

**MOVEMENTS, HOME RANGE, AND HABITAT
PREFERENCE ASSESSMENT OF BOG TURTLES
(*Clemmys muhlenbergii*) IN SOUTHWESTERN VIRGINIA**

by
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THE HABITAT ECOLOGY OF BOG TURTLES (*Clemmys muhlenbergii*) IN
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(ABSTRACT)

I radiotracked 31 bog turtles (*Clemmys muhlenbergii*) from May 1995 to December 1996 at 4 study areas in southwestern Virginia. Radio location data were used to provide measures of annual activity, spatial distributions of animals, and habitat selection. The techniques I used in this study were as follows: distance measurements between consecutive locations, home range estimators (Minimum Convex Polygon [MCP] and cluster analysis), compositional analysis of habitat selection, and measurement of microhabitat variables.

Results suggest a random pattern of movement by bog turtles within habitats. Average net movements recorded between consecutive locations (separated by 7 days) during 1995 and 1996 measured 15 m and 20 m for females and 14 m and 23 m for males respectively. Eighty-six percent of all net movements ($n = 824$) were less than 30 m, whereas only 2% were greater than 100 m. In 1996, average home range sizes (95% MCP, 95% cluster) were 0.47 ha and 0.17 ha for females and were 0.57 ha and 0.13 ha for males. Bog turtles selected wet meadow areas and bulrush (*Scirpus* spp.) patches more than expected randomly and avoided dry meadow areas and streams. Turtles were located more frequently in mud ($\bar{x} = 24.3$ cm) and water ($\bar{x} = 5.2$ cm) than expected by random selection ($P < 0.001$). I found no differences between sexes in movement, home range, or habitat selection by bog turtles.

Bog turtles select specialized habitat types and microhabitats within wetlands. Large-scale movements are infrequent and the risk of site isolation may be high if wetland habitat loss continues at historic rates. Future management should protect spatially-close sites which contain multiple habitat types, soft substrate, and pockets of water.

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CHAPTER 1

SEASONAL ACTIVITY AND MOVEMENT PATTERNS BY BOG TURTLES (*Clemmys muhlenbergii*) IN SOUTHWESTERN VIRGINIA

INTRODUCTION

Bog turtles, *Clemmys muhlenbergii*, are small, semi-aquatic turtles believed to be declining throughout their range (Salazar 1967, Nemuras 1974, Bury 1979a, Tryon 1990). Population extinctions and declines (Nemuras 1976, Collins 1990) are believed to be the result of habitat loss and taking for the pet trade (Holub and Bloomer 1977, Ernst et al. 1994, Mitchell 1994). These turtles are currently afforded state threatened or endangered status by the 13 states in which they are found (Levell 1995), and are a candidate for federal listing under the Endangered Species Act. Bog turtles are extremely secretive animals (Arndt 1977, 1986), which makes the collection of basic natural history information difficult. Much of the previous work with this species deals with the distribution and status of populations (Zappalorti 1976, Herman 1981, Klemens and Warner 1983, Herman 1988, Mitchell and Buhlmann 1991, Tryon and Herman 1990, Buhlmann 1992, Beane 1993); relatively little is known about the behavior of this animal.

In the southern extent of their range, bog turtles occupy upland freshwater wetlands characterized by spring-fed wet meadows and seepages (Mitchell 1994). Wetland habitats in southwestern Virginia are patchily distributed over the landscape and bog turtle colonies in Virginia occupy small, connected patches of habitat (Buhlmann et al. in press). Little is known about the population dynamics of this species or the role of multiple sites within single drainages. A landscape-level focus, which considers movement corridors, has been suggested when managing colonies contained within the same stream drainages and watersheds (Buhlmann et al. in press). However, the frequency and magnitude of movements by bog turtles within and among sites must be better understood for management at the landscape level to be effective.

Gibbons (1990) suggested purposes for intrapopulation and extrapopulation movements by freshwater turtles in Carolina Bays. Intrapopulation movements are generally related to feeding, reproducing, basking, or hiding whereas extrapopulation movements are characterized by migration to or from seasonal habitats, nesting by females, or mate searching by males. Extrapopulation movements may be rare and may serve to acquire new mates or find new habitats. Adult males of several species of freshwater turtles move longer distances and more frequently than conspecific females (Bury 1979b, Gibbons 1986). This difference may reflect the differential reproductive strategies of males and females (Morreale et al. 1984). Sexual strategies, such as mate searching by males and movement to nesting areas by females, will result in a sexual bias for either sex. Equal

movements for males and females are expected while foraging for food, escaping temporary habitats, or moving to overwintering sites.

Most measures of activity and movement in bog turtles have been obtained through visual searching and mark-recapture techniques. Bog turtles may exhibit the highest levels of surface activity in the early spring (Ernst et al. 1994) and decrease their activity during the summer months (Ernst and Barbour 1989). For example, 81% and 87% of all bog turtle captures occurred before July in Delaware (Arndt 1977) and Pennsylvania (Ernst 1977), respectively. However, Holub and Bloomer (1977) noted continued activity throughout the summer season. The extreme secretiveness of bog turtles and an increased density of vegetation, such as sedges and rushes (*Carex* spp., *Juncus* spp.), during the summer months often make visual searching difficult. Consequently, the assumed lower levels of activity during the summer months may actually represent a lower capture probability as habitats become more dense (Ernst et al. 1994).

Radiotelemetry offers the advantage of repeated observation of known individuals so that turtles can be located throughout the year, even when dense vegetation precludes effective visual searching. Periodic monitoring of individuals using radiotracking techniques can provide consecutive movement data and consecutive movements have been shown to be accurate measures of animal activity (Palomares and Delibes 1991). These movements are defined by the shortest distance between two consecutive locations. However, potential problems with this method arise when the time between consecutive locations is not held constant. If a directional movement pattern for a turtle is assumed, the length of consecutive distances would be expected to steadily increase as the amount of time between measurements increased. As the animal moves away from its previous location, the distance from that location should increase with time. Under this assumption, the consecutive distances can be divided by the number of days (Lovich et al. 1992) or hours (Lovich 1990) between locations. However, if the animal follows a different pattern of movement, dividing cumulative distance by the time interval between measurements may artificially decrease the measure of movement.

If turtles deviate from unidirectional movement, the consecutive movement distances will underestimate the amount of animal activity. The actual distance traveled will be larger than the net distance. The attachment of a thread spool to a small animal so that it leaves a marker along the animal's exact path ("threadspooling") may be a more accurate way of assessing the actual amount of turtle movement (Wilson 1994). In Maryland, net distances of 11 radio-telemetered bog turtles averaged 1-2 m whereas threadspooling showed movements of up to 30 m in less than a 24 hr. period (Chase et al. 1989). By comparing consecutive distance measurements to threadspooling distances, the bias associated with using point-to-point distances as a measure of actual activity can be calculated.

My study objectives were to: 1) quantify the frequency and magnitude of short- and long-distance movements by bog turtles, and describe differences in these movements attributable to sex or season; 2) identify and describe patterns (e.g., random, directional, or systematic) associated with bog turtle movements; and 3) assess the bias of using consecutive net distances obtained with radiotelemetry as a measure of animal activity. The

purpose of these objectives was to gain insight into the magnitude and nature of movements by bog turtles. A better understanding of these movements can aid management by describing how far and how often bog turtles can move between isolated sites.

METHODS

Study Areas

Four study areas in Floyd County, Virginia, were selected based upon previous (Mitchell and Buhlmann 1991, Buhlmann 1992) and recent surveys for bog turtles. Exact locations are not given in this paper because of the endangered status of the bog turtle in Virginia. Three of the areas are grazed, wet meadows with spring seepages and rivulets. The fourth is an abandoned beaver pond. All 4 areas are separated from each other by mixed deciduous forest and are all contained within an area 2.5 km in diameter. Two convergent streams connect each of the 4 sites. One wet meadow site was only included for the 1996 period because it was not known to contain bog turtles until June of that year.

Field Methods

Radiotelemetry

I captured turtles by visually searching and probing within occupied habitats. In 1995, I attached radios to 10 males and 9 females and, in 1996, I attached radios to 11 males and 10 females. Approximately half of the turtles monitored in 1996 were radioed in the previous year (4 of 11 males and 5 of 10 females), yielding a total of 31 radioed turtles over the study period. This provided across-year location data on some individuals, while also allowing an increase in total sample size.

I used single-stage radio transmitters, with 90 - 165 days of life (AVM Instrument Company, LTD., Livermore, CA and L.L. Electronics, Mahomet, IL). The radios measured 15 x 25 x 10 mm in size, used 15-18 cm antennas, and weighed 4.5 grams before attachment. All radios were attached to the right or left 5th plural scute of the turtle with the antenna extending caudally. Five-minute epoxy putty (Duro Master Mend™, Loctite Corporation, Rock Hill, CT) was used for module attachment. Each radio base was concave to reduce the amount of putty required for attachment. The total amount of time for radio attachment was 20 minutes. Post-attachment transmitter weight was 6-7 g and did not exceed the recommended 7% of body weight guidelines (Schubauer 1981, Eckler et al. 1990).

Radioed turtles were located using a handheld receiver and a two-element flexible, directional antenna (AR 8000 by AOR™, and Rubber Ducky by Telonics, respectively). Following initial radio location, each turtle was sighted if possible, but radiotracked turtles were rarely handled. When a turtle could not be sighted, its location could be accurately estimated to the nearest 1-m². This accuracy was determined by locating turtles several times by digging in the mud when they could not be seen at first and comparing the estimated location of the animal before sighting with the turtle's actual location.

Radio Location Sampling Intervals

Radiotracking began in May of 1995 and 1996 and continued until mid-December of each year. Some turtles were monitored throughout the winter to detect time of emergence from hibernacula the following year. In 1995, radioed animals were tracked an average of 9 times per month at each of 3 sites. I located radioed turtles on 6 consecutive days for 1 week at the beginning of each month and once per week for the remainder of the month. This sampling interval was used to collect as much detailed information as possible over a short period of time, without trampling these fragile environments. Turtles were found to the nearest meter whenever possible. However, this precision often required walking repeatedly through seepages and rivulets which are easily disturbed. Any trampling that occurred at the sites as a result of the 6 consecutive daily measurements apparently recovered during the less intensive visits for the remainder of the month.

In 1996, I used a different sampling protocol. Turtles at each of 4 sites were located twice weekly. This reduced the number of samples for each turtle (8 locations / month), but yielded more evenly spaced data than 1995. Because of varying seasonal conditions and the different sampling strategies detailed above, the data collected for each year were treated separately in all analyses.

Net Distances

I marked the locations of radioed turtles using small (20 cm), wooden stakes. The straight-line distance between consecutive locations was measured to the nearest meter. I collected net distance measurements from approximately May to December in both 1995 and 1996. Measurements were no longer recorded when a turtle's net distance was 0 m > 10 consecutive days. Turtles only exhibited this prolonged inactivity after late-November of each year and this was attributed to the onset of hibernation. I eliminated 0 m movements in late fall because of the independence problem associated with burrowing animals (O'Conner et al. 1994). Movements that are closely tied to a fixed location, such as a burrow or hibernacula, cannot be considered independent samples.

Threadspooling

I used threadspooling to provide an alternative index of animal movement. I attached thread bobbins to 5 radioed turtles (2 males and 3 females) in July and August 1996. The thread bobbins weighed approximately 3 grams after attachment. Each bobbin was coated with a rubberized compound to prevent water leakage into the thread spool using techniques described in Wilson (1994). Thread spools were attached using 5-minute epoxy putty to the marginal scutes along the posterior carapace of the turtle. Each thread bobbin contained 180 m of textile thread. When I located a turtle using radiotelemetry techniques I recorded the net distance (as described in "net distances" section). The thread was then cut and re-attached to a stake at the turtle's present location. Consecutive locations were not more than 24 hrs. apart to reduce the likelihood of turtle entanglement. Expelled thread was collected and measured to the nearest meter.

Movement Patterns

I compared 3 hypothetical distributions for describing movement patterns when analyzing the net movement data. Biologically plausible movement patterns could be defined as directional, systematic, or random. Directional movement stipulates that the net distances traveled would be expected to increase in proportion to the number of days between consecutive measurements. As the amount of time between turtle locations increases, the turtle is afforded more time to move away from its previous location and the net distances increase accordingly. Systematic movement patterns are defined by a repeated relationship in the movement data over a multiday period. A turtle may have a systematic pattern when it moves away from its initial location, then returns after a given period of time. For example, if a bog turtle spends half of each week at different ends of a wetland, a weekly sampling period might show very little movement whereas a biweekly sampling strategy might show several long distance movements each week. In this example, the net distance measured every 7 days might be expected to be less than the net distances collected at 3- or 4-day intervals. Note that daily movement patterns might also be expected (Gibbons 1990), however, no net distances were collected within a 24 hour period. My third movement hypothesis implies a lack of any time-dependent movement pattern. Net distances traveled by a bog turtle are independent of the amount of time between consecutive measurements. Under this random movement hypothesis the net distances within any specified time period are expected to be equal and not to be correlated with time.

Data Analysis

Net Distances and Movement Patterns

The net distances and threadspooled distances were compared using a Mann-Whitney U test ("W", $\alpha = 0.05$). A 95% confidence interval for threadspooled distances was calculated using a Wilcoxon Signed-Rank Confidence Interval test ("WS"). Across-year mean and maximum movements were compared using a Kruskal-Wallis test ("H", $\alpha = 0.05$).

I examined the net distance data for 1 of 3 movement pattern distributions by inspecting scatterplots. I constructed scatterplots of net distances as a function of the number of days between measurements for the 1995 and 1996 data. The scatterplot y-axes were truncated to 100 m to provide consistent visual comparisons for each plot. Expected patterns were 1) an increasing trend as the number of days increased, 2) a sinusoidal trend if a systematic movement pattern existed, or 3) an equal dispersion of points across all days apart if movement was random. Patterns up to 7 days apart were examined using this technique and I assumed each of these patterns to be mutually exclusive.

A shortcoming of the scatterplot technique is the lack of equal sample units across each time period between measurements. The different sampling strategies used in 1995 and 1996 created a different number of samples for each day apart measurement (Appendices 1.1, 1.2) and it is difficult to visually compare distances if the sample sizes for each time category are unequal. To better identify trends in the scatterplots, all possible combinations of consecutive measurements were estimated using the UTM locations for

each turtle. If 6, 1-day apart measurements were collected, I also calculated 3 - 2-day apart distances, 2 - 3-day apart distances, and 1- 4-, 5-, and 6- day apart distances. Although the actual data were only collected at 5 1-day intervals, the additional distances reflect what I actually would have measured if a different sampling strategy was used. This technique provided larger sample sizes for each of the days between measurement groups and this allowed a better visual comparison for any trends or patterns. Only the 1995 movement data were used in this analysis because the biweekly sampling protocol of 1996 prohibited collection of 1- and 2- day apart measurements and made the calculation of additional data impossible for most of the day-apart measurements less than 7 days (only 3- and 6- day apart data could be used).

Correlation analysis also was used to test for movement patterns. Under movement hypothesis 1, directional movement, the distance traveled between consecutive measurements is expected to increase as the time between measurements increases. I calculated a Pearson correlation coefficient for each turtle and for all turtle movements combined to test for any positive associations with net distances and time between measurements. While positive correlation supports directional movement, no correlation would be expected under systematic or random movement patterns.

Seasonal Trends

I examined seasonal trends in distances moved between consecutive radio locations (net distances) for individual turtles using scatterplots. Net distances for turtles were plotted as a function of day of year for 1995 and 1996. A continual decrease in net movement was anticipated based upon previous descriptions of seasonal activity (Ernst et al. 1994, Mitchell 1994). Only turtles with a minimum of 2 samples / week for 2 months (i.e., > 16 samples for each turtle) were plotted.

Movement Data Distribution

Previous work with terrestrial turtles suggests a negative exponential distribution for turtle movements (O'Conner et al. 1994), that is, most movements are short and longer distance movements become increasingly rarer with increasing distance. The underlying distribution of movement data not only determines the appropriate statistical methods (e.g., parametric vs. nonparametric), but also may be helpful in characterizing the biological processes affecting movement. For example, if a specific distribution for movement data holds across multiple taxa, the probability of particular kinds of movements (e.g., the proportion of short- and long-distance movements) can be assessed. I plotted the distribution of my movement data for 1995 and 1996 to examine if a negative exponential distribution accurately described the movement data.

RESULTS

From May to December 1995, 271 net distance measurements were made on 16 bog turtles, which provided an average of 17 observations per turtle. Male bog turtles moved an average (mean [SE]) of 14 m (2.4) between consecutive sightings ($\underline{n} = 8$, range: 9-28 m, 1-9 days apart); females moved an average of 15 m (2.9) between sightings ($\underline{n} = 8$, range: 7-34 m, 1-9 days apart). Over the same time period in 1996, 553 net distance measurements were made on 25 bog turtles, for an average of 22 locations per turtle. Male bog turtles moved an average of 23 m (2.7) between consecutive sightings ($\underline{n} = 12$, range: 8-42 m, 1-9 days apart) and female bog turtles moved an average of 20 m (3.0) between sightings ($\underline{n} = 13$, range: 3-45 m, 1-9 days apart). Eighty-six percent of all net movements ($\underline{n} = 824$) were < 30 m, whereas only 2% were > 100 m (Figures 1.1 - 1.4).

No differences were detected in average movement distance between male and female bog turtles for 1995 or 1996 ($W = 74$, $df = 14$, $\underline{P} = 0.5635$ and $W = 156$, $df = 23$, $\underline{P} = 0.4966$, respectively). Males had significantly larger average movements (mean [SE]) in 1996 than in 1995 (1995: $\bar{x} = 14$ m [2.4], 1996: $\bar{x} = 23$ m [2.7], $W = 55$, $df = 18$, $\underline{P} = 0.0279$); females did not (1995: $\bar{x} = 15$ m [2.9], 1996: $\bar{x} = 20$ m [3.0], $W = 71$, $df = 19$, $\underline{P} = 0.2321$). The mean net distances for 8 bog turtles (3 male, 5 female) tracked in both 1995 ($\bar{x} = 15$ m [3.0]) and 1996 ($\bar{x} = 21$ m [4.1]) were also larger in 1996 ($WS = 3.0$, $\underline{P} = 0.0420$). The maximum net distances recorded for bog turtles in 1995 ($\underline{n} = 16$, $\bar{x} = 61$ m [12], range: 20 - 170 m) and 1996 ($\underline{n} = 25$, $\bar{x} = 108$ m [21], range: 9 - 530 m) did not differ between years ($H = 2.62$, $\underline{P} = 0.1060$) or differ with respect to sex (1995: $H = 2.62$, $\underline{P} = 0.634$; 1996: $H = 2.16$, $\underline{P} = 0.1420$).

Scatterplots of net distances as a function of the number of days between measurements showed no increasing or systematic patterns for either sex for 1995 or 1996 (Figures 1.1 - 1.4). All axes were truncated to 100 m for visual comparison. All possible days-between-measurement comparisons (up to 7 days apart) calculated for 1995 also showed no increasing or systematic pattern (Figure 1.5). The median net distance for each time period (1 - 7 days between measurements) appeared to be similar (1 day = 10 m, 2 days = 11 m, 3 days = 21 m, 4 days = 18 m, 5 days = 23 m, 6 days = 20 m, and 7 days = 23 m).

Net distance measurements were not correlated with time between measurements for either sex or year when the movements of individual turtles were compared using correlation analysis (1995: $r = 0.0002$ (0.15)) for males [$\underline{n} = 6$, range: -0.5520-0.5630], $r = 0.2785$ (0.08) for females [$\underline{n} = 4$, range: 0.1380-0.4700]; 1996: $r = 0.0876$ (0.07) for males [$\underline{n} = 9$, range: -0.0920-0.5520], $r = 0.0820$ (0.06) for females [$\underline{n} = 8$, range: -0.0960-0.4240]). Using the movements as the sample units and combining males and females, no correlation existed between the net distance traveled or the time between measurements for either year (1995: $r = 0.0740$ [$\underline{n} = 216$]; 1996: $r = 0.125$ [$\underline{n} = 483$]). No statistical tests were performed to test for net distance differences through time using calculated data because the data were not independent samples.

