *K. subrubrum* to be restricted (Mahmoud 1969; Scott 1976). A similar assumption was made for the closely related and highly aquatic *Sternotherus odoratus* (Mahmoud 1969), which was unsupported by subsequent studies (Ernst 1986; Edmonds 1998; Smar and Chambers 2005; Rowe et al. 2009). With the exception of the work of Rowe et al. (2009), these studies detected sex-specific movement patterns in which males traveled greater distances and had larger home ranges than did females. To assess sex-specific and aquatic movement patterns, we radio-tracked *K. subrubrum* in the Mid-Atlantic region of the United States, where published data on many aspects of its biology are not available and some populations are of conservation concern (Larese-Casanova 1999; Hulse et al. 2001).

Methods. — This study was conducted at the Jug Bay Wetlands Sanctuary (JBWS) (lat 38°47′N, long 76°42′W) in Lothian, Maryland. The site encompasses the Patuxent River and a large (~ 90 ha) freshwater tidal wetland. The main river channel has a maximum depth of 3–4 m, and is normally 100–120 m wide. Wetland vegetation beds are 10–1600 m wide. Adjacent terrestrial environments consist of upland mixed eastern deciduous forests, where we hand captured turtles as they headed to the wetlands from their overwintering sites in April 2008. Turtles were sexed and weighed, and their carapace length (CL) was measured. Transmitters (Holohil Systems, Ltd) were affixed to the left posterior carapace of 5 adult females and 5 adult males. Transmitters (mean: 4.1 g) did not exceed 6% of body mass (mean: 154.7 g; range 82.2–291.1 g). Turtles were held in the lab for 16–24 hrs before being released at their exact capture locations and tracked during 2 consecutive field seasons (April through November in 2008 and 2009) using a radio receiver (Advanced Telemetry Systems, Inc). Mean tracking interval during the aquatic activity season (April through August) was 5.3 ± 6.1 d in 2008 and 4.4 ± 5.4 d in 2009.

Table 1. Home-range size and distance-traveled estimates in 2008 and 2009 by *Kinosternon subrubrum* at Jug Bay Wetlands Sanctuary. Mean maximum convex polygon home range (MCP HR), mean maximum distance traveled (max. dist.), maximum aquatic distance traveled (max. aquatic dist.), maximum terrestrial distance traveled (max. terrestrial dist.), and distance traveled to overwintering sites (OW site dist.) are followed by ± 1 SD.

Year	MCP HR (ha)	Max. dist. (m)	Max. aquatic dist. (m)	Max. terrestrial dist. (m)	OW site dist. (m)[a]
Females					
2008	8.3 (4.9)	553 (205)	485 (195)	68 (35)	133 (75)
2009	12.2 (7.7)	766 (327)	634 (274)	133 (75)	109 (61)
Males					
2008	28.9 (30.1)	1221 (402)	1145 (395)	76 (45)	123 (76)
2009	23.1 (26.5)	1131 (286)	1008 (318)	123 (76)	96 (29)
All Turtles					
2008	18.6 (23)	887 (463)	815 (455)	72 (38)	129 (70)
2009	16.3 (16.3)	903 (346)	774 (331)	129 (70)	103 (47)

[a] Distance to the nearest wetland's edge.

Observations for each turtle in 2008 (mean: 19; range: 9–30) and 2009 (mean: 12; range: 8–17) were recorded using a global positioning system (GPS) unit (± 5–10 m) and projected onto maps in ArcGIS 9.3 (ESRI, Inc). We monitored the turtles periodically (7–21 d) during the overwintering period (September through March) and replaced their transmitters during March and April 2009.

We estimated the minimum convex polygon (MCP) home-range size for 2 discrete (2008 and 2009) activity seasons in program Biotas 1.03 (Ecological Software Solutions, LLC). The home range was defined as the area that included all observations during the aquatic activity period, including locations during the annual migration from overwintering sites to the wetlands. The maximum straight-line distance traveled was recorded beginning with the locations of the initial capture (2008) or overwintering sites (2009) and ending with the farthest point traveled during the year. Distances of points of initial capture or overwintering sites from the nearest wetland's edge (maximum terrestrial distance traveled) were subtracted from the overall maximum distance traveled to estimate the maximum aquatic distance traveled. The Wilcoxon signed-rank test was used to assess significance in the means of 2008 and 2009 estimates. Significance in the innerannual means of male and female estimates was assessed using the Mann–Whitney test. In addition, univariate regression on $\log_{10}$-transformed data was employed to test whether maximum distance traveled, size (CL), body mass, and sampling effort had an effect on home-range size. Statistical analyses were conducted in JMP 8 (SAS, Inc).

