

Movements and Activity of Bog Turtles (*Clemmys muhlenbergii*) in Southwestern Virginia

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ABSTRACT.—We radio-tracked 35 adult bog turtles (*Clemmys muhlenbergii*) at four study sites in southwestern Virginia (May 1995 to December 1996) to assess the scale and frequency of movement within and between wetlands and to identify the potential for population isolation. Net movements between subsequent locations recorded during 1995 (N = 18) and 1996 (N = 27) averaged 17 m and 18 m for females and 16 m and 23 m for males, respectively, and did not differ with respect to sex for either year. Net distances underestimated true bog turtle activity (measured by threadspooling) by a factor of 6.5. The length of time between net distance measurements (1–9 d) did not influence the resulting distance measured, suggesting that relatively short time intervals may not need to be considered when calculating activity estimates. Seventy-five percent of all net movements were <20 m, whereas only 2% were >100 m. Large-scale movements between wetlands were observed infrequently. Information regarding distance, timing, and proximate cues for movement is essential to further understanding of the behavior and ecology of turtles. Dispersal, although poorly studied, has profound implications for social behavior, genetic structure, and persistence of populations. If successful dispersal is limited to infrequent, large-scale movements, future wetland loss may serve to isolate some populations of bog turtles. Further study of the importance long-distance movements play in maintaining populations is needed to aid future conservation strategies in southwestern Virginia.

Bog turtles, *Clemmys muhlenbergii*, occupy freshwater wetlands characterized by spring-fed wet meadows and seepages (Ernst et al., 1994; Mitchell, 1994). In southwestern Virginia these wetlands are distributed as small (<2 ha) areas of habitat often connected by streams (Buhlmann et al., 1997). Multiple wetlands are commonly contained within the same stream drainage, yet little attention has been given to the movements within and among wetland habitats by bog turtles. The ability of semiaquatic turtles to move between aquatic and terrestrial habitats may influence population structuring (Scribner et al., 1984, 1995) and effective metapopulation size. An understanding of patterns of movement is necessary to describe distribution and abundance, gene flow, and behavioral interactions among individuals (Johnson and Gaines, 1990), yet in many taxa dispersal is the least studied demographic process, with little information available concerning daily movement patterns, much less large-scale dispersal events (Zeng and Brown, 1987; Clobert and Lebreton, 1991; Xiao, 1996; Haas, 1998).

Wetland habitat loss at bog turtle sites has been documented (Holub and Bloomer, 1977; Ernst et al., 1994; Mitchell, 1994) and implicated

in population declines and local extinctions (Nemuras, 1976; Collins, 1990). Loss of small wetlands may further reduce the probability of successful dispersal by turtles and increase the risk of local population extinction (Gibbs, 1993). In Virginia, wetland habitats are being lost by draining for development and agriculture (Mitchell et al., 1991). Also, these wetlands are typically ephemeral because plant succession can rapidly lead toward drier habitats (Ernst et al., 1994).

The magnitude and frequency of bog turtle movements can have significant influence on dispersal, and ultimately population persistence. We used radiotelemetry to investigate bog turtle movement within and among isolated, partially ephemeral wetlands in southwestern Virginia. We also examine factors that may influence bog turtle movements; these are sex, habitat area, and precipitation.

MATERIALS AND METHODS

Study Area.—We selected four study sites in Floyd County, Virginia, known to contain bog turtles. Exact locations and site descriptions are not provided because of the endangered status of this species in Virginia (Mitchell et al., 1991) and its recent federal listing (US Fish and Wildlife Service, 1997). Three of the sites are grazed, wet meadows and the fourth is an abandoned

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beaver (*Castor canadensis*) pond. Data from one wet meadow site are only included for the 1996 period because it was not known to contain bog turtles until June of that year. Each site contains several spring-fed seepages and flora typically associated with bog turtles (Ernst et al., 1994): sedges (*Carex* spp., *Cyperus* spp., *Eleocharis* spp., *Scirpus* spp.); rushes (*Juncus* spp.); peat moss (*Sphagnum* spp.); and smooth alder (*Alnus serulata*). Detailed floral descriptions of these sites are available (Carter et al., 1999).

We selected the four sites to examine movements within and among wetlands because they were separated by relatively small distances and contained similar habitats. Each site was separated by deciduous forest and grazed agricultural lands. The average distance between each study site was 0.5 km (range = 0.4–0.6 km), although such close proximity between sites is rare in southwestern Virginia. The average distance from each study site to the nearest occupied wetland that was not a study site was 1.15 km (range = 0.5–1.6 km). We defined total site area by the outer perimeter of radio locations for bog turtles within each site. Site areas measured 33 ha, 19 ha, and 0.5 ha.