I plotted net distances as a function of day of year for 5 turtles in 1995 (3 males, 2 females) and 13 turtles in 1996 (7 males and 6 females). Each turtle was located at least 21 times ($\bar{x} = 24.5$, range: 21-28 locations) and locations spanned a period of at least 101 days ($\bar{x} = 115.3$, range: 101-126 days) with extreme dates being 5 May and 23 December. Plots suggested a seasonal decline in movement distances but correlation coefficients were all below 0.2 (Figures 1.6 - 1.9).

The distribution of all turtle movements appeared to conform to a negative exponential distribution. Data for 1995 and 1996 had a similar distribution (Figure 1.10).

Five turtles (2 males, 3 females) were followed using threadspools for a total of 13 days. The mean distance of expelled thread ($\bar{x} = 34$ m [7.7]) from threadbobbins ($\underline{n} = 13$) over 24 hours was significantly longer (median difference = 20.50, range: 4.5-114.0, WS = 0.0, $\underline{P} < 0.001$) than mean net distance between locations ($\bar{x} = 7$ m [0.9], $\underline{n} = 13$). Threadspooled distances averaged 6.4 times longer than net distance measurements (95% CI = 2.6 m, 11.4 m) for the same turtles on the same days.

DISCUSSION

The net distances I report for male and female bog turtles are consistent with other studies on bog turtles, however the lack of differences between the sexes is not (Arndt 1977, Lovich et al. 1992). I found no differences between the sexes in mean or maximum net movement during 1995 and 1996. Mean distances moved by males in 1996 were significantly longer than movements by males in 1995. Three factors may explain annual differences in movement by bog turtles. The first 2 explanations deal with sampling biases. The total sample sizes were not equal for 1995 (16 turtles, 17 observations/turtle) and 1996 (25 turtles, 22 locations/turtle). If the turtles in 1995 were not a representative of the true population, or if the turtles added to the 1996 sample were prone to moving longer than average distances, then larger net movements in 1996 would be expected. However, the turtles that were tracked across both sampling years also had larger movements in 1996, suggesting the larger movements in 1996 are not a result of additional turtles.

Second, the sampling protocols used to collect movement data were not the same for both years. The data were collected at 1- and 7-day intervals in 1995, and at 3- and 4-day intervals in 1996 (Appendices 1.1, 1.2). However, the amount of time between measurements does not appear to influence the net distances that are measured (Figure 1.5). This suggests that different sampling intervals for both years probably does not explain the movement differences between years.

Finally, greater movements in 1996 may reflect a behavioral difference by bog turtles between years. Monthly and cumulative precipitation near the 4 study areas was higher in 1996 (total precipitation = 133 cm) than in 1995 (total precipitation = 92 cm) (Figure 1.11). If precipitation is related to the amount of wetland habitat available, and if bog turtle movements are restricted to wetland habitats (see Chapter 2), then larger and more frequent movements would be expected in wetter years.

The apparent lack of differences between the sexes in movement contradicts other accounts of freshwater turtle movements that suggested males travel longer distances more frequently than do females (Bury 1979b, Morreale 1984, Gibbons 1986, 1990). I offer the following explanation for my results. First, males and females may move equally long distances at different times of the year. If both males and females move equally long distances, but at different times of the year, then an overall comparison of annual movements would appear to be equal. Male bog turtles might be expected to move longer distances than females to seek out and secure matings during the breeding season. On 10 June 1996, a 9-year-old male bog turtle was captured crossing a road 2700 m (straight line distance) from where it was captured the previous year. It was approximately 1400 m from the closest known area occupied by bog turtles. Over the next 24 hours, it traveled 375 m through a white pine (*Pinus strobus*) plantation from its previous location. Contact with the animal was lost on the third day and its final destination could not be ascertained. This movement may have been related to breeding activity or simply been an exploratory foray. Two pairs of bog turtles had been found mating a few weeks before (24, 25 May,

respectively), suggesting the long distance movement was made during the breeding season.

Females may be expected to move greater distances than males during the nesting season. In 1995, a gravid female moved > 200 m into a known nesting area and returned to her previous location within 4 days. She was gravid upon moving into the nesting area and was no longer gravid when she returned to her initial location. If female bog turtles prefer to lay their eggs in specific habitats (e.g., sphagnum [*Sphagnum* spp.] hummocks or sedge [*Carex* spp.] tussocks as described by Ernst et al. [1994]), then I might expect to see long distance movements by females into these habitat types during the nesting season.

A better test of this hypothesis would be a comparison between male and female movements during the breeding and nesting seasons. I make no such comparisons because of the possible confounding effects of different sites, different ages of individuals, and small sample sizes over the breeding and nesting periods (mid-May to mid-June).

No clear pattern of movement was indicated by the scatterplots of net distances as a function of days between measurements. The distances between consecutive locations up to 7 days apart appeared to be distributed equally. This tendency was especially apparent when I plotted all of the possible net distances I could have recorded between 1 and 7 days apart (Figure 1.5). Also, no correlation was found between the number of days between distance measurements and the distances measured. The net distances traveled by bog turtles did not increase with the amount of time between locations. This suggests a random movement pattern for bog turtles. If movement within a given area is random, the likelihood of a turtle being located at any location within a habitat is equal. On average, a bog turtle would be just as likely to be found at any given spot within a habitat regardless of the number of days between measurements. On a finer scale this is less likely to be true. Bog turtles are often found on discrete "runways" (pers. obs.) and would be more likely to follow these runways than to travel randomly within habitat patches. However, these runway systems can be extremely intricate and many runways would be expected to transect any given 4-m² (the resolution of the location data). Secondly, it is likely that bog turtles follow daily patterns. Freshwater turtles can have well-developed basking or foraging patterns, in which they visit certain areas on daily basis (Bury 1979b). The net distance measurements were collected at different times of the day for each turtle on consecutive days so the probability of detecting these patterns of movement is less likely at this study scale.

The lack of a directional movement pattern suggests that dividing the number of days between measurements into the net distance measurements may lead to underestimation of animal movement. No positive trend in the movement data (i.e., directional movement) was found through time for up to 7 days. If the amount of movement is roughly equal for each time interval, regardless of how many days apart the consecutive measurements were taken, then the measures of activity would become smaller as time increases. Bog turtles appear to be able to move across most of their home range within 24 hours, the shortest interval at which we sampled. Therefore, a better approximation of animal activity may be to assume time between measurements is not an

important factor in determining net distances for up to a specified period of time (in this study, 7 days).

Despite not dividing by the time between measurements, my net distances are still likely an underestimate of turtle activity. Threadspooling results suggest turtles can remain active in late summer, moving over 119 meters in a single day while only traveling a net distance of 5 meters from the previous location. This tends to support the hypothesis that bog turtles remain active throughout the summer.

A scatterplot of all the movement data appears to fit a negative exponential distribution (Figure 1.10), which was suggested by O'Conner et al. (1994) as an appropriate distribution for desert tortoise (*Gopherus agassizii*) movements in Nevada. If the data were negatively exponential, the majority of movements (e.g., movement frequency) would be expected at the smallest end (e.g., shortest distances) of the distribution and my data appear to show this.

Plots of net movements throughout the year for bog turtles show a gradual decrease in movement. This is not surprising given the behavior of ectothermic organisms in the winter months. However, if I assume activity does not decline throughout the summer months (based on limited threadspooling data), this may suggest some fidelity to particular areas later in the year by bog turtles. The threadspooling data suggest that turtles may remain more active in late summer than is suggested by net distance measurements. If bog turtles remain active throughout the year, but move less from previous locations as the year progresses, this suggests that the turtles are prone to stay in restricted areas later in the year (i.e., smaller activity areas). However, a small activity area does not indicate inactivity or aestivation (Chase et al. 1989). The reasons for smaller activity areas in the late summer and fall could be varied, but may relate to habitat use. The wetlands occupied by bog turtles become drier in late summer and fall. If bog turtles are closely tied to water, then their movements may be limited more during late summer because less suitable habitat is available.

A better test of the seasonally-restricted activity area hypothesis would include threadspooling and net distance comparisons throughout the entire activity season. If the consecutive distances show a decline through the year, but threadspooled distances remain similar, this would better support an increase in fidelity for particular areas later in the year.

CONCLUSIONS

The mean distances between consecutive locations for both males and females did not differ throughout the year and suggest that both sexes are capable of the same magnitude of movements. However, the magnitude of these movements is small. The majority of movements (86% [712/824]) were < 30 m, and only 2% (20/824) of all movements were > 100 m, suggesting large-scale movements are infrequent. The average distance from each study site to the nearest wetland was 415 m. If large movements by bog turtles are uncommon, sites may become isolated by distance if habitat loss continues at historic rates and this should be considered when managing multiple bog turtle colonies.

The movement data suggest a random movement pattern by bog turtles within their habitats. Also, bog turtles remain active in late summer, as suggested by threadspooling data. Therefore, active management at bog turtle sites, such as mowing or burning, should be done during the overwintering period if possible to minimize the potential injury to turtles above ground.

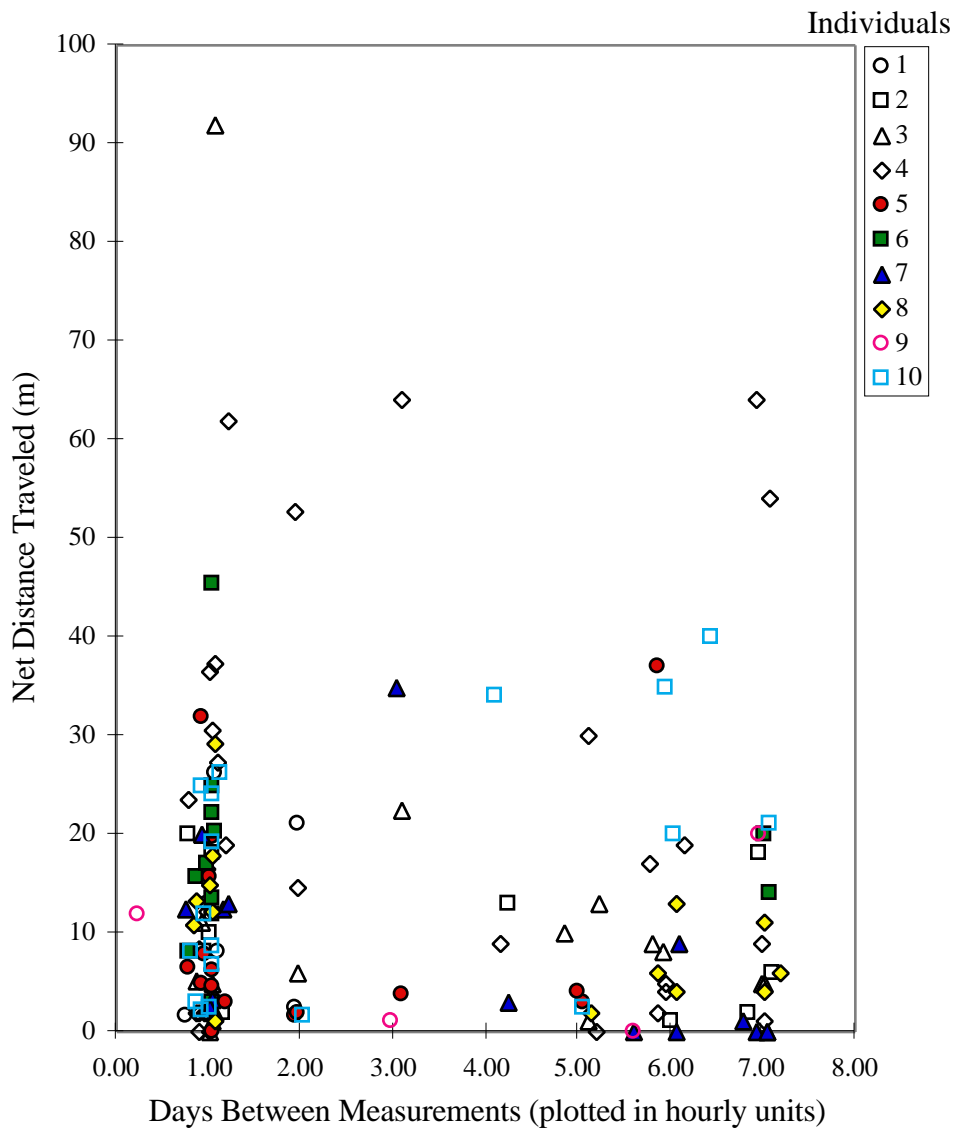


Figure 1.1. The net distances traveled by male bog turtles ($n = 10$) in 1995 as a function of the number of days between measurements. The distances traveled are similar, regardless of the number of days between locations.

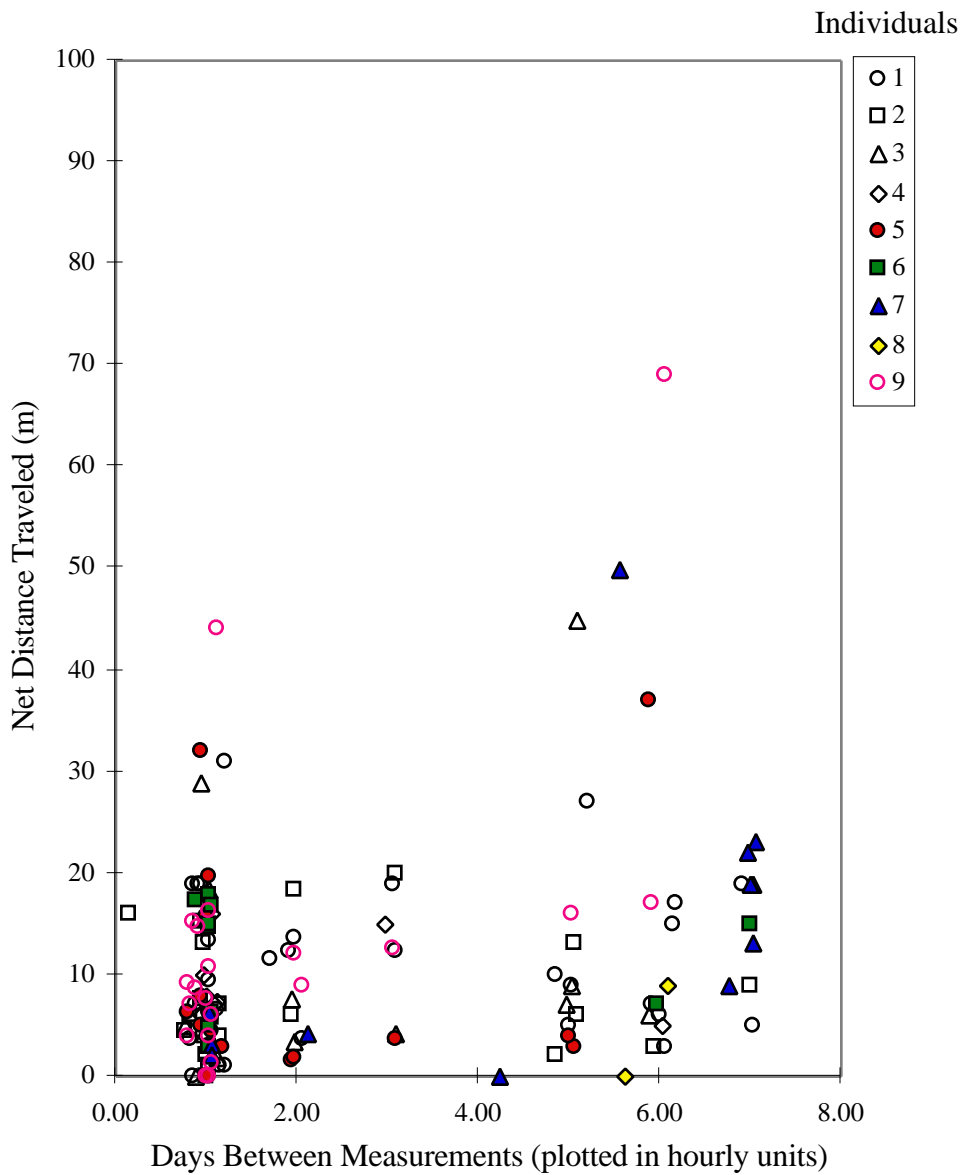


Figure 1.2. The net distances traveled by female bog turtles ($n = 9$) in 1995 as a function of the number of days between measurements. The distances traveled are similar, regardless of the number of days between locations.

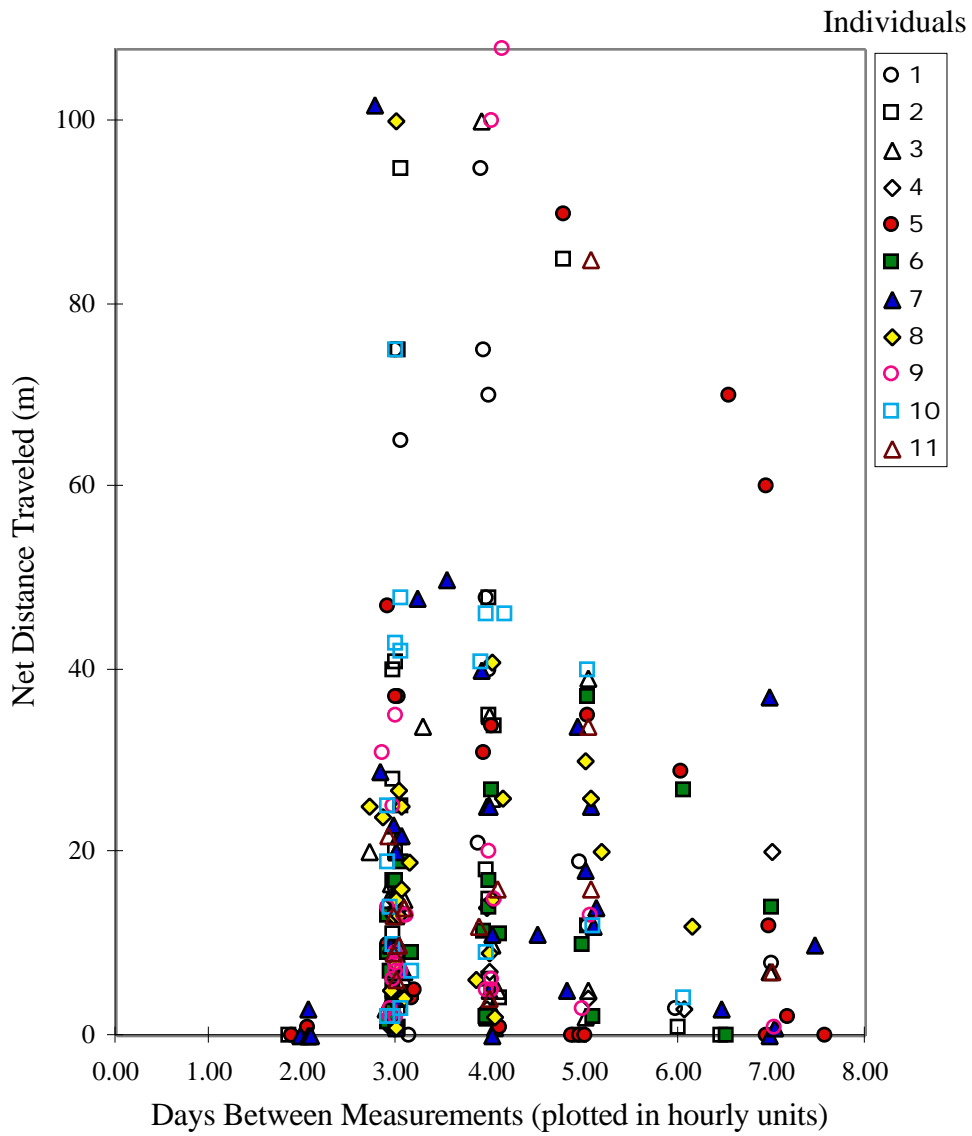


Figure 1.3. The net distances traveled by male bog turtles ($n = 11$) in 1996 as a function of the number of days between measurements. The distances traveled are similar, regardless of the number of days between locations.