Results. — Means did not differ significantly between years for home-range size (W = 12, $p = 0.10$), maximum distance traveled (W = 8, $p = 0.31$), or maximum aquatic distance traveled (W = 6, $p = 0.46$). The mean for maximum terrestrial distance traveled differed significantly between 2008 and 2009 (W = 16, $p < 0.05$). Maximum distance traveled, maximum aquatic distance traveled, and home-range size of males exceeded that of females; overall, maximum aquatic distance traveled exceeded terrestrial distance traveled (Table 1). Mean maximum distance traveled by females versus males was significant in 2008 (U = 40, $p < 0.05$) but not in 2009 (U = 19, $p = 0.13$). Mean maximum aquatic distance traveled by females versus males was significantly different in 2008 (U = 40, $p < 0.05$) but not in 2009 (U = 19, $p = 0.13$). The greatest distance traveled by a turtle was 1733 m in 2008. Mean home-range size of females was not significantly different from males (U = 33, $p = 0.29$ in 2008; U = 14, $p = 0.99$ in 2009).

Sampling effort, size, and body mass did not have an effect on home-range size (all p-values > 0.05). Maximum distance traveled explained a moderate proportion of variation in home-range size, but the relationship was not significant ($R^2 = 0.36$, $F_{1,8} = 4.4$, $p = 0.06$ in 2008; $R^2 = 0.47$, $F_{1,6} = 5.3$, $p = 0.06$ in 2009). All female home ranges were restricted to the east side of the Patuxent River (Fig. 1), where 2 nested during 2–26 June of both years. Four of 5 males had home ranges that were mostly on the west side of the river (Fig. 1). Aquatic movement from the interior of the wetland and to the wetland–forest interface began in late August, and terrestrial movement toward overwintering sites began in September for most turtles. Mean overwintering site distance from the nearest wetland's edge in 2008–2009 did not differ significantly (W = 8, $p = 0.20$) to that of the 2009–2010 overwintering period. The difference in the mean maximum terrestrial distance traveled by females versus males was not significant in 2008 (U = 28, $p = 0.99$) and 2009 (U = 14, $p = 0.99$).

Discussion. — Long distance movements by *K. subrubrum* at JBWS were generally a combination of seasonal migration from the uplands to the wetlands and aquatic movement within home ranges. Adult females and adult males displayed movement patterns that were consistent with sex-specific life-history strategies in turtles (i.e., Morreale et al. 1984). Males did not leave aquatic habitats during the activity season and, thus, traveled longer distances away from overwintering sites and into the wetland's interior, whereas females remained within