Net Movement Distances.—We captured bog turtles by visually searching and probing within occupied habitats. We marked every bog turtle we handled by shell-notching (Carter, 1997) and recorded locations of all subsequent captures of marked bog turtles. Recapture rate of marked, non-radioed bog turtles was low and sporadic and we do not include distances moved between recapture events in our analyses. However, we documented long-distance movements not detectable with radios and we report these extreme movements.

We attached radios to eight males and ten females in 1995 and to 12 males and 15 females in 1996. Eight of the turtles we monitored in 1996 also were radio-tracked in the previous year (three males and five females), yielding a total of 35 radioed adult turtles over the study period.

We used single-stage radio transmitters with 90–165 d of life (AVM Instrument Company, LTD., Livermore, California, USA and L. L. Electronics, Mahomet, Illinois, USA), 15 × 25 × 10 mm in size, with 15–18 cm antennas, and weighing 4.5 g before attachment. We attached transmitters according to techniques outlined by Carter (1997). Radio attachment was completed in the field in <20 min and post-attachment weight did not exceed the arbitrary 7% of body weight guidelines established by others (Schubauer, 1981; Eckler et al., 1990).

We used a handheld receiver (AR 8000 by AOR, LTD., Tokyo, Japan) and a two-element flexible, directional antenna (Rubber Ducky by

Telonics, Mesa, Arizona, USA) to locate turtles carrying radio transmitters. Each radio location was marked and measured (nearest meter) as the straightline distance between the previous and consecutive locations ("net distance"). Radio-tracking began in May 1995 and 1996 and continued through November of each year. We stopped recording movements when bog turtles did not move for at least three sampling periods (≈10 consecutive days) and attributed this prolonged inactivity to the onset of hibernation. We eliminated zero meter movements in late fall from our analyses because movements that were closely tied to a fixed location, such as a burrow or hibernaculum, cannot be considered independent samples (O'Conner et al., 1994).

We located bog turtles an average of nine times per month at each of three sites in 1995. At the beginning of each month we located radioed turtles on six consecutive days for one week and once per week for the remainder of the month. We used this sampling method to allow trampled microhabitats to recover after repeatedly locating bog turtles. However, this sampling method produced unevenly spaced location data and we used a modified sampling protocol the following year. In 1996, we located bog turtles at each of four sites twice weekly. This reduced the number of samples for each turtle (eight locations/month), but yielded more evenly spaced data than the previous year.

We treated data collected for each year separately in all analyses because of varying seasonal conditions and the unevenly spaced location data. We tested the effects of sex, site, and year on average and maximum net movements by bog turtles simultaneously using a mixed ANOVA design. The time interval between turtle locations (1–9 d) was treated as a covariate in the model.

Threadspooling.—Straightline distances can underestimate true bog turtle activity (Chase et al., 1989). We used small thread bobbins attached to the carapace to assess the true path of turtles (Wilson, 1994). By comparing net distances to threadspooling distances, bias associated with using point-to-point distances as a measure of actual activity can be calculated. We attached thread bobbins to five radioed turtles (two males and three females) in July and August 1996. Each thread bobbin weighed approximately 3 g after attachment and was coated with a rubberized compound to prevent water leakage as described in Wilson (1994). Thread bobbins contained ≈180 m of textile thread and were attached using 5-minute epoxy putty (Duro Master Mend[®], Loctite Corporation, Rock Hill, Connecticut, USA) to the marginal scutes along the posterior carapace of the turtle. We relocated bog turtles every 24 h to reduce

the likelihood of entanglement. We collected expelled thread and measured it to the nearest meter. The thread was then cut and reattached to a marker at the turtle's present location. We compared net distances and threadspooled distances with a Wilcoxon Signed-Rank test (WS). A 95% confidence interval for threadspooled distances was calculated using a Wilcoxon Signed-Rank Confidence Interval test.

Precipitation.—We acquired monthly precipitation for 1995 and 1996 from the National Climatic Data Center (<http://www.ncdc.noaa.gov>). Precipitation data were collected at a local weather station <10 km from the study sites. Annual precipitation can influence total wetland area and vegetation density and may directly influence bog turtle movements. Hence, we compared annual precipitation to the average net movements by bog turtles for both study years.