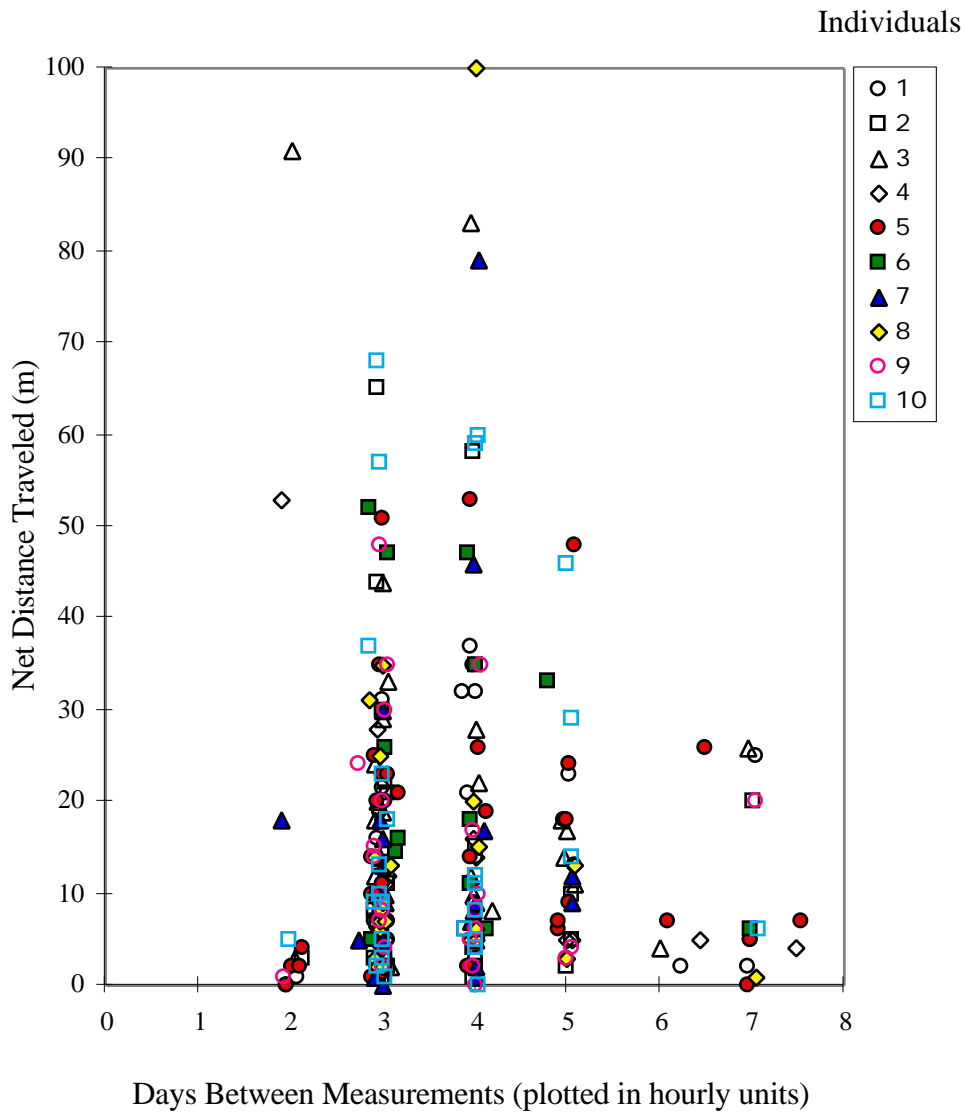


Figure 1.4. The net distances traveled by female bog turtles ($n = 10$) in 1996 as a function of the number of days between measurements. The distances traveled are similar, regardless of the number of days between locations.

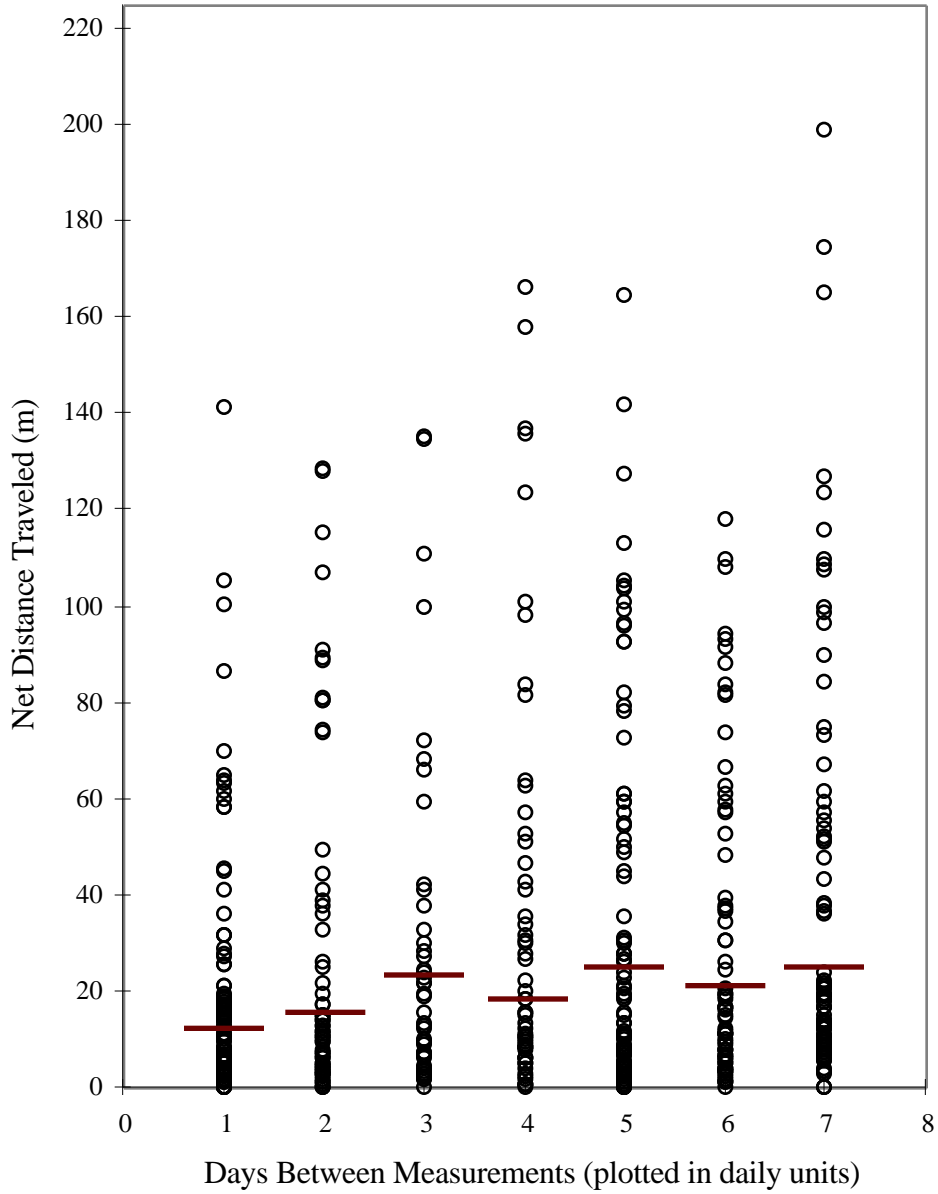


Figure 1.5. Scatterplot of calculated net distances of radio tracked bog turtles. All net distances that would have been measured between 1 and 7 days apart are shown. Medians for each time interval are indicated by horizontal lines.

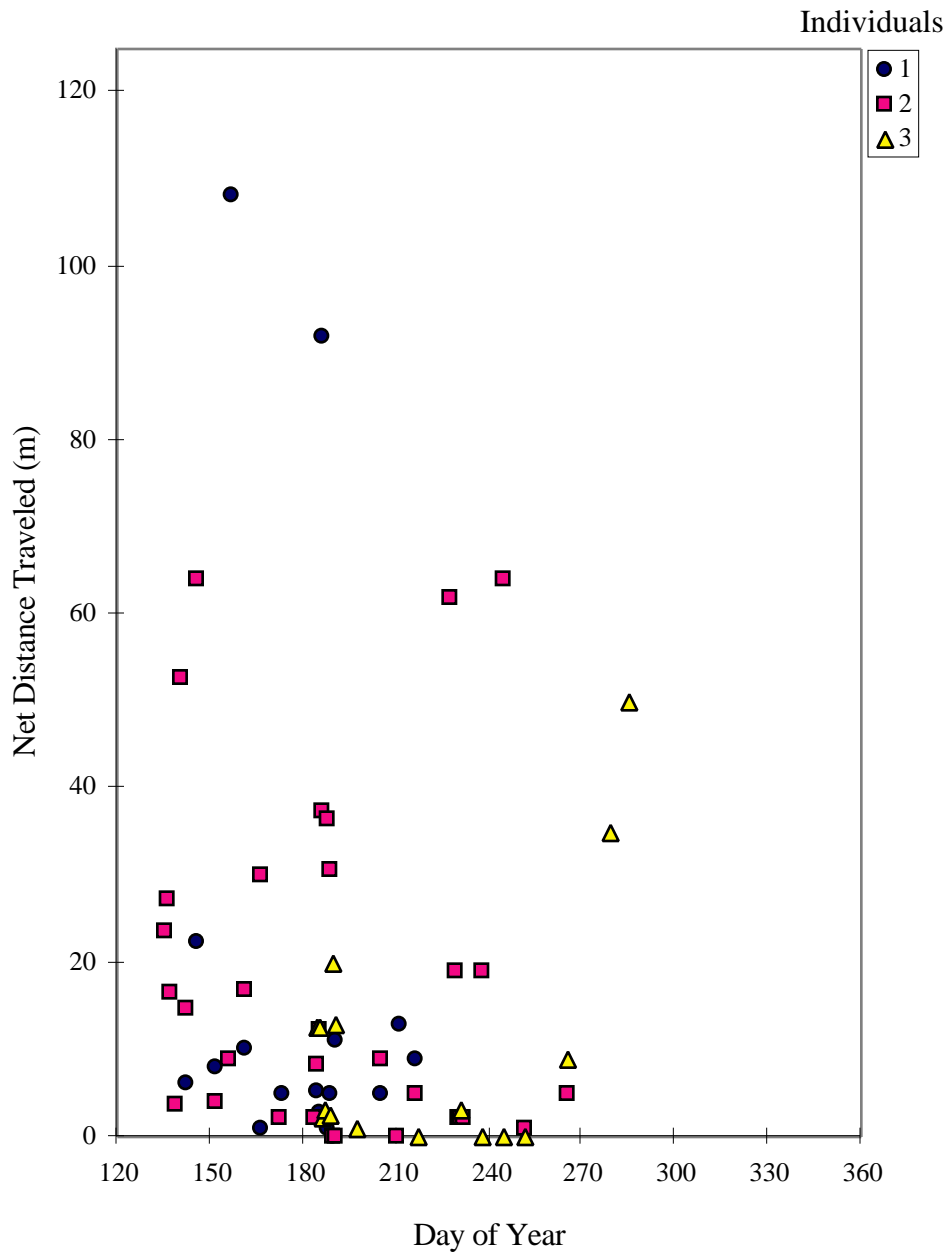


Figure 1.6. The net distances traveled by male bog turtles ($n = 3$) in 1995 as a function of the day of year.

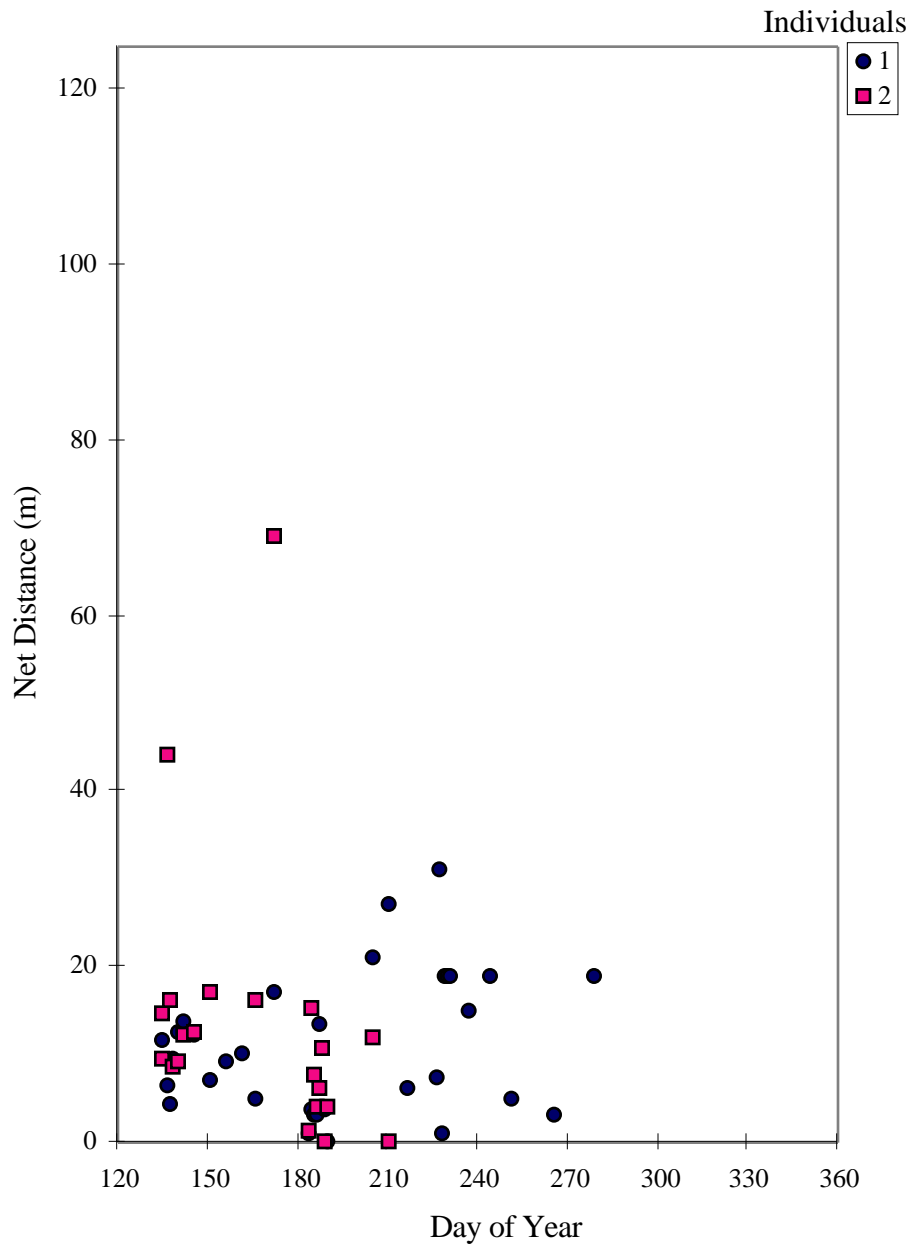


Figure 1.7. The net distances traveled by female bog turtles ($n = 2$) in 1995 as a function of the day of year.

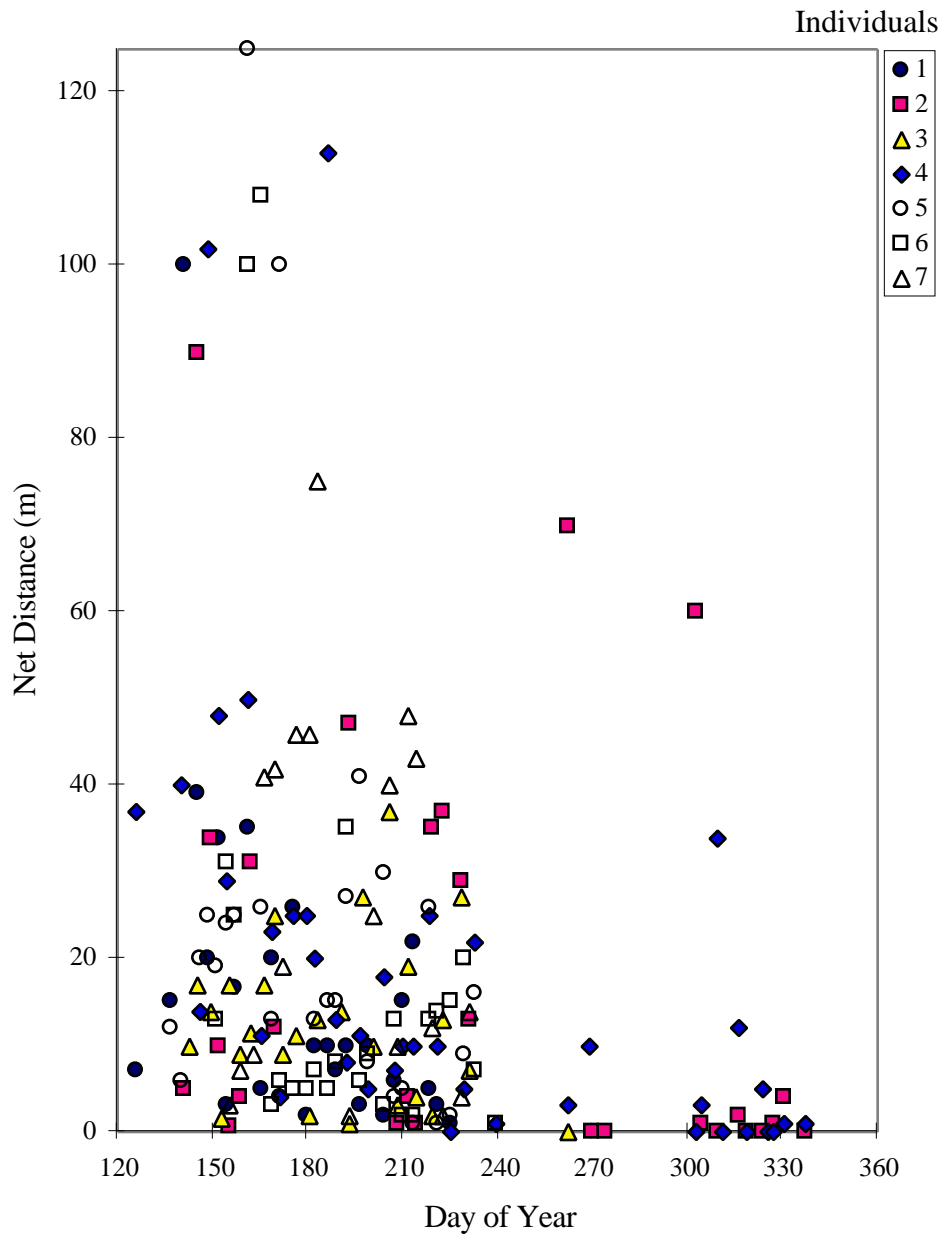


Figure 1.8. The net distances traveled by male bog turtles ($n = 7$) in 1996 as a function of the day of year.

