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HOME RANGE AND HABITAT SELECTION OF BOG TURTLES IN SOUTHWESTERN VIRGINIA

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Abstract: Bog turtle (*Clemmys muhlenbergii*) populations are believed to be declining, in part, because of habitat loss. However, a detailed understanding of the specific habitat requirements for bog turtles is lacking. We used radiotelemetry on adult bog turtles to examine home range size (M: $n = 13$; F: $n = 12$) and habitat selection (M: $n = 12$; F: $n = 17$) at 3 sites in southwestern Virginia from May 1995 to December 1996. Home range size did not differ between males and females, as calculated via minimum convex polygon (MCP) analysis ($P = 0.785$) or cluster analysis ($P = 0.722$) during the 20-month study period. Habitat selection also did not differ by sex ($P = 0.441$). Mean 95% home range area pooled across sexes was 0.52 ha via MCP analysis and 0.15 ha via cluster analysis. We located bog turtles in areas closer to patches of shallow water, in deeper mud (21 cm) and water (9 cm), and in taller (55 cm), denser vegetation than expected if selection was random. Bog turtles selected wet meadow, smooth alder (*Alnus serrulata*) edge, and bulrush (*Scirpus* spp.) vegetation types more than expected randomly, and avoided dry meadow vegetation and streams. This species selects multiple microhabitats within wetlands and is restricted to small home ranges. Future bog turtle habitat conservation in southwestern Virginia should identify occupied wetlands containing the habitat components we describe, quantify management practices aimed at slowing succession and habitat loss, and reduce threats that may affect wetland hydrology.

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The northern population of bog turtles was recently listed as threatened by the U.S. Fish and Wildlife Service (Federal Register 1997) because of threats posed by habitat loss and collection by the pet trade. In Virginia, wetland habitats are being lost by drainage for development and agriculture (Mitchell et al. 1991). Wetlands used by bog turtles also are typically ephemeral because plant succession can rapidly lead toward drier habitats (Ernst et al. 1994).

Bog turtles are known to occur in freshwater wetlands characterized by spring-fed wet meadows and seepages (Bury 1979, Mitchell 1994), but few data exist on microhabitat requirements and corresponding home range size. Wetlands occupied by bog turtles are generally <2 ha (Lee and Norden 1996) and are distributed in Virginia as a patchy network within the floodplains of small streams (Buhlmann et al. 1997). Bog turtles are closely associated with spring-

fed pockets of shallow water and bottom substrate of soft mud and rock (Chase et al. 1989). However, the selection by bog turtles for particular microhabitats remains unknown.

Biological requirements for microhabitats within wetlands should be reflected by home range size, which should be restricted if bog turtles are confined to these small wetlands. Home range sizes reported previously for bog turtles were 0.176 ha for males and 0.066 ha for females in Maryland, based on harmonic mean analysis (Chase et al. 1989), and 1.33 ha for males and 1.26 ha for females in Pennsylvania, based on the MCP technique (Ernst 1977). Discrepancies in home range size for these 2 regions are probably the result of different estimation techniques but may also reflect geographic differences in habitat characteristics.

While management options addressing the pet trade seem clear, recovery options leading to long-term population viability are unclear until bog turtle habitat needs are understood. This study used radiotelemetry to describe home range size and what floristic and structural fea-

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tures influenced habitat selection by adult bog turtles in southwestern Virginia.

STUDY AREA

We selected 3 study sites in Floyd County, Virginia, known to contain bog turtles. Exact locations and descriptions are not provided because of the endangered status of this species in Virginia (Mitchell et al. 1991) and its recent federal listing (Federal Register 1997). Two sites were grazed wet meadows with spring seepages and rivulets, and the third site was an abandoned beaver (*Castor canadensis*) pond. All 3 sites were separated from each other by mixed deciduous forest and agricultural land. Each site contained flora typically associated with bog turtles (Ernst et al. 1994): sedges (*Carex* spp., *Cyperus* spp., *Eleocharis* spp., bulrush), rushes (*Juncus* spp.), peat moss (*Sphagnum* spp.), and smooth alder.