RESULTS

Net Distances Moved.—From May to November 1995 we obtained 313 net distance measurements on 18 bog turtles (\bar{x} = 17 observations/turtle). Male bog turtles (N = 8) moved an average (\pm SE) of 16 ± 2.4 m (range = 9–29 m) between consecutive sightings (range = 1–9 d); females (N = 10) moved 17 ± 3.8 m (7–48 m) between sightings. Over the same time period in 1996, we obtained 606 net distance measurements on 27 bog turtles (\bar{x} = 22 observations/turtle). Male bog turtles (N = 12) moved 23 ± 2.8 m (9–41 m) between consecutive sightings and female bog turtles (N = 15) moved 18 ± 2.1 m (3–35 m) between sightings.

Average net movements did not differ between male and female bog turtles (F = 0.20, P = 0.6553) for either year (F = 0.57, P = 0.4776) or between any site (F = 0.15, P = 0.9312). The amount of time did not significantly determine the resulting net movement (F = 4.39, P = 0.0810), and the amount of time between radio locations was not correlated with the net distance traveled (ρ = -0.04, P = 0.5166). No factors interacted significantly (maximum F = 0.63, maximum P = 0.4588).

Maximum net distances recorded for radioed bog turtles in 1995 (N = 18, \bar{x} = 62 ± 12.1 m, 18–200 m) and 1996 (N = 27, \bar{x} = 95 ± 13.4 m, 9–263 m) also did not differ between years (F = 1.31, P = 0.2651), with respect to sex (F = 1.74, P = 0.2010), or site (F = 0.17, P = 0.9136). Recapture of marked turtles without radios extended the range of maximum distances moved by a factor of five. On June 10, 1996, we captured a marked 9-year-old male bog turtle crossing a road 2700 m (straight-line distance) from where it was captured the previous year. During the next 24 h, it travelled 375 m from its previous location through a white pine (*Pinus*

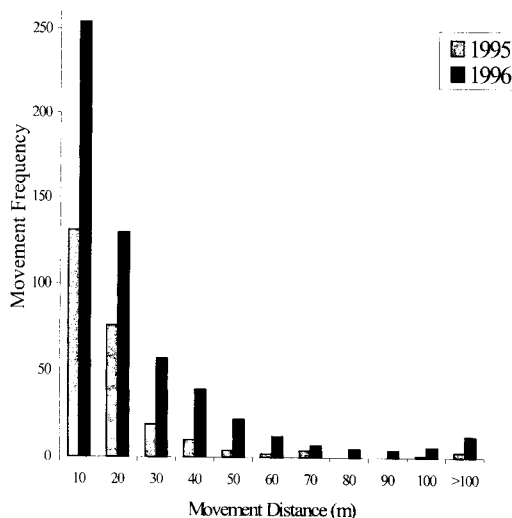


FIG. 1. Movement frequency of net distances within six distance categories for bog turtles (1995–1996).

strobis) plantation. The following day we lost radio contact with the bog turtle and could not determine its final destination.

Movement Frequencies.—Large-scale movements were relatively infrequent and small-scale movements were relatively common. The frequency distribution of movements appears to be negatively exponential (Fig. 1). Seventy-five percent of all net movements (N = 919) were <20 m, whereas only 2% were >100 m. In 1995, no radioed bog turtles moved away from the three study sites. In 1996, three bog turtles (two females, one male) moved successfully into neighboring sites and returned a total of four times. One of these movements was measured reliably at 530 m straightline distance each way, with the others at least >200 m.

Threadspooling.—We followed five turtles (two males, three females) using thread bobbins for 13 d. Median distance of expelled thread (26.5 m) from thread bobbins (N = 13) over 24 h was longer (median difference = 20.5 m, 4.5–114.0 m, WS = 0.0, P < 0.001) than median net distance between locations (7.0 m). Median threadspooled distances were 6.5 times longer than net distance measurements for the same turtles on the same days.

Precipitation.—Average precipitation was 9.9 ± 1.38 cm/mo (3.8–13.5 cm) in 1995 and 15.4 ± 2.09 cm/mo (6.7–22.4 cm) in 1996. We consider precipitation data only during the study period (May–November) because turtles entered hibernacula in late November. Total precipitation during the study periods was 69.3 cm in 1995 and 107.6 cm in 1996. From May–October in both years turtle activity (as measured by mean net distance) reached a minimum during the

TABLE 1. Average (\pm SE) net distances (m) traveled by bog turtles at four study sites in southwestern Virginia (1995–1996). Sample sizes (number of turtles) are in parentheses. ¹ Distances were not significantly different among sites ($F = 0.15$, $P = 0.9312$). ² Distances were not significantly different between years ($H = 0.57$, $P = 0.4776$).