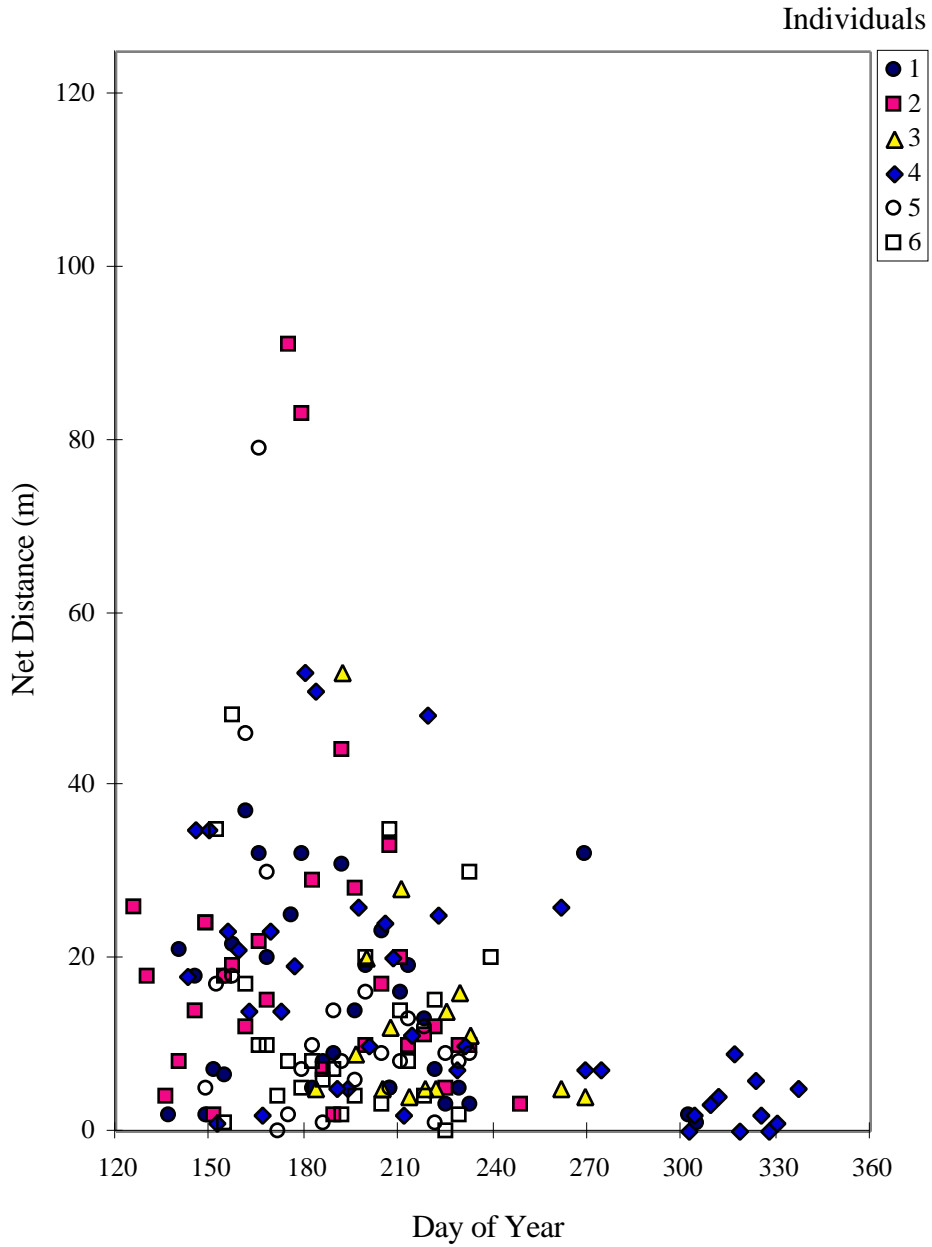


Figure 1.9. The net distances traveled by female bog turtles ($n = 6$) in 1996 as a function of the day of year.

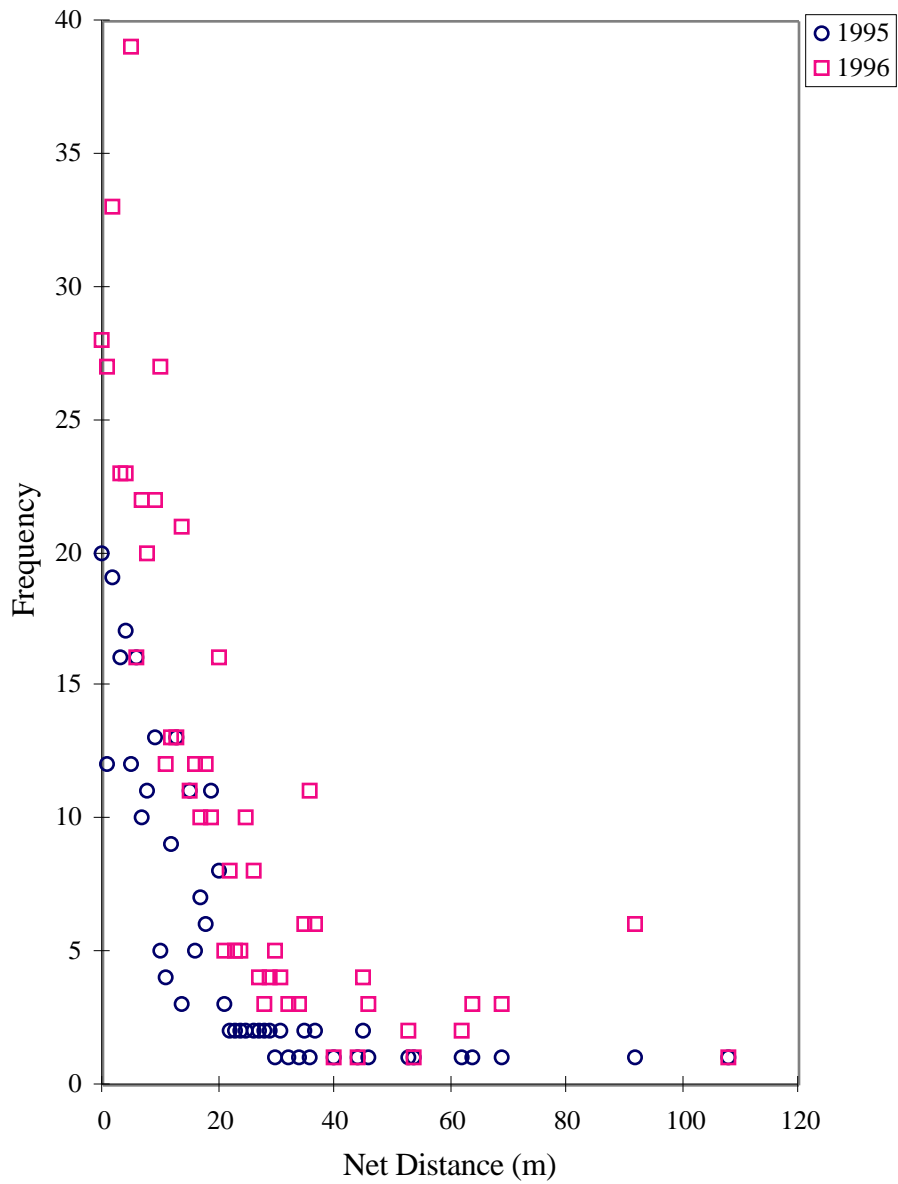


Figure 1.10. Distribution plot of net distances moved by bog turtles at 3 study sites in southwestern, Virginia. The data for both years may approximate a negative exponential distribution.

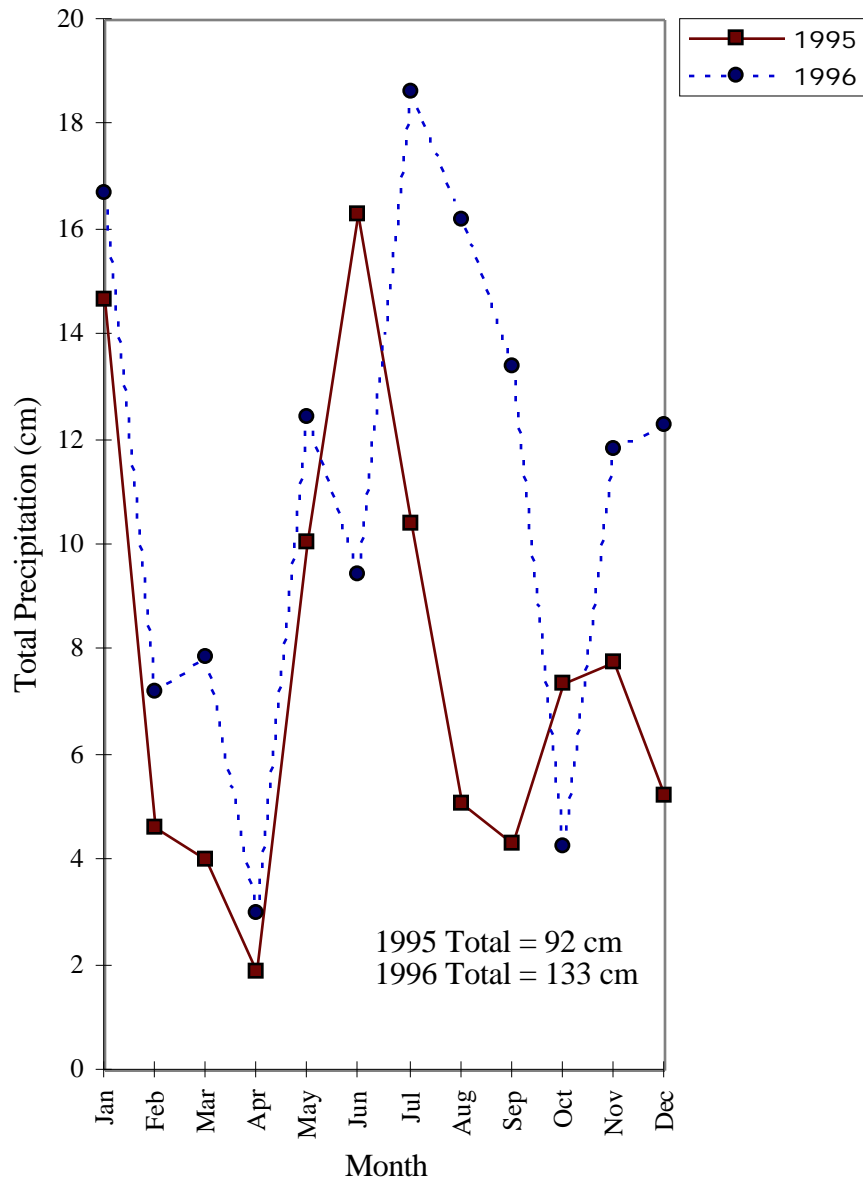


Figure 1.11. Total precipitation for each month in 1995 and 1996. Data are from the National Weather Service station at the Blacksburg Regional Airport, Blacksburg, Virginia.

CHAPTER 2

HOME RANGE AND HABITAT PREFERENCE OF BOG TURTLES (*Clemmys muhlenbergii*) IN SOUTHWESTERN VIRGINIA

INTRODUCTION

In Virginia, bog turtles occupy upland freshwater wetlands characterized by spring-fed wet meadows and seepages (Mitchell 1994). The plant associates within areas occupied by bog turtles have been described (Tryon and Herman 1990, Ernst et al. 1994) as has the relationship between population size and certain habitat characteristics (Chase et al. 1989). However, the relative preference of bog turtles for particular habitat features, such as substrate depths and specific habitat types, remains unknown. Information about turtle selection of specific habitat features is needed for habitat management.

Wetland habitats in southwestern Virginia are patchily distributed over the landscape and extant bog turtle populations in Virginia are limited to these relatively small and isolated patches (Buhlmann et al. in press). If animals are closely tied to particular habitat features that meet specific biological requirements (e.g., food or shelter), then the size, number, and spatial distribution of these patches may influence the persistence of remaining populations (Wiens 1996).

A potentially important habitat characteristic of wetlands occupied by bog turtles in Virginia may be the presence of spring-fed seepages. In Maryland, bog turtles are closely associated with “spring-fed pockets of shallow water” and “a bottom substrate of soft mud and rock” (Chase et al. 1989). The greatest distance any turtle was observed away from water was 7 m in Maryland. Such a close association with particular microhabitat variables may imply habitat specialization by bog turtles. Bog turtles commonly occur in small pools of mud and water that they use for escape and hibernation (Holub and Bloomer 1977) and thermoregulation (Ernst 1977).

The size of a home range helps define the usual movements of an animal during its lifetime (White and Garrott 1990) and may be useful when comparing the area requirements of particular species. Previous home range sizes reported for bog turtles in Maryland were 0.176 ha for males and 0.066 ha for females 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 Minimum Convex Polygon (MCP) technique (Ernst 1977). Such a large discrepancy in home range size for these two locations may be a result of using different home range estimation techniques or geographic differences in habitat characteristics.

A variety of home range estimation techniques are available, although no single technique is error free (White and Garrott 1990). Using Monte Carlo simulation, harmonic

mean estimators have been shown to be one of the least biased for several data types, but are also one of the least accurate techniques (Boulanger and White 1990). The precision of this technique is reduced because it is nonparametric and no specific home range shape is assumed. A problem associated with the MCP technique is the potential for incorporating unused areas of habitat into the home range estimate (Kenward 1987). The possibility for error is especially high when animal locations are distributed as multiple clusters of use (Kenward 1992). Consequently, the MCP technique overestimates home range area for patchily distributed location data.

When the distribution of animal locations contains isolated areas of activity, separated by areas the animals rarely visit, cluster analysis may be an appropriate technique (Badyaev et al. 1996). Cluster analysis reduces the potential for the inclusion of unused habitat by identifying clusters of locations and grouping them according to a specified joining method (Kenward 1992). Convex polygons are then drawn around clusters for a specified percentage of area. Although cluster analysis attempts to rectify the problem of inclusion of unused areas, an underestimation bias may be introduced with this technique if the number of locations is small. A compromise between both techniques might address the biases toward over- and underestimation of home range size.

In this study I use both techniques to provide a potential range of home range sizes, with MCP likely overestimating home range area and cluster analysis likely underestimating it. I do not use harmonic mean analysis here because of its potentially inaccurate results (Boulanger and White 1990), and its dependency on a pre-defined grid size that makes comparisons to other estimates using the same technique difficult (White and Garrott 1990).

I used radiotelemetry to gather information on home ranges and habitat preferences of bog turtles at 3 sites in southwestern Virginia. My study objectives were to: 1) quantify home range size of bog turtles, and determine if differences in home range size or habitat selection between male and female bog turtles exist; 2) determine which habitat types were preferred or avoided; and 3) quantify important microhabitat characteristics within used areas. The overall goal of these objectives was to identify important habitat characteristics within my study populations that may help managers maintain habitats and also to describe potential area requirements of bog turtles.

METHODS

Study Areas

Three study areas in Floyd County, Virginia, were selected based upon previous (Mitchell and Buhlmann 1991, Buhlmann 1992) and recent surveys for bog turtles. Exact locations are not given in this paper because of the endangered status of the bog turtle in Virginia. Two of the areas are grazed, wet meadows with spring seepages and rivulets. The third is an abandoned beaver pond. All 3 areas are separated from each other by mixed deciduous forest and are all contained within an area 2.5 km in diameter. Two convergent streams connect each of the 3 sites.

Radiotelemetry

Radiotelemetry techniques used in this study are described in Chapter 1.

Sampling Strategies

Radio locations

Radiotracking began in May of 1995 and 1996 and continued until mid-December of each year. When I located a turtle, I recorded its position as a bearing (nearest^o) and distance (nearest 1.0 m) from a known location. Known locations, or “fixes”, are landmarks for which Universal Transverse Mercator (UTM) coordinates are known. I measured the UTM coordinates for fixes using a Corvallis GPS receiver. I measured linear distances between fixes to the nearest meter using a meter tape and adjusted UTM coordinates to reflect 2-m accuracy with the ground-truthed distances.

The x,y coordinates for all turtle locations then were calculated based upon their bearing (converted to radians) and distance from fixes using trigonometry (White and Garrott 1990). As a result, the x,y coordinates used should reflect 4 m² accuracy if bearings and distances were recorded without error.

All radio locations were collected at sampling intervals 24 hours and were assumed to represent independent samples (Swihart and Slade 1985a). Nine turtles were radiotracked in both 1995 and 1996. I assumed the data collected across years for the same individuals were not independent. Pooling data across years for some individuals, but not for all, would not allow representative comparisons for all individuals (e.g., home range estimates). Also, if any individual shifted its home range across years, the pooled home range may be inflated. Consequently, data for individuals that were radiotracked across multiple years were treated as discrete annual samples for home range analyses but pooled for habitat preference analyses (Appendix 2.2).

Habitat Use

When a turtle was located in 1995 and 1996, I measured 3 elements of the surrounding habitat - vegetation type, water depth, and mud depth. In 1995 only, I measured additional habitat elements - vegetation height, canopy density, and distance to water. In 1996, I measured the presence or absence of water at previous turtle locations. The vegetation type was determined within approximately 2.5 m diameter circle centered on the turtle's location. I classified habitats into 7 habitat types - alder (*Alnus serrulata*), bulrush (*Scirpus* spp.), stream, dry meadow, wet meadow, alder edge, and bulrush edge. If two-thirds or greater of the canopy area of vegetation within the circular plot was composed of a single genus of plant, that genus was used to designate the category (i.e., alder or bulrush). The surface area of water was substituted for the canopy area of vegetation when large areas of water were present in the habitat sample (i.e., stream). If the circular plot contained a heterogeneous assemblage of wetland-associated plants in which no particular genus constituted two-thirds or more of the plot, it was assigned to the wet meadow category. Alternatively, if the plot contained a mixed assemblage of meadow/old field associates, it was assigned to the dry meadow category. The 2 edge categories, alder edge and bulrush edge, were recorded when a plot within a discernible habitat type edge contained 1/3rd or more of each of two genera of plants. Although many potential edge categories exist, only alder edge and bulrush edge are examined because of little representation of other edge categories. The 2 edge categories I describe are not mutually exclusive. When both alder and bulrush occupied more than 1/3rd of the circular plot, it was considered both alder edge and bulrush edge habitat. This was rarely observed however, and those samples were excluded from subsequent analysis.

To assess mud and water selection, I measured the depths of these features at turtle locations and random locations. Depths were measured with a 6-mm diameter dowel. Water depth (to the nearest cm) was defined as the distance from the surface to the transition zone of the water/mud interface. I measured soft substrate depth to the point of first refusal. The point of first refusal was determined by pushing the dowel vertically into the substrate until it met with complete resistance and could be pushed no further.

Water depths were recorded at bog turtle locations in 1995 and 1996. Mud depths were only measured in 1996. I measured mud and water at the location of first sighting ("At") and at the 4 cardinal directions approximately 1/4 m and 3/4 m (one arm's length and two arm's length, respectively) away from the center location (Appendix 2.1). This sampling method yielded 9 water and mud depths for each turtle location and each random location. The repeated samples at 2 distances from the turtle location were used to provide a contour of the surrounding mud and water environment.

Random locations for mud and water depth measurements were selected based upon a random bearing (0-360°) and distance (0-100 paces [47 m]) from the sighted turtle's location. I chose a distance of 100 paces because this approximated the radius of an average home range in 1995. Random locations provided paired estimates of mud and water availability. Soil moisture and water conditions can vary seasonally. The wetlands occupied by bog turtles become drier during late summer and early fall and thus preclude measurement of total mud and water availability at a single point in time for all turtles.

Consequently, I collected a random sample of mud and water depth each time a turtle was located. In this way, I accounted for any differences in seasonal availability of mud and water.

In 1995 only, random locations were used to provide paired estimates of overall vegetation height and canopy density at the study areas. Maximum vegetation height at turtle-centered and random locations was measured to the nearest cm with a graduated measuring pole. Canopy density was measured using the ratio of light intensity (lux) at 1-m and ground-level heights. A ratio of light intensity was used instead of a single, ground-level measurement to account for overcast conditions on some sampling days. The light intensity above the vegetation canopy (i.e., 1 m height) was divided by the light intensity striking the soil surface (i.e., ground-level height) to provide a ratio of light occluded by the vegetation canopy. A large light ratio value reflected relatively more canopy coverage than a low ratio value.