METHODS

Radiotelemetry

Bog turtles were collected under Virginia Department of Game and Inland Fisheries permits ESP 9404, 9504, and 9610, and National Park Service activity permits to JCM. We captured turtles by visually searching and probing the soil at each site and attached radios to 7 males and 8 females in 1995, and 9 males and 15 females in 1996. We radiotracked 10 turtles (4 M, 6 F) for both years, yielding a total of 29 adults over the study period. We used single-stage radio-transmitters with 90–165 days of life (AVM Instruments, Livermore, California, USA, and L. L. Electronics, Mahomet, Illinois, USA) attached to the right or left fifth plural scute with the antenna extending caudally. Postattachment transmitter mass was 6–7 g and within recommended guidelines (7% of body mass) for turtles (Schubauer 1981, Eckler et al. 1990). We located radiomarked bog turtles via a hand-held receiver (AR 8000; AOR, Tokyo, Japan) and 2-element, flexible directional antenna (Rubber Ducky; Telonics, Mesa, Arizona, USA).

Home Range Area

We recorded bog turtle locations as a bearing (nearest degree) and distance (nearest m) from permanent reference points. We calculated the X–Y coordinates for location data based on the bearing (converted to radians) and distance from reference points (White and Garrott 1990). The average time between radio loca-

tions (\pm SE) was 5 days for both years (1995: 5 ± 0.4 days, range = 1–60 days; 1996: 5 ± 0.2 days, range = 1–70 days). Our minimum sampling interval was 1 day, which was a sufficient amount of time for a bog turtle to travel the diameter of an average home range (Carter 1997). Therefore, we considered these observations independent (White and Garrott 1990).

We used incremental area analysis (IAA) to determine the minimum number of locations required for stable home range estimates (Kenward and Hodder 1996). For comparative purposes, we calculated 95% home range size for each bog turtle by using both the MCP and cluster techniques with RANGES V (Kenward and Hodder 1996). We used 2 analyses to provide a range of home range size because MCP may have a bias toward overestimation by incorporating unused areas of habitat, and cluster analysis may underestimate home range size if the number of locations is relatively small (Kenward 1987). We used the harmonic mean of all radio locations to estimate the group center for both techniques.

We compared differences in home range size between years and number of cluster nuclei (cluster technique) via a Mann-Whitney *U*-test (*U*). We also tested for location shifts in home range for bog turtles radiotracked for both years by using multiresponse permutation procedures (MRPP; default values) in program BLOSSOM (W. L. Slauson et al. 1991. User manual for BLOSSOM statistical software, unpublished. National Ecological Research Center, U.S. Fish and Wildlife Service, Fort Collins, Colorado, USA). We tested for differences between the 2 home range techniques via a Wilcoxon signed rank test (*WS*). We predicted median MCP estimates would exceed cluster analysis estimates because of biases described earlier. We tested site-specific differences in home range size with a Kruskal-Wallis test (*H*).

Habitat Use and Selection

We assessed habitat use by measuring these floristic and structural elements: habitat category, height, and canopy density; mud and water depth; and absence or presence and distance to water. We used an approximately 3-m-diameter circle to define 7 habitat categories: alder, bulrush, stream, dry meadow, wet meadow, alder edge, and bulrush edge. We classified the habitat as alder or bulrush if the circular plot

contained a canopy area $\geq 67\%$ for either habitat category. We substituted the surface area of water for vegetation canopy area when water was present in the habitat sample (stream). We classified wet meadow habitat as containing a heterogeneous assemblage of wetland-associated plants (e.g., bulrush, *Carex* spp.) in which no particular genus constituted 67% or more of the plot. Alternatively, if the plot contained a mixed assemblage of meadow and old-field associates (e.g., bluestem [*Andropogon* spp.], goldenrod [*Solidago* spp.]), we assigned it to the dry meadow category. We recorded 2 edge categories (alder edge, bulrush edge) when a plot fell within the transition zone between 2 habitats. Although many potential edge categories existed, we considered only alder edge and bulrush edge because other edge categories seldom occurred ($< 1\%$ of habitat sample).