Site ¹	Area (ha)	1995 ²	1996
1	33	17 \pm 3.6 (10)	17 \pm 1.7 (13)
2	19	19 \pm 5.2 (4)	24 \pm 5.1 (5)
3	7	13 \pm 2.1 (4)	24 \pm 5.1 (5)
4	0.5	— (0)	21 \pm 5.4 (4)

month with the lowest precipitation (August in 1995 and October in 1996). However, the general relationship between precipitation and net movement was weak for both years (1995: $\rho = 0.45$, $P = 0.3129$; 1996: $\rho = 0.36$, $P = 0.4324$).

DISCUSSION

The net distances we report are consistent with other studies on bog turtles. However, the lack of differences between the sexes is not. Other studies reported that male bog turtles are more active than females (Ernst, 1977; Chase et al., 1989; Lovich et al., 1992). We found no differences between sexes in mean or maximum net movements during either sampling year. Longer, more frequent movement by males has been observed in freshwater (Morreale et al., 1984; Gibbons et al., 1983; Tuberville et al., 1996) and terrestrial (Rose and Judd, 1975) turtles. Sex-biased movement differences may be related to mate searching by males (Morreale et al., 1984). A lack of such a difference in our study may reflect sampling error, geographic or habitat influences, or true behavioral differences. A small or nonrepresentative sample probably does not explain our results because the overall sample size and number of replicates we report are larger than previously published studies on bog turtles. Geographic or habitat differences, such as site area and floristics, may confound comparison with other studies. The short duration of this study may limit our ability to draw general conclusions about these data.

Net distances recorded for bog turtles in all of our study sites within one week or less were equal (Table 1), despite potential differences according to sampling frequency. Calculating rates of movement by dividing net movements by the number of days between measurements (m/day) will underestimate true activity, especially when measurement intervals are long. An improved approach may be to assume that time between measurements is not an important factor in determining net distances at a duration

≥ 1 day and for up to a specified period of time (in this study, 9 d). Net distances, though useful in understanding bog turtle movement, can dramatically underestimate true activity, as previously suggested by Barton (1957) and Chase et al. (1989). Bog turtles in our study moved an average of 6.5 times more than estimated by net distances. Although this bias is known, such large discrepancies suggest that threadspooling, in lieu of radio tracking, may best elucidate future questions concerning bog turtle activity and movement.

The majority of movements in this study were small in scale, suggesting that large-scale movements are infrequent at the time frame we examined (2 yr). Although uncommon, long-distance movement among wetlands was demonstrated by three adult bog turtles (two females, one male). Ten percent of radioed adult bog turtles (3 of 31) used neighboring sites greater than 200 m away and returned, demonstrating that some bog turtles use multiple sites over the course of their life. Maximum distances recorded for bog turtles in unaltered habitats from other parts of its range (e.g., 2700 m (this study), 750 m [Eckler et al., 1990]; 225 m [Ernst, 1977]) suggest that factors other than habitat drying may explain long-distance movements between wetlands. The probability of locating long-distance dispersers decreases exponentially with increasing dispersal distance. The negative exponential distribution is typical of dispersal distances measured by radiotracking when the probability of detection decreases geometrically with increasing area (Koenig et al., 1996). However, in this case we do not believe a negative exponential distribution is a sampling artifact of the net distance data because bog turtles seldom moved out of detectable range. We failed to detect radio signals in only 1.3% (1995—1.5% [4/275], 1996—1.0% [6/576]) of attempts to locate bog turtles.

A relatively low level of gene flow may be required in long-lived organisms, such as turtles, to counteract genetic costs associated with population isolation (Kiestler et al., 1982; Scribner et al., 1984). Additionally, our data suggest that the probability of detecting successful dispersal may be low because large scale movements are infrequent (Fig. 1). If the ability to move between wetlands is important for bog turtle survival, then the continued loss of wetlands throughout its range may increase the probability of population extinction, particularly if a species is unable to move between more and more isolated wetland patches (Gibbs, 1993; Thomas, 1994; Semlitsch and Bodie, 1998). Direct observations of how the landscape has been changed by humans in the past several hundred years are few, but it is reasonable to assume that

the number of wetland habitats used by bog turtles has decreased and that landscape features connecting them have been altered (Herman and Tryon, 1997). Future conservation efforts for this species may be improved by identifying the determinants of successful dispersal between populations in southwestern Virginia and quantifying the results of dispersal between wetlands on population structure.

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