The distance to water (nearest 0.5 m) was measured from turtle-centered and random locations to assess any association between bog turtle presence and surface water. Pockets of water larger than the average body size of a bog turtle (30 mm x 90 mm) were considered when measuring distances.

In 1996 only, I measured the presence or absence of surface water within 2.5 m of radioed turtles' previous locations. When a turtle was located using radio telemetry, its current location was marked. Upon subsequent location, I recorded if water was at the turtle's previously marked location. By monitoring if water was still available at a turtle's previous location, I could determine if turtle movements out of an area were associated with habitat drying.

Habitat Availability

I measured habitat availability at each of the 3 study sites using line transects. All transect measurements were made during August and September of 1996. Total available habitat at each site was defined as the area delimited by 10 m beyond the outermost radio locations of bog turtles within each site. Line transects were established south-to-north at each site. I initiated the first transect in the far southwest corner of the defined perimeter and extended it at 0° until the northernmost perimeter was reached. Subsequent transects ran parallel to each previous transect and were laid eastward until the far east perimeter of the study area was reached. Each subsequent transect was initiated 5 m east of the previous transect.

I recorded vegetation categories at 5-m intervals along each south-to-north transect using the circular plot protocol described above. This provided a 2.5-m diameter circle of a vegetation category for each 5 x 5-m² transect area at the study site. In addition to recording the habitat type at each 5-m interval along the transect, I used a point-intercept technique (Bonham 1989) to identify the genus of the plant directly below the 5-m increment of the transect line. A 6-mm diameter dowel was dropped perpendicular to each 5-m increment along the transect. The genus of the first plant the dowel intercepted was recorded. This provided a list of genera contained within each of the 7 habitat categories

described earlier. A plant list and frequency distribution of the genera found within each of the 7 habitat categories was then constructed.

The availability of habitats to each turtle was assumed to be site-specific. Although the 7 habitat categories were represented at each of the study areas, the relative proportions of those habitats were not necessarily equal. Some sites contained more or less of any given habitat than other sites. Consequently, the availability I measured for each site I considered available only for turtles at each given study area. The sizes of each study area were estimated by multiplying the total number of habitat plots measured at each site by the size of each plot (25 m²).

Habitat Selection Assessment

I define habitat selection (= habitat preference) as the occupancy (= use) of specific habitat types by bog turtles significantly more than is expected if these habitat types were used in proportion to their availability. Under this definition, if habitat use by bog turtles is random, they will use particular habitats in direct proportion to the amount in which those habitats were present.

I used compositional analysis (Aebischer et al. 1993) to provide a relative ranking of selected and non-selected habitat types. Previously available techniques used to evaluate habitat preference violate several statistical assumptions (Alldredge and Ratti 1986, 1991), namely independence of proportions and maintaining a lack of serial correlation (Swihart and Slade 1985b). The proportions that describe habitat use must sum to one (the unit-sum constraint). A consequence of this constraint is that any preference for a particular habitat leads to an apparent avoidance of another habitat (Aebischer et al. 1993). Compositional analysis (Aitchison 1986) uses log-ratio analysis ($\ln [x_{U2}/x_{U1}] - \ln [x_{A2}/x_{A1}]$, where x_{U1} , x_{U2} , are proportions of habitat use and x_{A1} , x_{A2} , are proportions of available habitat) of proportional data to overcome the lack of independence of proportions.

Home Range Estimation

Minimum Sample Sizes

I used Incremental Area Analysis (IAA) to define the minimum number of locations required to calculate home range estimates (Kenward 1996). This technique plots home range area as a function of each successive radio location. An outline is drawn around the first 3 fixes and an area estimate is calculated based upon the specific home range technique used. Each successive fix is added to the area estimate until all of the locations are used. The minimum number of locations is determined by visually estimating when the area estimate stabilizes. Stabilization occurs when an additional successive location does not increase the estimated home range area, resulting in a level area curve.

Analytical Procedures

For comparison purposes, the 95% home range size was calculated for each turtle using both the MCP and cluster techniques with RANGES V (Kenward 1996). The harmonic mean of all radio locations was used to estimate the group center for both

techniques. Cluster analysis uses a nearest neighbor joining method to join groups of locations. It begins the first cluster of points by identifying the 2 locations that are closest together and have the nearest 3rd location. It then selects the next closest location to the cluster and assigns it to either the first cluster or a new cluster based upon the smallest distances between locations (Kenward 1987). Convex polygons are then drawn around the final clusters to estimate home range area.

Statistical Procedures

Log-ratios of habitat use and habitat availability were calculated using the bulrush edge habitat category as a denominator. The choice of denominator does not affect the results of the analysis because of the invariance properties of log-ratio transformations (Aitchison 1986). When turtle use was 0%, zero values were replaced with 0.01% to avoid division by zero. This substitution is necessary and does not affect the outcome of ranking (Aebischer et al. 1993). One assumption of compositional analysis is that the compositions derived from different animals are equally accurate. However, this assumption may fail if the number of radio locations differ greatly between animals. A suitable adjustment for unequal sample sizes between individuals is to weight individuals by the square root of the number of samples (Aebischer et al. 1993). I weighted the differences in log-ratios for each turtle by the \sqrt{n} before calculating the pairwise differences. If habitat use is random, the average log-ratio difference should equal 0.0 (Aebischer and Robertson 1992). The differences from 0.0 over all habitat types were examined for significance simultaneously using a MANOVA and Wilk's lambda test. Using a MANOVA model also allows for the comparison of non-random habitat use when classed by sex. This allowed me to test for differences between the sexes explicitly in the MANOVA approach. If used habitat types differed significantly from random for at least 1 habitat type, average pairwise differences between each habitat combination were calculated and compared to a t_{df-1} distribution (2-sided) for significance ($\alpha = 0.05$). Habitats were then ranked in the order of preference. A lack of significant difference between ranked habitats suggests their ranks are interchangeable (Aebischer and Robertson 1992).

Mud and water depths, vegetation heights, canopy density measurements, and distances to nearest water, collected at turtle-centered locations and paired random locations were compared using a Wilcoxon Signed-Rank test ("WS"). The median difference between turtle-centered and random plots was expected to be greater than 0.0 for all paired samples. Mud and water depths within each plot were compared using a Mann-Whitney test ("W"). Movement by bog turtles out of areas no longer containing water into areas containing water was tested for significance using the McNemar test ("Wp") for significance of changes (Conover 1980). Only net distances - average were considered for analysis because only large-scale movements were expected to be the result of water-finding behavior. Differences in home range size for each technique were compared using a Mann-Whitney test. Differences in home range size and number of cluster nuclei (cluster technique) were compared with respect to sex using a Mann-Whitney confidence interval test.

MCP and cluster analysis home range estimates were tested for differences using a Wilcoxon Signed-Rank test. The median difference between cluster analysis estimates and the MCP technique was expected to be significantly < 0.0 because of the probable underestimation of the cluster technique and/or the overestimation of the MCP technique.

RESULTS

Habitat Selection

Habitat availability was based on 2,370 circular plots at the 3 sites. Genera of plants in each of the 7 habitat types are listed in Appendix 2.3. The estimated study area sizes were 33.2 ha, 18.7 ha, and 7.4 ha. Seventeen females and 12 males were selected for analysis (Tables 2.1, 2.2). Log-ratio differences were significantly different from 0.0 among habitat types for both males and females (Wilk's lambda [], males: $F = 0.15$, $P = 0.0300$; females: $F = 0.17$, $P = 0.0030$), but showed no difference with respect to sex ($F = 0.77$, $P < 0.4411$). The sexes were then pooled for subsequent analysis. The overall ranking of habitat categories was: wet meadow > bulrush > alder edge > alder > bulrush edge > dry meadow > stream (Table 2.3). Site differences could not be tested for significance explicitly in the MANOVA because of small sample sizes at 1 site. However, separate preference rankings were completed for qualitative comparison (Table 2.4). When the relative preference rankings were compared across study areas, the general pattern of selection was equivalent (Table 2.5).

In 1995, water depth measurements were taken for 17 turtles an average of 10 times each (Table 2.6). An average value for each individual turtle was calculated and used in the comparison. Water depth (mean [SE]) was significantly deeper ($WS = 152.0$, $P < 0.001$) at turtle locations ($\bar{x} = 8.15$ cm [1.2]) than at random locations ($\bar{x} = 1.40$ cm [0.5]). In 1996, water and mud depth measurements were taken for 27 turtles an average of 19 times each (Table 2.6). All paired differences between water depth and mud depth measurements at turtle locations and at random locations were significantly greater than 0.0. Within each plot, water depth differed significantly between turtle-centered and both the 1/4-m and 3/4-m locations while mud depth did not (Table 2.6). Water depth was significantly deeper at turtle-centered locations than at either of the 1/4-m and 3/4-m locations ($W = 968.0$, $P < 0.001$ and $W = 986.5$, $P < 0.000$, respectively). All other within-plot mud and water comparisons were not significant.

In 1995, vegetation height measurements were taken for 23 turtles an average of 6 times each. Vegetation height was significantly higher ($WS = 230$, $P = 0.0050$) at turtle locations ($\bar{x} = 55$ cm [3.8], range: 0.2-1.1 m) than at random locations ($\bar{x} = 36$ cm [6.5], range: 0.0-1.1 m). Light intensity ratios (= canopy density) were constructed for 24 turtles (1995, 6 observation/turtle). Canopy density was significantly higher ($WS = 252$, $P = 0.004$) at turtle locations ($\bar{x} = 13$ [2.0], range: 2-34) than at random locations ($\bar{x} = 7$ [1.3], range: 1-26).

In 1995, bog turtles selected areas significantly closer to water ($\bar{x} = 1$ m [0.4], range: 0-7 m, $WS = 0.0$, $P < 0.000$) than was randomly available ($\bar{x} = 11.5$ m [1.9], range: 0.5-40 m). In 1996, water presence or absence at previous turtle locations was not a good predictor of average movement ($n = 24$, 6 observations/turtle, $W_p = 1.78$, $P > 0.7500$). Bog turtles were equally likely to move out of areas containing or devoid of water.

Home Range Size

Incremental analysis showed home range areas stabilizing when an average of 17 locations were used (Table 2.7). I used 17 locations as the minimum sample size required for a stable home range estimate. I constructed home range estimates using both MCP and cluster analysis techniques for 13 female and 12 male bog turtles (Table 2.7). The home ranges for males in 1995 did not differ from those for 1996 using cluster analysis (1995: $\bar{x} = 0.06$ [0.020], 1996: $\bar{x} = 0.18$ [0.062]; $W = 24$, $P = 0.1222$) or MCP (1995: $\bar{x} = 0.17$ [0.083], 1996: $\bar{x} = 0.81$ [0.261]; $W = 22$, $P = 0.0658$). Likewise, the home ranges for females in 1995 did not differ from those in 1996 using cluster analysis (1995: $\bar{x} = 0.26$ [0.168], 1996: $\bar{x} = 0.14$ [0.043]; $W = 58$, $P = 0.7232$) or MCP (1995: $\bar{x} = 0.47$ [0.160], 1996: $\bar{x} = 0.51$ [0.106]; $W = 50$, $P = 0.7245$). Five females were tracked across both sampling years. Because I found no significant differences in home range across years for females and the dispersion of turtle locations across years appeared equal (Appendices 2.4, 2.5), I averaged the home range estimates for these 5 turtles for further analysis (Table 2.7).

Home range sizes for males and females did not differ (cluster: $W = 192.5$, $P = 0.722$; MCP: $W = 194.5$, $P = 0.785$). The average 95% home range size (mean [SE]) for females ($n = 12$) was 0.17 ha [0.05] (range: 0.04 - 0.59) based on cluster analysis and 0.47 ha [0.10] (range: 0.09 - 1.06) using MCP analysis. The average 95% home range size for males ($n = 13$) was 0.13 ha [0.04] (range: 0.01 - 0.55) using cluster analysis and 0.57 ha [0.18] (range: 0.02 - 1.25) using MCP analysis (Table 2.7). The 95% home range estimates based on cluster analysis were significantly smaller for both males and females than estimates using the MCP method ($WS = 0.0$, $P = 0.003$ and $WS = 0.0$, $P = 0.001$, respectively). The number of clusters contained within a home range did not differ ($W = 184.5$, $P = 0.489$) between males ($\bar{x} = 2.08$ [0.21]) and females ($\bar{x} = 2.41$ [0.36]). Home range area did not differ between the 3 study sites ($H = 1.39$, $P = 0.4980$).

DISCUSSION

The results of compositional analysis do show a relative preference among habitat types but no single habitat category was selected more than all others. However, bulrush and wet meadow areas usually were selected by bog turtles, and streams and dry meadow habitat usually were not selected. Although I compare habitat preference over all sites, I account for site-specific differences by using the availability calculated for each site. The rankings of habitat preference for individual sites can only be interpreted qualitatively (Tables 2.4, 2.5) because of the small sample sizes at sites 2 and 3 (7 and 6 turtles, respectively). Compositional analysis requires > 6 individuals to show significant preference, but a sample of 30 individuals is recommended (Aebischer et al. 1993).

The results of any preference assessment are dependent upon the habitat categories that are compared. For this study, I tried to choose habitats that could be easily identified and seemed biologically meaningful. Sedges, rushes, and alders are frequently associated with wetlands containing bog turtles (Tryon and Herman 1990, Ernst et al. 1994), and streams may be important as corridors for movement (Buhlmann et al. in press). The 2 edge categories were included to examine if transition zones between habitats were used more than expected. If bog turtles require several habitat types to meet specific biological requirements, then areas that contain both types should be used more than expected randomly. For example, if bog turtles use bulrush patches for cover and wet meadow areas for foraging, then a transition zone (e.g., bulrush edge) could provide both of these functions. The results of compositional analysis do not support a strong selection of these areas more than expected randomly. The 2 edge habitat categories were neither selected or avoided (Table 2.5).

The seasonal preference for particular habitats was not investigated here because of small and unequal samples throughout the year. Qualitative examination of seasonal variation in habitat use shows a pattern similar to the results of compositional analysis (Table 2.8). I calculated the frequency of use of the 7 habitat types by males and females for each month in 1995 and 1996. Sample sizes for each month are unequal and represent 1 to 14 individuals (Table 2.8). I interpret these data not as a lack of preference for any single habitat, but as a selection of several habitats throughout 1995-1996. Selection of multiple habitats throughout a season and the lack of a singular habitat type preference suggest that bog turtles may be using different habitats to meet different requirements.

In 1995, bog turtles selected areas of habitat with higher vegetation and greater canopy density. Collection of these data was discontinued in 1996 because of the probable correlation of these variables with water. Any non-random selection of higher or denser vegetation by bog turtles may only reflect selection for water by the turtles because wetland vegetation often grows taller and denser than surrounding plants at the study areas. Consequently, detailed mud and water measurements were collected in lieu of vegetation measurements in the subsequent year.

Bog turtles selected areas closer to water and containing significantly deeper mud and water than what was available randomly. As in the Maryland study (Chase et al. 1989), in 1995 no turtle was ever observed > 7 m from water. Also, water depth at turtle-centered locations was significantly deeper than that at either 1/4-m and 3/4-m distances. This suggests turtles select areas containing standing water on a relatively small (1.5-m diameter) scale. The mud and water associated with turtle-centered locations was deeper than expected if selection was random within habitats. Such a close association of bog turtles with mud and water may imply they use this soft substrate to meet specific biological requirements. Predator avoidance is one possibility. These turtles are commonly found submerged in mud, either actively escaping or inactive. The use of radiotracking to collect habitat and substrate information undoubtedly introduces bias into the data (White and Garrott 1990). If bog turtles exhibit escape behavior when they are located, the habitat selection data I present here may be biased toward habitat selection of escaping bog turtles. Subsetting the data according to behavior may better address biases, however sample sizes are substantially reduced when data are subdivided and behaviors are often difficult to categorize.

In 1996, I recorded the behavior of each turtle when it was first sighted to qualitatively assess if any particular behavior was prominent (e.g., escaping). The behavioral categories I chose were - active, basking (inactive above the surface), escaping, and inactive (fully or partially submerged in mud or water). Active behavior was when the turtle was moving, but did not appear to respond to the person tracking it. A turtle was considered escaping when it appeared to move quickly away from the person tracking it. A turtle was considered basking when its shell was dry and its head and limbs were extended out of its shell. A turtle was considered inactive when it was within its shell and was partially or fully submerged in mud or water. These categories may not always be exclusive, and were used only to provide qualitative information. No particular behavior was clearly dominant for males or females when they were first sighted (Table 2.9). Consequently, I believe the strong selection for deep mud and water reflect an overall preference rather than a particular behavioral response.

The absence of water at previous locations did not cause larger than average movements by bog turtles. Water was found in areas where turtles were previously located as often as it was absent. This suggests habitat drying may not be a primary factor in determining movement by bog turtles out of particular areas of habitat.

Home range sizes for 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 range in freshwater turtles are conflicting and that any differences in the size of home ranges between males and females may be species-specific. My data do not confirm any tendency for males to have larger home ranges than females, although this has been reported in other studies of bog turtles (Ernst 1977, Chase et al. 1989). No sexual differences were discovered using cluster analysis or the MCP technique. A lack of difference might reflect a small sample size or some sample bias. Yet, the sample sizes I report are larger than several studies that showed sexual differences.

Chase et al. (1989) based home range differences upon a comparison of 2 males and 2 females. Although Ernst (1977) used 19 bog turtles to estimate home range, no turtles were located > 10 times in his study. Additionally, I found no significant differences in average daily movements with respect to sex by bog turtles during the same reporting period (see Chapter 1). Further investigation into the reasons for differential movement by sex should be investigated in Virginia to determine if a true difference exists with respect to sex.

CONCLUSIONS

My data suggest bog turtles prefer specialized areas of habitat. The presence of soft mud and water were closely associated with bog turtle occupancy. No particular habitat type was consistently the most preferred of the habitats I examined, yet 2 habitats (i.e., wet meadow and bulrush) were selected significantly more often than expected randomly. A mosaic of habitat types may be utilized by this species, rather than any particular habitat. Soft substrate and persistent water seem to be important in determining where bog turtles are found. This may be of special concern to managers, as many of the vegetation types I describe do not necessarily coincide with soft substrate or spring-fed seepages. Many *Carex* spp., *Scirpus* spp., and *Juncus* spp. dominated wetlands in southwestern Virginia do not contain the soft substrate preferred by bog turtles. Multiple habitat types that may serve separate, biological functions, and spring-fed seepages or deep, alluvial soils that contain persistent water and soft mud should be protected and maintained within wetlands occupied by bog turtles.

Table 2.1. Percentage use and availability (mean [SE]) of 7 habitat types for male and female bog turtles. Use is defined by the percentage of radio locations for each turtle found within a particular habitat type. Availability is defined by vegetation sampling at 3 study areas in southwestern Virginia (1995-1996).

Habitat Type	Male Use ($\underline{n} = 12$)	Female Use ($\underline{n} = 17$)	Available Habitat
Dry Meadow	10.89 (3.43)	11.75 (4.58)	58.67 (13.50)
Wet Meadow	26.38 (6.16)	28.75 (6.69)	9.67 (1.45)
Alders	14.71 (4.73)	35.59 (8.00)	21.33 (12.83)
Scirpus	32.27 (6.87)	13.50 (5.28)	4.67 (2.03)
Stream	0.77 (0.76)	0.84 (0.61)	3.67 (2.19)
Alder edge	7.95 (4.62)	8.34 (2.18)	1.34 (0.67)
Scirpus edge	0.36 (0.35)	1.26 (0.57)	0.67 (0.33)

Table 2.2. Percentage of habitat use and availability of 7 habitat categories* by male and female bog turtles at 3 sites in southwestern Virginia (1995-1996). See text for definitions of habitat categories. The turtle identification number and the sampling year are provided. Zero percent use was replaced by 0.01 percent (Aebischer et al. 1993) to construct log-ratios.