We measured maximum vegetation height (1995 only) with a graduated measuring pole (nearest cm), and canopy density with a light intensity meter at ground level (Lux meter; Extech Instruments, Boston, Massachusetts, USA). A large light intensity value at ground level resulted when canopy coverage was relatively low (Pleszczynska 1978). We measured mud and water depths with a 6-mm-diameter dowel. Water depth (nearest cm) was defined as the distance from the surface to the transition zone of the water–mud interface. We measured soft substrate depth by pushing the dowel vertically into the substrate until it met with complete resistance and could be pushed no further. We measured mud and water depths at the sighted bog turtle's location and the 4 cardinal directions approximately 0.25 m and 0.75 m away.

We examined the relation between bog turtles and pockets of surface water by measuring the presence or absence of water contained within habitat plots and the distance (nearest 0.5 m) we sighted bog turtles from water. Bog turtles use pockets of surface water for escape (Holub and Bloomer 1977) and thermoregulation (Ernst 1977); hence, we only measured water larger in area than the average body size of an adult bog turtle (9×4 cm). Additionally, we examined the association between habitat drying and bog turtle movements by recording the presence or absence of surface water (1996 only) within a 1.5-m radius of a turtle's previous location. By ascertaining if water was still available at a bog turtle's previous location, we could

determine if movements out of an area were associated with habitat drying.

We measured the availability of habitat categories via line transects (Aug–Sep 1996) and defined available habitats at each site by the outermost radio locations of all bog turtles within each site, plus a 10-m buffer zone. We added 10 m to each transect to include all possible habitat types in our samples. We recorded vegetation categories at 5-m intervals along each transect, using the circular plot protocol described above. We ran transects parallel at 5-m intervals until the far perimeter of the study area was reached. We assumed habitat availability to be site-specific and analyzed each site separately. We estimated site area by multiplying the total number of habitat plots by plot size (25 m^2). This calculation yielded 2,370 circular plots, resulting in estimated study site areas of 33.2, 18.7, and 7.4 ha.

We determined availability of the additional structural habitat elements by using paired samples at a random direction ($0\text{--}360^\circ$) and distance ($0\text{--}50$ m) from sighted bog turtle locations. We chose a maximum distance of 50 m because it approximated the average radius of a bog turtle home range.

To assess habitat selection, we compared the vegetation categories used by bog turtles to the proportions available within each study site. We used compositional analysis to provide a relative ranking of selected, neutral, and avoided vegetation categories (Aebischer and Robertson 1992, Aebischer et al. 1993).

We used a Wilcoxon signed rank test to compare mud and water depths, vegetation heights, canopy density measurements, and distances to water. We compared mud and water depths within each plot via a Mann-Whitney *U*-test. We tested movements by bog turtles out of areas no longer containing water into areas containing water by using the McNemar test (W_p ; Conover 1980). We considered only movements greater than the average net distance moved by bog turtles in 1996 for this analysis because only large-scale movements were expected to be the result of water-finding behavior.

RESULTS

Home Range Area

Home range areas stabilized after an average of 17 locations; hence, we used 17 locations as our minimum sample size required to estimate

Table 1. Median number of locations per bog turtle and home range areas (ha) of male ($n = 13$) and female ($n = 12$) bog turtles in southwestern Virginia (1995–96), estimated via cluster (CL) and minimum convex polygon (MCP) analyses. The MCP estimates (95%) were significantly larger than CL estimates (95%), but both estimates did not differ between years or between sexes. Combined averages (SE) are provided at the bottom of the table for comparison.

	Number of locations		95% CL		Number of clusters		95% MCP	
	Median	Range	Median	Range	Median	Range	Median	Range
Males	25	17–48	0.06	0.01–0.55	2	1–3	0.34	0.02–2.26
Females	25	18–45	0.11	0.04–1.09	2	1–4	0.35	0.09–1.09
Combined \bar{x}	34 (3.3)		0.15 (0.033)		2 (0.2)		0.52 (0.105)	

home range area. We constructed home range estimates for 12 females ($\bar{x} = 25$ obs/turtle) and 13 males ($\bar{x} = 25$ obs/turtle) via MCP and cluster analyses (Table 1).