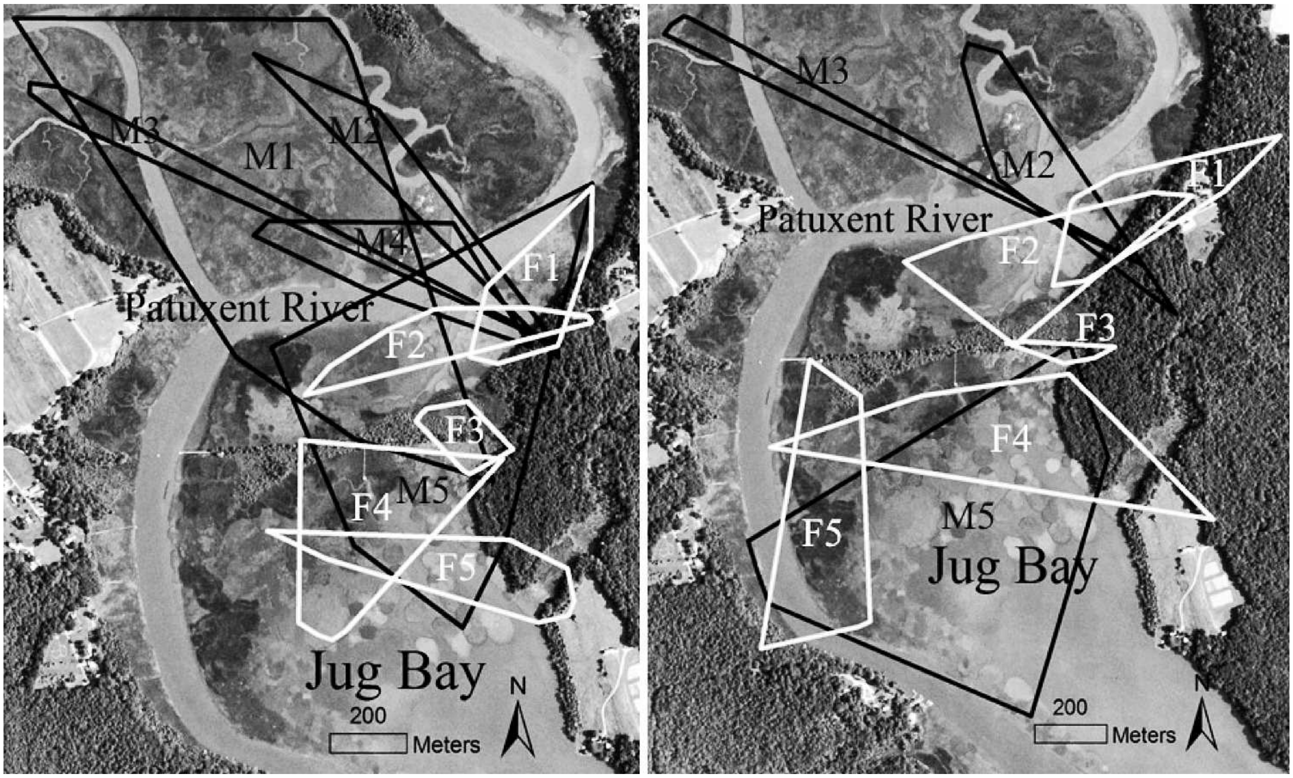

Figure 1. Left: 2008 minimum convex polygon home ranges for 10 *Kinosternon subrubrum* (5 males; 5 females) in the Jug Bay Wetlands Sanctuary (n = 10). Right: 2009 home ranges (n = 8); male home ranges for 3 males and 5 males. Males are represented by dark-colored polygons and females by light-colored polygons labeled by individual.

relatively close distances to nesting habitats on the east side of the Patuxent River. All observed mud turtles at JBWS overwintered terrestrially, as they did in Georgia (Steen et al. 2007), South Carolina (Bennett 1972; Burke and Gibbons 1995), and North Carolina (Harden et al. 2009). However, aquatic overwintering has been observed occasionally in some southern populations (Mahmoud 1969; Scott 1976; Buhlmann and Gibbons 2001). It is unclear what factors influence this choice (see Ultsch 2006).

The greatest distance traveled by *K. subrubrum* at JBWS was over 1.7 km, compared to a maximum of 600 m in South Carolina (Bennett et al. 1970) and 900 m in New York (Larese-Casanova 1999). Our estimates of maximum distance traveled are comparable to data reported for other kinosternid species, where most observations were in terrestrial environments (reviewed in Cordero and Swarth 2010). Our data suggest that *K. subrubrum* is adapted for movement in the aquatic environment. This was somewhat unexpected based on conclusions from laboratory (Davenport et al. 1984) and field studies (Mahmoud 1969; Scott 1976). This species was described as a poor swimmer that prefers walking short distances in muddy aquatic substrates. Although *K. subrubrum* may travel long distances in terrestrial environments as an adaptive response to droughts (Bennett et al. 1970; Gibbons et al. 1983), such behavior may not be physiologically optimal relative to long-distance travel in aquatic environments. Aquatic movement, and therefore home-range size in the bottom-dwelling *K. subrubrum*, is not constrained within JBWS. This is consistent with the expectation that home-range size is proportional to habitat dimensions because the latter may limit movement in turtles (Rowe et al. 2009). We provide limited support for this assumption because of our small sample size. Nevertheless, our findings represent a baseline for future research on the aquatic habitat ecology of *K. subrubrum*.

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