	# locations	DM	WM	A	Sc	St	AE	SE
Females								
1-95	8	0	63	12	12	13	0	0
2-95	6	0	67	33	0	0	0	0
3-95,96	50	4	28	0	68	0	0	0
4-95,96	39	0	10	28	56	0	0	0
5-95,96	35	0	9	6	69	0	16	0
6-95,96	32	16	31	0	53	0	0	0
7-95,96	23	26	30	5	30	0	0	0
8-95,96	6	0	50	0	50	0	0	0
9-96	36	3	28	0	57	0	6	6
10-96	24	17	8	63	0	0	12	0
11-96	24	38	8	8	46	0	0	0
12-96	20	0	0	40	55	0	5	0
13-96	16	6	50	44	0	0	0	0
14-96	15	13	14	0	73	0	0	0
15-96	11	45	19	0	18	0	18	0
16-96	9	0	0	11	11	0	78	0
17-96	6	17	83	0	0	0	0	0
Males								
1-95	14	0	86	0	14	0	0	0
2-95	8	49	25	13	0	0	13	0
3-95	7	29	57	0	0	0	14	0
4-95,96	45	7	20	49	11	7	4	2
5-95,96	39	0	11	28	56	0	0	5
6-95,96	34	6	35	15	38	0	6	0
7-95,96	33	0	21	30	30	3	12	4
8-96	28	7	29	31	4	0	35	4
9-96	26	4	8	80	4	0	4	0
10-96	24	8	0	79	5	0	8	0
11-96	16	31	31	38	0	0	0	0
12-96	14	0	22	64	0	0	14	0
Site								
1	1328	38	7	46	5	1	2	1
2	747	84	10	3	1	2	0	0
3	295	54	12	15	8	8	2	1

*Habitat category abbreviations: DM = dry meadow, WM = wet meadow, A = alder, Sc = scirpus, St = stream, AE = alder edge, SE = scirpus edge

Table 2.3. Matrices of pairwise log-ratio differences for 7 habitat categories* used by bog turtles (sexes combined) over all sites. Significance is upon a t-distribution (two-sided). A significant (0.05), positive value is shown by "+++" and a significant, negative value is shown by "---". Non-significant positive and negative differences are shown by a "+" and "-" respectively. Rankings are calculated by tallying positive and negative differences. Final ranks show relatively non-selected (0) to most selected (6) habitats.

	DM	WM	A	Sc	St	AE	SE
Dry Meadow		-5.78	-1.94	-3.54	1.10	-3.31	-1.43
Wet Meadow	5.78		2.51	0.66	9.60	1.44	5.48
Alder	1.94	-2.51		-1.70	4.19	-1.27	1.00
Scirpus	3.54	-0.66	1.70		6.57	0.78	3.80
Stream	-1.10	-9.60	-4.19	-6.57		-5.43	-4.71
Alder Edge	3.31	-1.44	1.27	-0.78	5.43		2.63
Scirpus Edge	1.43	-5.48	-1.00	-3.80	4.71	-2.63	

	DM	WM	A	Sc	St	AE	SE	Rank
Dry Meadow		---	-	---	+	---	-	1
Wet Meadow	+++		+++	+	+++	+	+++	6
Alder	+	---		-	+++	-	+	3
Scirpus	+++	-	+		+++	+	+++	5
Stream	-	---	---	---		---	---	0
Alder Edge	+++	-	+	-	+++		+++	4
Scirpus Edge	+	---	-	---	+++	---		2

*Habitat category abbreviations: DM = dry meadow, WM = wet meadow, A = alder, Sc = scirpus, St = stream, AE = alder edge, SE = scirpus edge

Table 2.4. Matrices of pairwise differences between habitat types* for bog turtles (sexes combined) at each study site (1995-1996). Significance is based upon a t-distribution (two-sided). A significant (0.05), positive value is shown by "+++" and a significant, negative value is shown by "---". Non-significant positive and negative differences are shown by a "+" and "-" respectively. Rankings are calculated by tallying positive and negative differences. Final ranks show relatively non-selected (0) to most selected (6) habitats.

Study Site 1							
	DM	WM	A	Sc	St	AE	SE
Dry Meadow		-3.10	-0.72	-2.42	1.11	-1.50	0.05
Wet Meadow	3.10		1.60	-0.46	5.31	0.98	3.85
Alder	0.72	-1.60		-1.83	2.20	-0.87	1.20
Scirpus	2.42	0.46	1.83		4.72	1.24	3.64
Stream	-1.11	-5.31	-2.20	-4.72		-3.27	-1.46
Alder Edge	1.50	-0.98	0.87	-1.24	3.27		1.84
Scirpus Edge	-0.05	-3.85	-1.20	-3.64	1.46	-1.84	

	DM	WM	A	Sc	St	AE	SE	Rank
Dry Meadow		---	-	---	+	-	+	1
Wet Meadow	+++		+	-	+++	+	+++	5
Alder	+	-		-	+++	-	+	3
Scirpus	+++	+	+		+++	+	+++	6
Stream	-	---	---	---		---	-	0
Alder Edge	+	-	+	-	+++		+	4
Scirpus Edge	-	---	-	---	+	-		2

Study Site 2							
	DM	WM	A	Sc	St	AE	SE
Dry Meadow		-3.62	-0.14	-0.80	0.95	-1.30	-0.70
Wet Meadow	3.62		3.14	2.56	30.13	2.01	4.71
Alder	0.14	-3.14		-0.42	1.08	-0.94	-0.36
Scirpus	0.80	-2.56	0.42		1.96	-0.58	0.37
Stream	-0.95	-30.13	-1.08	-1.96		-2.82	-2.86
Alder Edge	1.30	-2.01	0.94	0.58	2.82		1.04
Scirpus Edge	0.70	-4.71	0.36	-0.37	2.86	-1.04	

	DM	WM	A	Sc	St	AE	SE	Rank
Dry Meadow		---	-	-	+	-	-	1
Wet Meadow	+++		+++	+++	+++	+	+++	6
Alder	+	---		-	+	-	+	2
Scirpus	+	---	+		+	-	+	3
Stream	-	---	-	-		---	---	0
Alder Edge	+	-	+	+	+++		+	5
Scirpus Edge	+	---	-	-	+++	-		4

Table 2.4 (Cont.)

	Study Site 3						
	DM	WM	A	Sc	St	AE	SE
Dry Meadow		-3.18	-2.71	-3.83	-1.09	-1.98	-1.55
Wet Meadow	3.18		1.64	-1.65	2.53	1.71	2.43
Alder	2.71	-1.64		-2.04	1.00	-0.08	0.24
Scirpus	3.83	1.65	2.04		2.54	2.21	3.00
Stream	1.09	-2.53	-1.00	-2.54		-0.78	-0.64
Alder Edge	1.98	-1.71	0.08	-2.21	0.78		0.47
Scirpus Edge	1.55	-2.43	-0.24	-3.00	0.64	-0.47	

	DM	WM	A	Sc	St	AE	SE	Rank
Dry Meadow		---	---	---	-	-	-	0
Wet Meadow	+++		+	-	+	+	+	5
Alder	+++	-		-	+	-	+	4
Scirpus	+++	+	+		+	+	+++	6
Stream	+	-	-	-		-	-	1
Alder Edge	+	-	+	-	+		+	3
Scirpus Edge	+	-	-	---	+	-		2

*Habitat category abbreviations: DM = dry meadow, WM = wet meadow, A = alder, Sc = scirpus, St = stream, AE = alder edge, SE = scirpus edge

Table 2.5. Results of pairwise comparison rankings to determine habitat types selected by bog turtles in southwestern Virginia. Habitat types are described in methods. Underlined categories are not significantly different (0.05).

Overall						
Wet Meadow	Scirpus	<u>Alder Edge</u>	<u>Alder</u>	Scirpus Edge	Dry Meadow	Stream
Site 1						
Scirpus	Wet Meadow	<u>Alder Edge</u>	Alder	Scirpus Edge	Dry Meadow	Stream
Site 2						
Wet Meadow	<u>Alder Edge</u>	Scirpus Edge	Scirpus	Alder	<u>Dry Meadow</u>	Stream
Site 3						
Scirpus	Wet Meadow	Alder	<u>Alder Edge</u>	Scirpus Edge	Stream	Dry Meadow

Table 2.6. Mud and water depths (mean [cm] [SE]) taken at bog turtle-centered ($n = 513$) and paired random locations during 1996. Measurements at 1/4 m and 3/4 m represent averages collected at 4 cardinal directions. Results of a Wilcoxon Signed-Rank test were significant ($P < 0.001$) for all turtle-centered and random comparisons.

Turtle-centered plots	Measurement Location		
	Center	1/4 m distance	3/4 m distance
Water - 95	8.15 (1.20)	-	-
Water - 96	5.18 (0.70)	2.43 (0.39)	2.10 (0.30)
Mud - 96	24.26 (1.28)	28.50 (1.31)	27.32 (1.27)
Random-centered plots	Center	1/4 m distance	3/4 m distance
Water - 95	1.40 (0.50)	-	-
Water - 96	0.79 (0.22)	0.65 (0.17)	0.63 (0.17)
Mud - 96	12.51 (1.37)	13.93 (1.47)	12.95 (1.30)

Table 2.7. Home range areas (ha) of male and female bog turtles in southwestern Virginia (1995-1996), estimated using cluster (CL) and Minimum Convex Polygon (MCP) analysis. Means (ha [SE]) are provided at the bottom of the table. Estimates are equal for both techniques when cluster analysis results in one nucleus. Home range estimates for 1995 and 1996 were not significantly different.

	# locations	IAA*	95% CL	# clusters	95% MCP
Males					
1-95	25	19	0.14	2	0.41
2-95	24	20	0.02	1	0.02
3-95	22	13	0.04	3	0.34
4-95	21	7	0.05	1	0.05
5-95	19	15	0.05	1	0.05
6-96	48	19	0.25	2	1.25
7-96	37	20	0.06	3	0.93
8-96	34	13	0.24	2	1.11
9-96	33	25	0.16	3	0.47
10-96	30	12	0.01	3	0.05
11-96	27	17	0.05	2	0.23
12-96	20	15	0.55	2	2.26
13-96	17	12	0.10	2	0.18
	27.46 (2.43)	15.92 (1.31)	0.13 (0.04)	2.08 (0.21)	0.57 (0.18)
Females					
1-95	18	18	0.10	1	0.10
2-95,96	80	21	0.11	2	0.26
3-95,96	66	22	0.59	2	1.06
4-95,96	55	20	0.13	4	0.86
5-95,96	54	18	0.04	4	0.25
6-95,96	54	17	0.08	4	0.39
7-96	45	24	0.04	4	0.21
8-96	30	11	0.07	2	0.91
9-96	28	27	0.14	1	0.14
10-96	25	10	0.20	2	0.82
11-96	21	13	0.06	2	0.09
12-96	19	11	0.52	1	0.52
	41.25 (5.94)	17.58 (1.58)	0.17 (0.05)	2.41 (0.36)	0.47 (0.10)

*IAA = Incremental Area Analysis

Table 2.8. Frequency of habitat use for male and female bog turtles at 3 study sites in southwestern Virginia (1995-1996). Use is given as the frequency of locations within each habitat per month. The highest percentage of use for each month is shown in bold. Locations were obtained from a varying number of turtles (indicated in parentheses) each year.

Females ($\underline{n} = 1 - 8$) - 1995								
	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Dry Meadow	0	5	0	0	0	0	-	0
Wet Meadow	0	45	43	83	20	100	-	75
Alder	0	5	30	0	0	0	-	0
Alder Edge	0	0	0	0	0	0	-	0
Scirpus	100	41	17	17	80	0	-	0
Scirpus Edge	0	5	4	0	0	0	-	25
Stream	0	0	4	0	0	0	-	0
# locations	1	22	23	6	5	3	0	4

Males ($\underline{n} = 1 - 9$) - 1995								
	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Dry Meadow	0	25	7	13	0	0	-	0
Wet Meadow	0	50	52	53	62	57	-	67
Alder	0	0	17	20	23	14	-	0
Alder Edge	0	0	0	0	0	14	-	0
Scirpus	100	19	17	0	0	0	-	0
Scirpus Edge	0	6	3	0	8	14	-	33
Stream	0	0	3	13	8	0	-	0
# locations	1	16	29	15	13	7	0	3

Females ($\underline{n} = 1 - 14$) - 1996								
	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Dry Meadow	5	17	25	10	0	0	6	0
Wet Meadow	21	15	19	8	60	38	11	0
Alder	12	19	15	17	0	0	6	0
Alder Edge	0	4	2	13	0	0	17	100
Scirpus	63	42	39	50	30	38	44	0
Scirpus Edge	0	2	0	2	10	25	17	0
Stream	0	0	0	0	0	0	0	0
# locations	43	52	89	52	10	8	18	1

Table 2.8 (Cont.)

	Males ($\underline{n} = 1 - 11$) - 1996							
	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Dry Meadow	0	13	12	2	25	0	0	0
Wet Meadow	9	15	13	11	0	0	25	33
Alder	56	30	32	56	50	88	25	0
Alder Edge	9	4	0	2	0	13	35	67
Scirpus	21	34	36	22	25	0	15	0
Scirpus Edge	6	4	0	0	0	0	0	0
Stream	0	0	7	7	0	0	0	0
# locations	34	47	75	45	4	8	20	3

Table 2.9. Percentage of 4 different behaviors observed when radioed bog turtles were first sighted using radiotelemetry at three study sites in southwestern Virginia (1996).

	# Observations	Active (%)	Basking (%)	Escaping (%)	Inactive (%)
Males	256	18	10	37	35
Females	284	13	15	39	33

CHAPTER 3

MANAGEMENT STRATEGIES FOR BOG TURTLES (*Clemmys muhlenbergii*) IN SOUTHWESTERN VIRGINIA

INTRODUCTION

The future management of the bog turtle in southwestern Virginia, and likely throughout its range, should focus on identifying new populations, distinguishing the relative importance of currently-known populations to species persistence, and determining threats to populations. In this study, I do not emphasize the identification of new bog turtles sites in southwestern Virginia. Much of the previous work and current work on this species has dealt with status surveys (Zappalorti 1976, Herman 1981, Klemens and Warner 1983, Herman 1988, Mitchell and Buhlmann 1988, Tryon and Herman 1990, Buhlmann 1992, Beane 1993). Surveys are needed because we still do not know how many populations of bog turtles may remain in the south (Tryon 1990) and without this information we cannot fully understand the rate of population decline or the threatened/endangered status of this species.

As new populations are identified, we must assess their quality relative to that of populations currently known. An understanding of the relative quality of each population or site can help managers prioritize the allocation of resources for conservation. Perhaps, the best method for comparing populations would entail measures of body condition (e.g., body fat %) or indices of "fitness" (e.g., reproductive success). However, no simple measure of body condition currently exists for chelonians (Jacobson et al. 1993) and fitness indices are difficult and time-consuming to obtain. In the absence of these measures of population quality and because turtles have indeterminate growth (Jacobson et al. 1993), I chose the total number of individuals and overall body size of adults as indices of population health.

Bog turtles are found in specific types of wetland habitat (Chapter 2). Therefore, an assessment of habitat parameters that indicate "high quality" habitat for bog turtles may provide useful information. The assumption that habitat quality in some way affects the carrying capacity of bog turtles is usually incorrect under natural conditions (Hobbs and Hanley 1990). However, because of the close association with bog turtles and wetland habitats and the extinction of populations when wetlands are lost, the identification of high quality habitat is important for this species.

Finally, when high-quality sites (populations) are identified, the threats to the site need to be identified. These threats can be to either the animals (e.g., vehicular traffic) or to the habitat (e.g., ditching and draining).

In this chapter I present data for turtles collected at 4 study areas (detailed in Chapters 1, 2). I compare these sites using habitat and population parameters I believe are meaningful, and using a technique described by Klemens (1993). I then address specific

sources of disturbance to these populations, discuss how management for this species should proceed, and outline directions for future research.

METHODS

Site Quality Assessment

I calculated several habitat and population parameters for each of the 4 study areas, including number of turtles captured, sex, body size, site area, and depth of water and mud (Tables 3.1, 3.2). Body size was calculated by multiplying the overall carapace length, width, and height for each turtle. Sizes are provided as cubic centimeters (Table 3.1). The methods for measuring site area, and mud and water depths are provided in Chapter 2. I then ranked each parameter according to site from smallest (0) to largest (3) and tallied the ranks (Table 3.3).

Klemens (1993) also proposed guidelines for site-quality analysis of bog turtle sites. Results of his technique also provide an overall score for each site and allow relative comparison of site quality. Klemens proposed evaluating site quality according to 4 criteria: site size/fragmentation, invasive plants/succession, proximal threats, and general habitat conditions. Several levels are given for each component of site quality. For example, site size/fragmentation levels ranged from a disjunct and small site (level 1) to an interconnected, large site (level 5). Additionally, 2 population criteria were proposed: population size and recruitment.

Guidelines for the assessment of site quality allow rapid determination of relatively high and low quality sites. This can aid managers when considering which sites should be conserved and managed. Under the guidelines Klemens (1993) provided, an interconnected wetland with few invasive/successional plants (e.g., red maple), few proximal threats (e.g., major highways), and very light land use (e.g., little grazing and development), would rank highest in site quality. Population quality is high when 25 adults and juveniles of 2 or more age classes (i.e., each year class below adult age [6 yr.]) are present.

RESULTS

Habitat comparisons

The overall size of turtles was greatest at site 2 (Table 3.1). The smallest turtles were found at the largest site (site 1). The number of turtles captured at each site corresponded with the site area (Table 3.2). The greatest number of turtles were caught at the largest site (62 turtles at site 1) and the fewest number of turtles were captured at the smallest site (6 at site 4).

Average mud and water depths at random locations (as provided in Chapter 2) were greatest at the site with the lowest grazing intensity (site 3). The relative ranking of each site according to my habitat and population parameters was site 2 > site 1 > site 3 > site 4 (Table 3.3). The relative ranking of each site according to Klemens (1993) site-quality analysis was site 2 = site 3 > site 1 > site 4 (Table 3.4). Thus, each method of site and population assessment provided similar results.

Potential Threats

Roads

Roads may pose a severe potential threat to bog turtles. Vehicular traffic is a documented source of mortality for bog turtles in Virginia (Mitchell 1994). At least one turtle was killed by a car over the study period and several additional road kills were reported for previous years. Roads also provide access opportunity for poachers. The likelihood of collecting is undoubtedly higher when roads allow sites to be seen and accessed easily. Access is high at all of the study areas. The greatest distance from the road for any site is 80 m and two sites are < 10 m from a road edge. Consequently, vehicular traffic and human access make roads a serious potential threat to bog turtles at the 4 study areas described.

Grazing

The highest grazing intensity was observed at site 4. No data for 1995 are presented for site 4, because grazing during this period removed all of the standing vegetation. Also, surveys by National Park Service personnel in 1995 found no turtles at site 4. In 1996, the grazing intensity was reduced, the vegetation returned, and 6 turtles were found. One adult female moved from site 1 to site 4 (550 m) and back during 1996. The apparent absence or low numbers of turtles at site 4 in 1995 and the presence of at least 6 in 1996 (1 from a neighboring site) may reflect random colonization from nearby areas or may suggest an ability to detect ephemeral sites on a large scale.

Grazing may have both beneficial and detrimental effects on sites occupied by bog turtles. Grazing may help slow succession of these habitats by reduction of woody vegetation. Also, bog turtles have been found foraging for invertebrates in cow hoofprints, which retain small pools of water. However, high grazing intensities may remove much of

the standing vegetation, and compact the soil. Of the sites discussed, the only ungrazed site (site 3) had deeper water and mud at random locations than any of the grazed sites (Table 3.2). Replication of different grazing intensities and grazed vs. ungrazed comparisons are needed to rigorously examine the impacts of grazing.