Median 95% home range size for females ($n = 12$) was 0.11 ha (range = 0.04–1.09) based on cluster analysis, and 0.35 ha (range = 0.09–1.09) based on MCP analysis. Median 95% home range size for males ($n = 13$) was 0.06 ha (range = 0.01–0.55) when we used cluster analysis and 0.34 ha (range = 0.02–2.26) when we used MCP analysis (Table 1). Home range sizes for males and females did not differ (cluster: $U = 192.5$, $P = 0.722$; MCP: $U = 194.5$, $P = 0.785$). Based on cluster analysis, 95% home range estimates were smaller for both males and females (M: $WS = 0.0$, $P = 0.003$; F: $WS = 0.0$, $P = 0.001$) than estimates calculated via the MCP method. Number of clusters contained within a home range did not differ ($U = 184.5$, $P = 0.489$) between males (median = 2) and females (median = 2). Sex did not influence home range size, and we pooled males and females to assess site-specific differences. Home range area did not differ among the 3 study sites ($H = 1.39$, $P = 0.498$).

We examined differences in home range size and location in 5 females tracked in both years. Median home range area did not differ between years (1995: median cluster = 0.11 ha, median

MCP = 0.37 ha; 1996: median cluster = 0.08 ha, median MCP = 0.41) for these females (cluster: $WS = 7.0$, $P = 0.584$; MCP: $WS = 6.0$, $P = 0.787$). However, individual bog turtles did shift locations between years, so home range location differed for all 5 bog turtles (MRPP: maximum delta $[\Delta] = -3.65$; maximum $P = 0.008$).

Habitat Use and Selection

We assessed habitat selection for 29 adult bog turtles (12 M, 17 F; Table 2). We calculated log ratios of habitat use and habitat availability by using the bulrush edge habitat category as a denominator and weighted these differences by \sqrt{n} for each bog turtle to account for unequal sample sizes (Aebischer et al. 1993). Multivariate analysis of variance showed nonrandom habitat selection by both males and females (Wilk's lambda $[\lambda]$; M: $\lambda = 0.15$, exact $F = 5.67$, $P = 0.030$; F: $\lambda = 0.17$, exact $F = 7.65$, $P = 0.003$), but showed no difference with respect to sex ($\lambda = 0.78$, exact $F = 1.02$, $P = 0.441$); hence, we pooled the sexes for subsequent analysis. The overall ranking of habitat categories was wet meadow > bulrush = alder edge > alder > bulrush edge > dry meadow > stream (Table 3). No single habitat type was preferred or avoided significantly from the next most preferred or avoided habitat category.

Table 2. Mean number of radio locations and percentage of habitat samples for bog turtles in southwestern Virginia (1995–96), and bog turtle habitat use (percentage of radio locations) and site availability (percentage of habitat samples within each category) of 7 habitats.

	Number of locations		Percentage of habitat						
	\bar{x}	SE	Dry meadow	Wet meadow	Alder	Bulrush	Stream	Alder edge	Bulrush edge
Use ($n = 29$)	22	2.4	11	29	23	26	1	9	1
Availability ($n = 3$)	790	299.0	58	10	21	5	4	1	1

Table 3. Results of compositional analysis for bog turtles in southwestern Virginia (1995–96). The matrix resulting from pairwise log-ratio differences for 7 habitat categories is shown. Rank is calculated by tallying significant positive and negative differences. Final rankings indicate relatively preferred (6) to avoided (0) habitat categories.

	Dry meadow	Wet meadow	Alder	Bulrush	Stream	Alder edge	Bulrush edge	Rank
Dry meadow		-5.78*	-1.94	-3.54*	1.10	-3.31*	-1.43	1.0
Wet meadow	5.78* ^a		2.51*	0.66	9.60*	1.44	5.48*	6.0
Alder	1.94	-2.51*		-1.70	4.19*	-1.27	1.00	3.0
Bulrush	3.54*	-0.66	1.70		6.57*	0.78	3.80*	4.5
Stream	-1.10	-9.60*	-4.19*	-6.57*		-5.43*	-4.71*	0.0
Alder edge	3.31*	-1.44	1.27	-0.78	5.43*		2.63*	4.5
Bulrush edge	1.43	-5.48*	-1.00	-3.80*	4.71*	-2.63*		2.0

^a Significance (*) is based upon a 2-sided *t*-distribution ($\alpha = 0.05$).