Ditching

Ditching was not observed at any site over the study period, however, it should be considered as a potential threat to bog turtle populations. Ditching is often used to drain wet meadows, increase pasture area, and create hayfields. This can immediately drain much of the surrounding wetland habitat. If allowed to fill in with sediment and vegetation, these ditches can be utilized by bog turtles. At site 1, four turtles used portions of filled drainage ditches over the study period. It appears ditching may have an immediately detrimental impact on the surrounding wetland, but this may be alleviated if the ditch is allowed to fill in over time.

DISCUSSION

Habitat and Population Management

There is no way of knowing what bog turtle habitat was historically, or how it was maintained. There is also no way to determine historic (assumed optimal) turtle sizes or population densities. Sites were probably maintained by the suppression of succession by site hydrology/deep sediments, seasonal grazing, beaver activity, fire, or some combination of these.

Southwestern Virginia has some of the last habitats connected within stream drainages (Buhlmann et al. in press). Throughout much of the bog turtle's remaining range, especially the northeast, populations are becoming further isolated by development and draining of wetlands. If Virginia populations resemble an historic landscape for bog turtles, we need to preserve this network of patches, even if we do not know the relative importance of each or how they were maintained.

The following things should be considered for future management of populations.

1. Habitat/population size

Bog turtle sites may persist under a source-sink dynamic where satellite populations wink in and out and only a few source populations are resistant to succession and drought. Under such a dynamic, preservation of source populations is important for the continued persistence of the species (Pulliam 1996). For example, site 1 is the largest of all the study areas and contains the most turtles, while site 4 is approximately 1/13th as large and may not be suitable every year. At least 1 female bog turtle was known to have moved into site 4 in early summer and returned to site 1 later in the year. Thus, bog turtles may occasionally occupy temporary, satellite areas and then return to major populations. If this is true, then preserving the absolute greatest number of animals and largest area possible can help protect against chance extinction when surrounding areas become unsuitable.

2. Mosaic of habitats

A complex of several habitat types might reflect an equilibrium that has been maintained historically. The most unsuitable site (4) lacked alders and contained large amounts of an invasive wetland plant, rice grass (*Leersia* spp.). Temporary sites may not develop certain characteristics, such as deep mud and alder stands, because they frequently dry up or undergo rapid succession. Thus, plant species which are typical of open and hydric sites should be identified when possible (Appendix 3.1).

3. Disturbance and long term management

Disturbance by factors listed above may have impacts on bog turtle populations. Sites where access and land use can be controlled (through ownership or easement) should be favored. Because the bog turtle is a long-lived species (ca. 30 years), long-term management should also be emphasized. Populations may persist for many decades, but may be effectively "extinct" if no recruitment takes place. Therefore, management goals should be long term and favor acquiring large habitats, minimization of habitat drying,

identification of successful recruitment, and assistance to private landowners to continue traditional land use practices.

FURTHER CONSIDERATIONS

The following information is still needed to effectively manage bog turtle populations in southwestern Virginia.

1. Health/condition index

A simple and reliable measure of turtle health or condition is needed to directly monitor the relative health of populations.

2. Critical habitat requirements

Bog turtles are found in a variety of habitats, ranging in size and structure. We need to assess if specific habitat types (e.g., nesting habitat) and habitat parameters (e.g., mud and water depth/area) are required for population persistence.

3. Movement corridors and demographic/genetic implications

We know that many occupied habitats in southwestern Virginia are connected by streams and are contained within the same watersheds (Buhlmann et al. in press), but it is not clear if streams are required for movement into disjunct areas. Streams may facilitate movement by bog turtles by providing temporary habitats along banks and sandbars. However, no evidence exists (to my knowledge) that suggests streams are required for movement and the relative isolation of disjunct habitats may only be affected by distance, not stream connectivity.

4. Succession management

Human modification of the landscape may suppress or facilitate succession of bog turtle habitats. We need to examine if succession is a threat to site quality, and if so, which management techniques (e.g., burning, cutting, or grazing) or combinations are most effective.

Table 3.1. Parameters used for population quality assessment. Data presented (mean [SE]) were collected at 4 study sites in southwestern Virginia (1995-1996). Overall turtle size is assumed to reflect overall body condition, and be related to population quality.

Females					
Site	# turtles	Carapace Length (mm)	Carapace Width (mm)	Shell Height (mm)	Size*
1	33	86.49 (1.28)	64.68 (0.70)	38.83 (0.98)	218
2	9	90.13 (2.73)	66.83 (1.92)	38.20 (1.18)	230
3	9	89.81 (1.70)	67.79 (0.98)	38.63 (0.85)	221
4	4	90.65 (1.33)	66.64 (1.25)	39.20 (0.56)	237
Males					
Site	# turtles	Carapace Length (mm)	Carapace Width (mm)	Shell Height (mm)	Size*
1	16	86.57 (2.50)	62.77 (1.35)	34.47 (1.06)	187
2	14	98.33 (0.96)	69.52 (0.86)	37.00 (0.44)	253
3	6	90.70 (4.31)	64.97 (2.38)	36.44 (1.44)	215
4	2	93.53 (0.18)	67.51 (0.40)	37.55 (0.50)	237
Juveniles					
Site	# turtles	Carapace Length (mm)	Carapace Width (mm)	Shell Height (mm)	Size* - age**
1	12	57.27 (3.72)	45.74 (2.52)	23.89 (1.70)	63 - 3
2	4	48.42 (6.54)	38.96 (4.87)	19.48 (2.74)	37 - 2
3	6	72.35 (0.92)	55.05 (0.89)	29.68 (0.17)	118 - 6
4	0	-	-	-	-

*Size units are cm³ and were calculated by multiplying overall carapace length, width, and height.

**Age is provided as the average of all individuals.

Table 3.2. Parameters used for habitat quality assessment. Data presented were collected at 4 study sites in southwestern Virginia (1995-1996). Site areas were defined by bog turtle home ranges. Mud and water values are the mean depths at random points as described in Chapter 2. Listed habitat parameters are assumed to reflect site quality.

Site	Area (ha)	Water (cm)	Mud (cm)	Access (m)*
1	33.2	0.6	12.1	10
2	18.7	0.6	8.8	80
3	7.4	2.3	21.5	10
4	0.5	0.2	10.3	60

*Access is the shortest distance from the site edge to the road edge (nearest 10 m)

Table 3.3. Relative ranking* of population and habitat parameters for bog turtles at 4 study sites in southwestern Virginia (1995-1996). High ranks indicate high quality sites.

Site	Body Size*	Area	# Turtles	Water	Mud	Access	Total Ranks
1	0, 0 = 0.0	3	3	1.5	2	0.5	10.0
2	2, 3 = 2.5	2	2	1.5	0	3.0	11.0
3	1, 1 = 1.0	1	1	3.0	3	0.5	9.5
4	3, 2 = 2.5	0	0	0.0	1	2.0	5.5

*Body size rank is given as male rank, female rank = mean rank.

Table 3.4. Site-quality assessment based on Klemens (1993) criteria for bog turtles at 4 study sites in southwestern Virginia (1995-1996). High ranks indicate high quality sites.

Site	Connectivity	Succession	Threats	Condition	Pop. Size	Recruitment	Score
1	5	3	2	3	5	5	23
2	5	4	3	3	5	5	25
3	5	4	1	5	5	5	25
4	5	3	2	3	2	1	16

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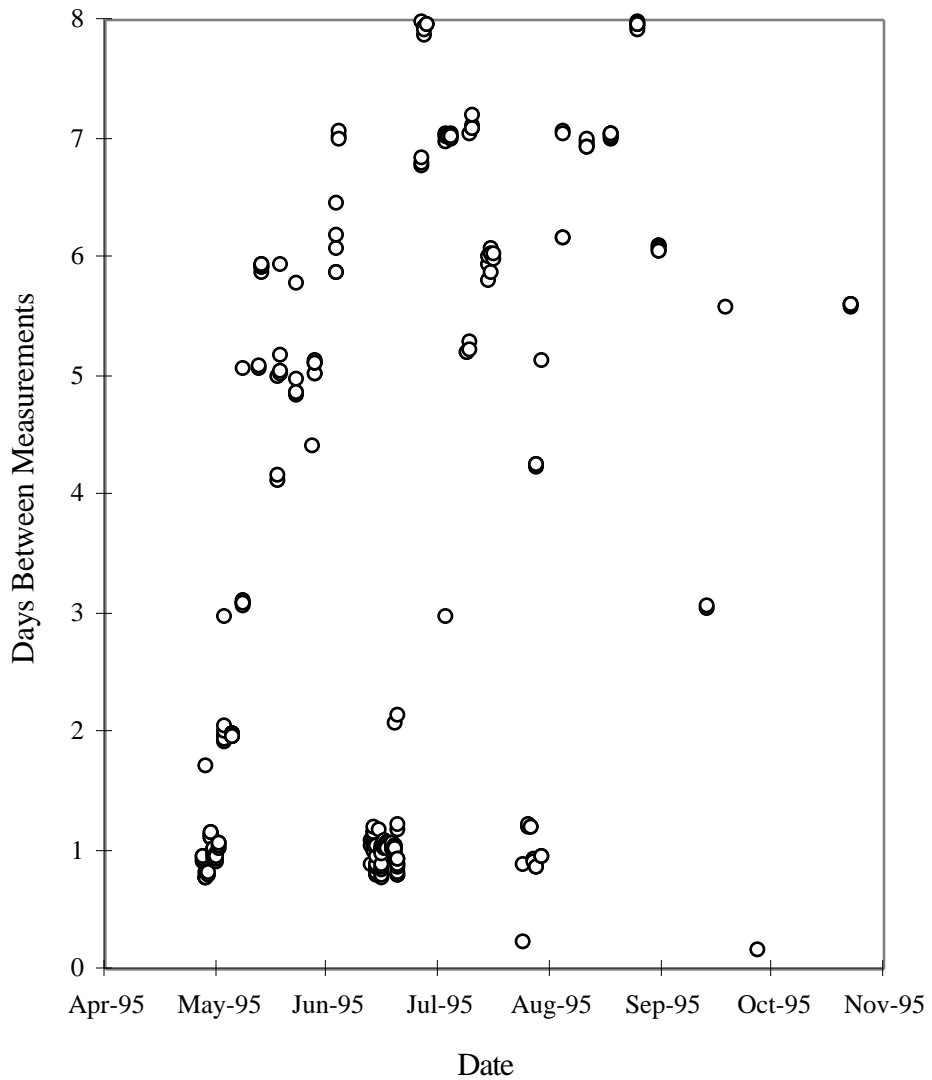
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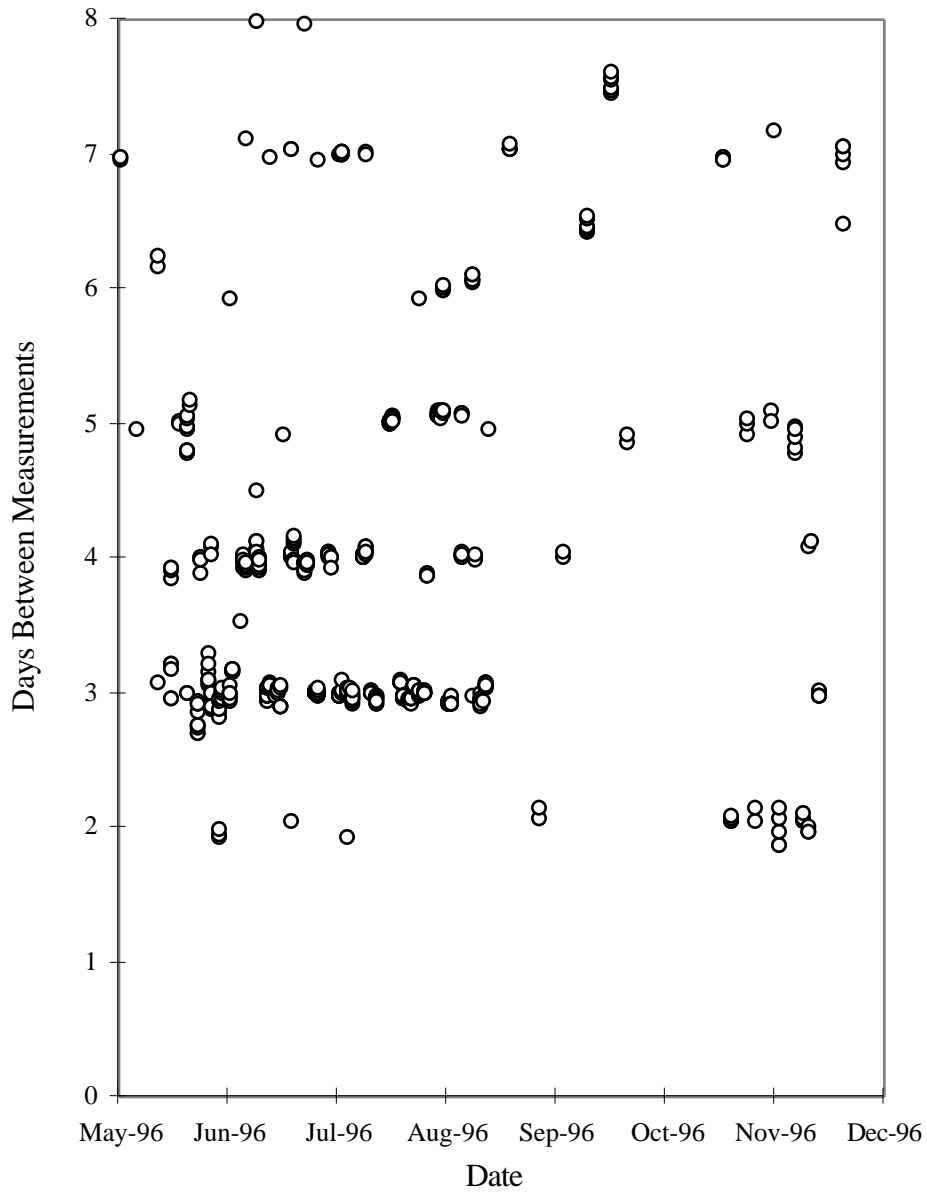
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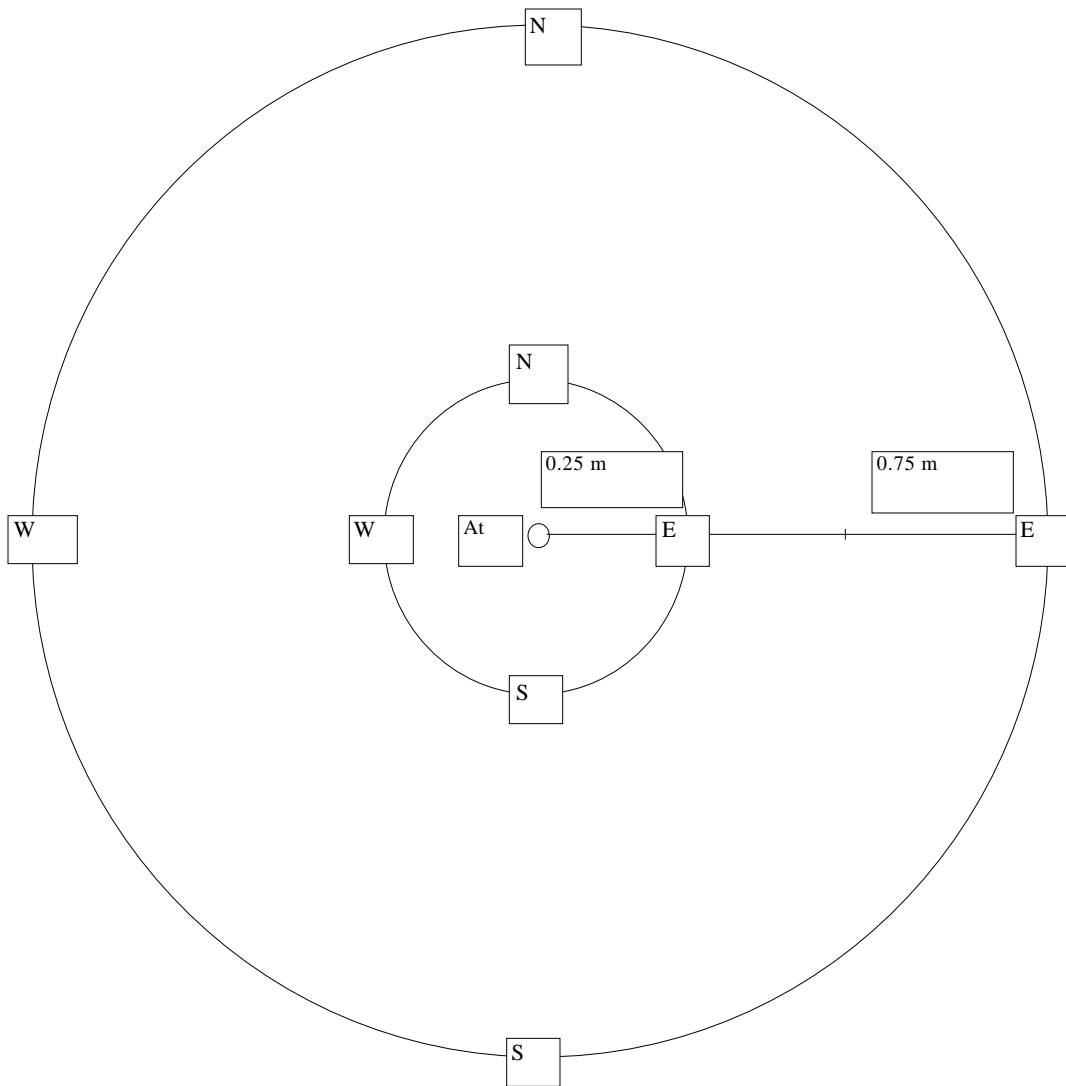
APPENDICES



Appendix 1.1. The time elapsed between sequential location of radioed turtles in 1995. Clusters of points reflect the sampling strategy used. Data were collected most frequently at 1-day intervals.



Appendix 1.2. The time elapsed between sequential location of radioed turtles in 1996. Clusters of points reflect the sampling strategy used. Data were most frequently collected at 3- and 4-day intervals.



Appendix 2.1. Overhead layout of the mud and water sampling protocol for turtle-centered and random locations.

Appendix 2.2. Weighted log-ratio differences for each habitat category.* Weights were calculated by taking the square root of the number of locations. The differences shown reflect the difference in log-ratios of use and availability.