We measured water depth for 26 bog turtles (1995: \bar{x} = 6 obs/turtle). An average value for each bog turtle was calculated and used in the comparison. Median water depth was deeper ($WS = 293.0, P < 0.001$) at bog turtle locations (median = 9.4 cm, range = 0–30) than at random locations (median = 0.0 cm, range = 0–10). Median water and mud depths (1996: \bar{x} = 14 obs/turtle, $n = 40$) were greater for all bog turtle-centered plots (Table 4). Within each plot type, water depth was deeper at bog turtle-centered locations than at both 0.25-m ($WS = 648.5, P < 0.001$) and 0.75-m locations ($WS = 713.5, P < 0.001$), while mud depth was not.

Median vegetation height (1995: \bar{x} = 6 obs/turtle, $n = 23$) was taller at bog turtle locations (median = 55 cm, range = 20–107) than at random locations (median = 25 cm, range = 2–106; $WS = 230, P = 0.005$). Median light intensity (1995: \bar{x} = 6 obs/turtle, $n = 24$) was lower at bog turtle locations (median = 7,650 lux, range = 1,700–44,000) than at random locations

(median = 11,100 lux, range = 900–102,100; $WS = 75.0, P = 0.033$), indicating a denser canopy at turtle locations.

Bog turtles (1995: \bar{x} = 5 obs/turtle, $n = 24$) selected areas closer to water (median = 0.1 m, range = 0–7; $WS = 0.0, P < 0.001$) than what was randomly available (median = 10 m, range = 0.5–40). Presence or absence of water at previous bog turtle locations was not a good predictor of large-scale movements (1996: \bar{x} = 6 obs/turtle, $n = 24$; $W_p = 1.78, P = 0.750$). Habitat drying did not appear to influence the magnitude of net movements. Bog turtles moved out of areas containing water as frequently as they moved out of areas devoid of water.

DISCUSSION

Calculated home range sizes for adult bog turtles in southwestern Virginia are smaller than estimates reported for Pennsylvania populations (Ernst 1977), but generally agree with estimates of home range size in Maryland populations (Chase et al. 1989). Gibbons (1990) noted that the limited information on home ranges in freshwater turtles is conflicting, and differences between male and female home range size may be species specific. Our data do not confirm any tendency for males to have larger home ranges than females, although a bias toward larger male home ranges has been reported for males in other studies of bog turtles (Ernst 1977, Chase et al. 1989). A similar study of longer duration might better address these inconsistencies by examining sex-based differences in home range size for multiple age classes.

The average home range size for bog turtles remained similar for both sexes and among bog

Table 4. Median mud and water depths (cm) taken at bog turtle-centered and paired random locations during 1995 ($n = 26$) and 1996 ($n = 40$). Results of Wilcoxon signed rank tests were significant for all comparisons between bog turtle-centered and random-centered plots. Within bog turtle-centered plots (1996), water was deeper at the bog turtle's location than at both measurement locations ($P < 0.05$).

	Measurement location		
	Center	0.25-m distance	0.75-m distance
Turtle-centered plots			
Water (1995)	9.4		
Water (1996)	3.7	2.0	1.7
Mud (1996)	21.6	25.0	23.5
Random plots			
Water (1995)	0.0		
Water (1996)	0.2	0.2	0.2
Mud (1996)	8.1	9.8	9.6

turtles at different sites, even though the 3 study sites differed in area by >400%. Also, none of the bog turtles radiotracked over both sampling years showed significant changes in home range size, although all shifted the location of their home range. These findings suggest the home range requirements for this species, at least in southwestern Virginia, may be relatively constant despite annual wetland variation. However, if bog turtles are closely tied to wetlands containing deep mud and pockets of surface water, year-to-year variation in the habitat structure of these wetlands may account for the shifts in home range location we observed. Bog turtles would be expected to shift their regular movements according to the distribution of particular microhabitats in these wetlands.