	# locations	Weight	DM / SE	WM / SE	A / SE	Sc / SE	St / SE	AE / SE
Females								
1-95	8	2.83	-11.28	17.72	12.39	14.17	14.40	-1.96
2-95	6	2.45	-22.13	4.66	5.87	-11.28	-12.98	0.00
3-95,96	50	7.07	16.64	42.37	-27.07	51.02	0.00	-4.90
4-95,96	39	6.24	-22.72	30.99	25.66	43.85	0.00	-4.33
5-95,96	35	5.92	-21.52	28.73	15.19	42.77	0.00	39.55
6-95,96	32	5.66	21.16	34.47	-21.66	39.41	0.00	-3.92
7-95,96	23	4.80	20.27	29.06	11.44	30.68	0.00	-3.32
8-95,96	6	2.45	-9.77	3.50	-6.63	4.49	-5.09	-1.70
9-96	36	6.00	-58.37	-32.20	-72.60	-14.12	-70.17	0.00
10-96	24	4.90	18.62	23.21	24.10	-7.88	0.00	31.34
11-96	24	4.90	20.84	20.57	19.48	31.13	-10.19	-3.40
12-96	20	4.47	-16.27	-8.70	19.97	31.32	0.00	24.69
13-96	16	4.00	11.04	26.29	18.24	-6.44	0.00	-2.77
14-96	15	3.87	13.68	20.52	-14.83	28.22	0.00	-2.68
15-96	11	3.32	-2.07	2.13	-18.92	9.59	-17.57	24.86
16-96	9	3.00	-10.91	-5.84	9.52	16.18	0.00	24.81
17-96	6	2.45	-3.91	5.18	-13.97	-11.28	-12.98	0.00
Males								
1-95	14	3.74	-33.81	8.05	-21.34	9.87	-19.82	0.00
2-95	8	2.83	13.74	16.63	9.45	-4.55	0.00	18.32
3-95	7	2.65	11.47	17.73	-10.13	-4.26	0.00	17.33
4-95,96	45	6.71	-18.36	-1.22	3.29	-2.51	-5.55	0.00
5-95,96	39	6.24	-61.53	-7.23	-13.15	5.04	-38.81	-43.14
6-95,96	34	5.83	14.04	33.09	26.85	35.94	-12.13	33.26
7-95,96	33	5.74	-57.33	-4.75	-3.98	-0.37	-13.60	2.33
8-96	28	5.29	-16.29	0.19	-9.42	-8.52	-31.70	6.03
9-96	26	5.10	12.00	24.16	26.30	22.34	0.00	27.02
10-96	24	4.90	14.93	-9.53	25.21	22.56	0.00	29.35
11-96	16	4.00	-3.99	4.53	10.16	-18.42	-21.19	0.00
12-96	14	3.74	-33.81	2.95	11.45	-17.23	-19.82	27.11

*Habitat category abbreviations: DM = dry meadow, WM = wet meadow, A = alder, Sc = scirpus, St = stream, AE = alder edge, SE = scirpus edge

Appendix 2.3. Genera of plants found within each habitat type** (by %) using the point-intercept method. Column totals do not add to 100% because only genera comprising > 1.0% are shown. Dry and wet meadow categories are the most heterogeneous.

Plants	DM	Plants	WM	Plants	A	Plants	Sc
<i>Poa</i>	15	<i>Eleocharis</i>	16	<i>Alnus</i>	86	<i>Scirpus</i>	74
grass*	14	<i>Carex</i>	14	<i>Cornus</i>	2	<i>Leersia</i>	9
<i>Trifolium</i>	8	<i>Scirpus</i>	11	<i>Rosa</i>	2	mud	3
<i>Carex</i>	7	<i>Panicum</i>	9	<i>Acer</i>	2	<i>Carex</i>	2
<i>Helenium</i>	6	grass*	7	<i>Aster</i>	2	water	2
<i>Eleocharis</i>	6	<i>Juncus</i>	9	<i>Vitis</i>	1	<i>Juncus</i>	2
<i>Digitaria</i>	6	<i>Helenium</i>	4			grass*	1
<i>Panicum</i>	5	mud	3			<i>Panicum</i>	1
<i>Juncus</i>	4	<i>Viola</i>	3			<i>Poa</i>	1
<i>Solidago</i>	3	<i>Galium</i>	2			<i>Aster</i>	1
<i>Lobelia</i>	3	<i>Leersia</i>	2			<i>Eupatorium</i>	1
<i>Veronia</i>	3	<i>Alnus</i>	1			<i>Cyperus</i>	1
<i>Viola</i>	3	<i>Osmunda</i>	1			<i>Festuca</i>	1
<i>Aster</i>	2	<i>Lobelia</i>	1			<i>Impatiens</i>	1
<i>Lycopus</i>	2	<i>Polygonum</i>	1			<i>Lobelia</i>	1
<i>Plantain</i>	2	<i>Veronia</i>	1			<i>Polygonum</i>	1
<i>Polygonum</i>	1	<i>Eupatorium</i>	1			<i>Sphagnum</i>	1
mud	1	<i>Cinquefoil</i>	1			<i>Spiraea</i>	1
<i>Urtica</i>	1	<i>Festuca</i>	1			<i>Trifolium</i>	1
<i>Scirpus</i>	1	<i>Impatiens</i>	1			<i>Veronia</i>	1
<i>Cinquefoil</i>	1	<i>Rosa</i>	1				
<i>Galium</i>	1	<i>Solidago</i>	1				
<i>Eupatorium</i>	1	<i>Spiraea</i>	1				
shrub*	1	<i>Glyceria</i>	1				
<i>Glyceria</i>	1						

* indicates the genus could not be identified

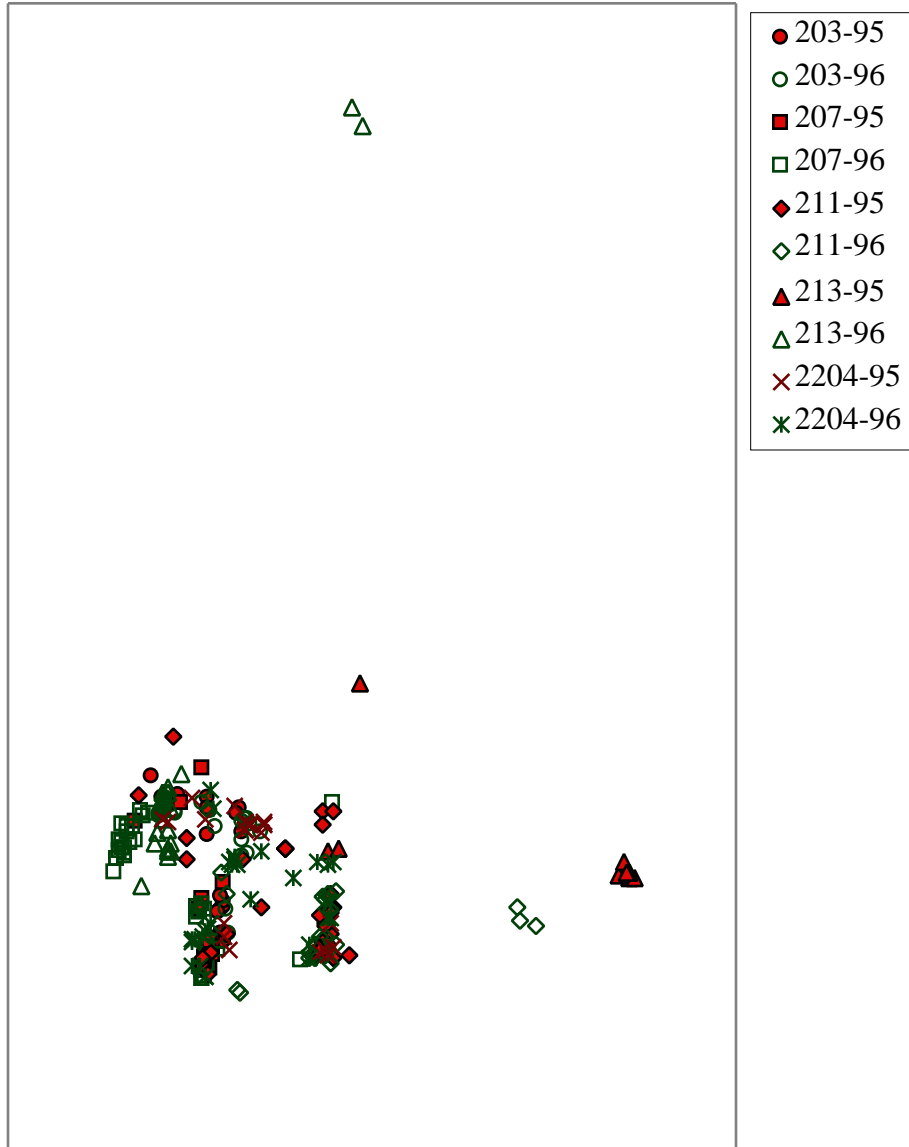
**Habitat category abbreviations: DM = dry meadow, WM = wet meadow, A = alder, Sc = scirpus, St = stream, AE = alder edge, SE = scirpus edge

Appendix 2.3 (Cont.)

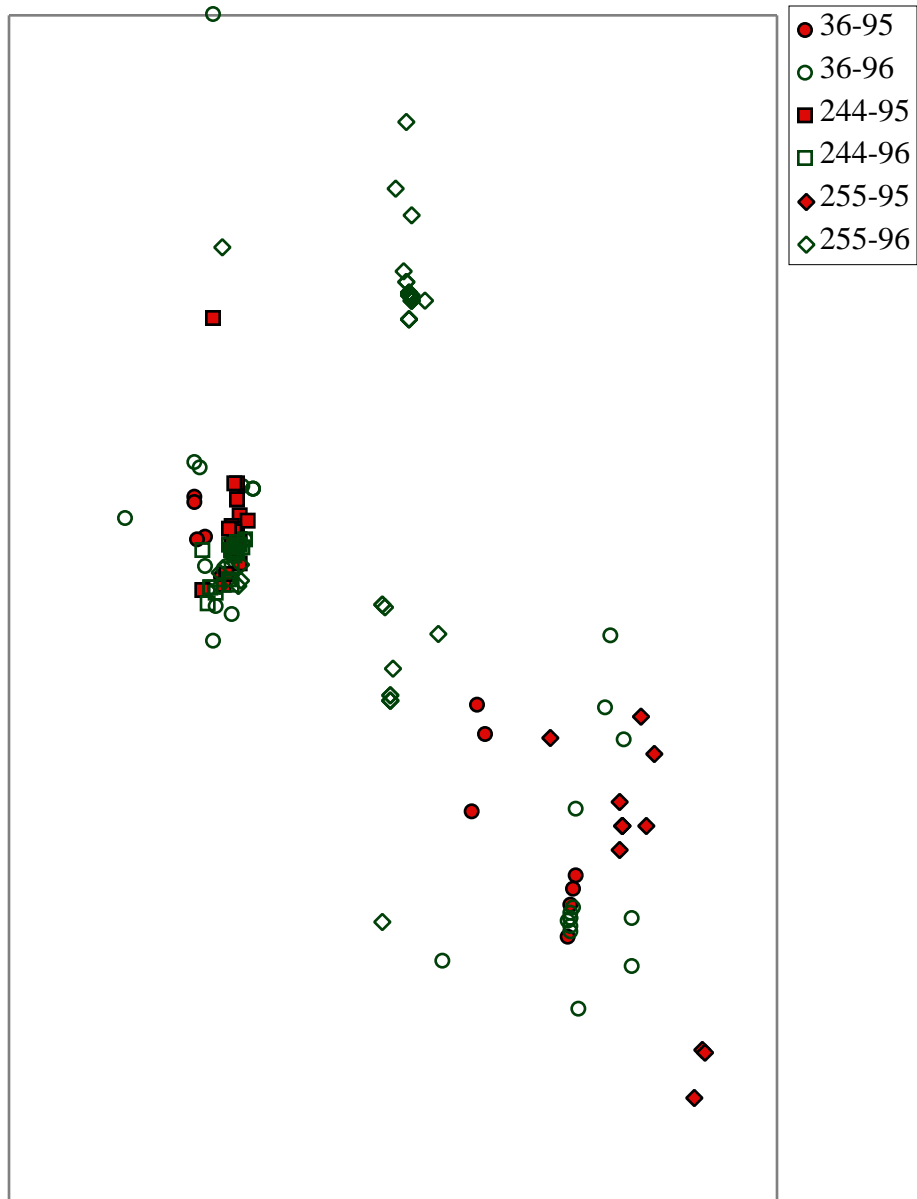
Plants	St	Plants	AE	Plants	SE
water	80	<i>Alnus</i>	36	<i>Scirpus</i>	57
mud	7	<i>Polygonum</i>	36	<i>Carex</i>	19
<i>Leersia</i>	5	<i>Aster</i>	14	<i>Leersia</i>	19
<i>Scirpus</i>	5	<i>Asclepias</i>	5	mud	5
<i>Poa</i>	2	<i>Solidago</i>	5		
<i>Trifolium</i>	2	<i>Veronia</i>	5		

* indicates the genus could not be identified

**Habitat category abbreviations: DM = dry meadow,
 WM = wet meadow, A = alder, Sc = scirpus, St = stream,
 AE = alder edge, SE = scirpus edge.



Appendix 2.4. Across-year radio locations for male and female bog turtles ($n = 5$) at a study site in southwestern, Virginia. Locations are similar for both years.



Appendix 2.5. Across-year radio locations for male and female bog turtles ($n = 3$) at a study site in southwestern, Virginia. Locations are similar for both years.

Appendix 3.1. Genus and species of plants identified at 3 study sites (Compiled by Thomas Weiboldt, VA Tech Herbarium, 19 June - 15 September 1995). Species typed in bold denote plants typically associated with open (full sun) habitat.

SCIENTIFIC NAME	COMMON NAME
FERNS/FERN ALLIES	
<i>Athyrium asplenoides</i>	southern lady fern
<i>Dryopteris cristata</i>	crested wood fern
<i>Onoclea sensibilis</i>	sensitive fern
<i>Osmunda cinnamomea</i>	cinnamon fern
<i>Osmunda regalis</i> (var. <i>spectabilis</i>)	royal fern
<i>Selaginella apoda</i>	meadow spikemoss
<i>Sphagnum</i> spp.	Sphagnum moss
GRASSES	
<i>Anthoxanthum odoratum</i>	sweet vernal grass
<i>Glyceria striata</i>	fowl mannagrass
<i>Holcus lanatus</i>	velvet grass
<i>Leersia oryzoides</i>	cutgrass
<i>Leersia virginica</i>	cutgrass
<i>Muhlenbergia schreberi</i>	muhlenbergia
<i>Muhlenbergia sylvatica</i>	muhlenbergia
<i>Panicum acuminatum</i>	panic grass
<i>Panicum clandestinum</i>	panic grass
<i>Panicum dichotomum</i> (var. <i>ramulosum</i>)	panic grass
<i>Panicum ensifolium</i>	panic grass
<i>Poa pratensis</i>	Kentucky bluegrass
<i>Poa trivialis</i>	rough bluegrass
<i>Sphenopholis pensylvanica</i>	swamp oatgrass, wedgegrass
SEDGES	
<i>Carex atlantica</i>	carex
<i>Carex leptalea</i>	carex
<i>Carex lurida</i>	carex
<i>Carex prasina</i>	carex
<i>Carex scoparia</i>	carex
<i>Carex vulpinoidea</i>	carex
<i>Cyperus flavescens</i>	umbrella sedge
<i>Cyperus strigosus</i>	umbrella sedge
<i>Eleocharis obtusa</i>	spikerush
<i>Eleocharis tenuis</i> (var. <i>verrucosa</i>)	spikerush
<i>Eriophorum virginicum</i>	cotton grass
<i>Rhynchospora capitellata</i>	beak rush
<i>Scirpus cyperinus</i>	bulrush
<i>Scirpus expansus</i> (dominant)	bulrush
<i>Scirpus purshianus</i>	bulrush
<i>Scirpus validus</i>	soft-stem bulrush

Appendix 3.1 (Cont.)

RUSHES

<i>Juncus acuminatus</i>	knot-leaved rush
<i>Juncus effusus</i>	soft rush
<i>Juncus marginatus</i>	rush
<i>Juncus subcaudatus</i>	rush
<i>Juncus tenuis</i>	path rush

OTHER MONOCOTS

<i>Acorus calamus</i>	sweet flag
<i>Arthraxon hispidus</i>	arthraxon
<i>Sagittaria latifolia</i>	arrowhead
<i>Sisyrinchium atlanticum</i>	blue-eyed grass
<i>Sparganium americanum</i>	bur-reed
<i>Spiranthes cernua</i>	ladies' tresses
<i>Symplocarpus foetidus</i>	skunk cabbage
<i>Xyris torta</i>	yellow-eyed grass

SHRUBS/WOODY

<i>Alnus serrulata</i>	smooth alder
<i>Cephalanthus occidentalis</i>	buttonrush, globeflower
<i>Rosa palustris</i>	swamp rose
<i>Rubus hispidus</i>	bristly dewberry
<i>Spiraea tomentosa</i>	steeplebush spirea

OTHER DICOTS

<i>Acalypha rhomboidea</i>	three-seeded mercury
<i>Asclepias incarnata</i>	swamp milkweed
<i>Aster puniceus</i>	aster
<i>Bartonia virginica</i>	screw stem
<i>Bidens cernua</i>	beggar's ticks
<i>Bidens tripartita</i>	beggar's ticks
<i>Caltha palustris</i>	marsh marigold
<i>Drosera rotundifolia</i>	sundew
<i>Epilobium coloratum</i>	willow-herb
<i>Epilobium leptophyllum</i>	willow-herb
<i>Eupatorium perfoliatum</i>	thoroughwort, boneset
<i>Galium asprellum</i>	bedstraw
<i>Galium tinctorum</i>	stiff marsh bedstraw
<i>Helenium autumnale</i>	sneezeweed
<i>Hydrocotyle americana</i>	water-pennywort
<i>Hypericum canadense</i>	St. John's wort
<i>Hypericum mutilum</i>	St. John's wort
<i>Impatiens capensis</i>	spotted touch-me-not
<i>Linum striatum</i>	flax
<i>Lobelia cardinalis</i>	cardinal flower
<i>Lobelia siphilitica</i>	great blue lobelia
<i>Ludwigia alternifolia</i>	water primrose, seedbox
<i>Ludwigia palustis</i>	marsh purslane

Appendix 3.1 (Cont.)

OTHER DICOTS (Cont.)

<i>Lycopus uniflorus</i>	water-horehound
<i>Lycopus virginicus</i>	horehound
<i>Mimulus ringens</i>	monkeyflower
<i>Pilea pumila</i>	clearweed
<i>Polygonum caespitosum</i>	tearthumb
<i>Polygonum sagittatum</i>	tearthumb
<i>Potentilla simplex</i>	cinquefoil
<i>Rhexia virginica</i>	meadow beauty
<i>Solidago patula</i>	goldenrod
<i>Solidago rugosa</i>	goldenrod
<i>Stellaria graminea</i>	stitchwort
<i>Veronia noveboracensis</i>	ironweed
<i>Viola cuculata</i>	marsh blue violet
<i>Viola primulifolia</i>	violet

Appendix 3.2. Chronology of behavioral observations for bog turtles at 4 study areas in southwestern Virginia (1995-1996).

Above ground activity (first date of observance in 1995-1997):

9 April 1995, 12 April 1996, 6 April 1997

Mating (Time of day, [male ID# : female ID#], date):

13:00, (234 : 233) 25 May 1996;

13:30 (232 : 257) 26 May 1996;

14:30 (234 : 250) 3 June 1997;

09:28 (9 : 504) 11 June 1997

Laying: 16 June 1995

Onset of hibernation (First date of inactivity [no movement for 10 or more consecutive days] for all turtles in 1995-1996):

3 December 1995, 3 December 1996

Food items:

25 May 1996 - tent caterpillar, 9 July 1996 - earthworm,

2 turtles were also observed eating unidentified berries in the summer of 1996

VITA

Shawn Lee Carter was born in Dansville, NY on November 10, 1971. After graduating from Wayland Central High School in 1990, he attended Cornell University's College of Agriculture and Life Sciences. In January of 1994, he graduated from Cornell with a Bachelor of Science degree in Natural Resource Management. Shortly after graduating, he conducted research involving the use of a pathogenic fungus as a biocontrol agent of white clover in turfgrass in Cornell's Horticulture department. During the summer and fall of 1994, he worked at a large nursery in Reston, Virginia, where he sold ornamental plant and shrubs and assisted with horticultural design. In May, 1995 he began work as a technician at Virginia Polytechnic Institute and State University assisting work examining the effects of silvicultural treatments on terrestrial salamander populations. In the fall of 1995, he was awarded a Graduate Research Assistantship at Virginia Tech where he pursued a Master of Science degree in Wildlife Sciences. He received his Master of Science degree in June of 1997.