All of the structural microhabitat features we examined are apparently important to bog turtles, as shown by greater than expected use. Adult bog turtles of both sexes selected areas closer to water, and those areas containing significantly deeper mud and water than was available randomly. The average distance we found bog turtles from water was 1 m and seldom exceeded 7 m. Also, water depth at bog turtle-centered locations was significantly deeper than that at either 0.25-m and 0.75-m distances, which suggests bog turtles select areas of a given water depth within a very small scale. Bog turtles selected areas of habitat with taller vegetation and greater canopy density, which may reflect preference for dense cover or may be an artifact of selection for wetter areas.

Such a close association of bog turtles with mud and shallow water suggests they use this soft substrate to meet specific biological requirements (e.g., predator avoidance or thermoregulation), which may be more a size-related trait than a trait associated with a particular species or group. Juvenile Blanding's turtles (*Emydoidea blandingii*) of similar size (50–100 mm in carapace length) also selected habitat with shallow, standing water and a deep, organic muck substrate with sedge and alder hummocks versus open water habitats (Pappas and Brecke 1992).

Although bog turtles were closely associated with pockets of shallow water, the absence of water at previous locations did not cause larger than average movements, which suggests habitat drying may not be a primary factor in de-

termining movement out of particular areas. This result contrasts with responses reported for other turtles in drying wetlands. For example, freshwater turtles inhabiting Carolina bays migrate to other aquatic habitats when these wetlands dry during severe droughts (Gibbons et al. 1983), and turtles in drained lakes and ponds emigrate quickly (Cagle 1944, Lindeman and Rabe 1990). The different response in bog turtles may be a matter of scale. We examined only larger than average movements out of relatively small, drying habitats; however, we did not address large-scale wetland drought as a reason for bog turtles leaving previously occupied locations.

Bulrush, wet meadow, and alder edge areas usually were selected by bog turtles, whereas streams and dry meadow habitats usually were avoided. Results of this preference assessment are dependent upon the particular habitat categories we defined, and we chose habitats that could be identified easily and deemed biologically meaningful based on experience and information from the literature. Sedges, rushes, and alders are frequently associated with wetlands containing bog turtles (Tryon and Herman 1990, Ernst et al. 1994), and streams may provide travel corridors that facilitate movement between patches of favorable habitat (Buhlmann et al. 1997).

Transition zones between habitats should be selected over individual habitats if bog turtles require several habitat types to meet their specific biological requirements. We observed no universal trend in habitat selection, which suggests bog turtles respond more to structural habitat components (for example, mud and water) than floristic components. Detailed measurements of site hydrology and soil type may better characterize the habitat features important to bog turtles.

MANAGEMENT IMPLICATIONS

Our conclusions are limited by the exclusive study of adult bog turtles and the short duration of this study relative to the lifespan of bog turtles. However, our data may help define a habitat conservation strategy for bog turtles in southwestern Virginia. Soft, deep substrate and persistent shallow water were the most important factors that determined where bog turtles were found, and tall wetland vegetation with a dense canopy was selected. Small home range size and a dependence on soft substrate and

persistent water within wetlands may make bog turtles particularly susceptible to habitat drying and loss.

A conservation strategy that reduces threats to suitable habitat should first identify wetlands occupied by bog turtles and containing patches of shallow water (9 cm), deep mud (21 cm), and tall (55 cm), dense vegetation. Threats in loss of such habitat should be avoided (i.e., wetland draining, succession). Mowing, burning, grazing, and the promotion of beaver activity have been proposed by managers as tools to slow succession and maintain wetland habitats for bog turtles. However, little evidence has been provided that demonstrates the effectiveness of management practices that halt or reverse these threats. An important next step toward bog turtle habitat conservation must be manipulative studies that quantify how proposed management practices influence the important microhabitat variables we describe and the subsequent effects on bog turtle populations.

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