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Movement patterns of Blanding's turtles (*Emydoidea blandingii)* in the suburban landscape of eastern Massachusetts

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Abstract. We studied Blanding's turtle (*Emydoidea blandingii*) home range and seasonal movement patterns at 10 sites in suburban eastern Massachusetts during 2001 and 2002. Radio telemetry was used to track 51 turtles (31 females and 20 males) and home range was estimated during 4 seasonal activity periods using the 95% fixed kernel estimator. Sex, year, and site were not found to affect home range size due to the large amount of variation between and within individuals. There were significant differences in home range length between activity periods, with longest movements occurring during the period of 15 April to 31 May as animals moved to ephemeral wetlands. Mean annual home range size for Blanding's turtles was 22 ha, and mean home range length was 856 m. Animals frequently had annual home ranges that overlapped little from year to year, indicating that our calculations greatly underestimate the lifetime home range of an individual. Due to the large area needs of Blanding's turtles, and the diversified ownership of lands in eastern Massachusetts, numerous stakeholders will need to be involved to effectively protect viable populations for the foreseeable future.

Keywords: home range, vernal pools, seasonal movement, home range length, fixed kernel method

Introduction

Blanding's turtles (*Emydoidea blandingii*) are medium-sized, semi-aquatic turtles that utilize habitats in lakes, ponds, rivers, streams, marshes, vernal pools, bogs, fens, and sloughs (Graham and Butler, 1993; Graham and Doyle, 1977; Herman *et al.*, 1994; Joyal *et al.*, 2001; Pappas and Brecke, 1992; Ross and Anderson, 1990; Rowe and Moll, 1991). The core of the Blanding's turtle distribution is located in the Great Lakes region and continues west into Nebraska (Ernst *et al.*, 1994). In addition, there are three disjunct populations located in (1) the lower Hudson River Valley of New York, (2) eastern Massachusetts, southeastern New Hampshire, and southern Maine, and (3) southern Nova Scotia (Ernst *et al.*, 1994). Blanding's turtles are listed as a species of Special Concern, Threatened, or Endangered in 15 of 16 states within their range. All disjunct populations within the United States and Canada are listed as Threatened or Endangered, with the exception of the little studied population in New Hampshire.

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Blanding's turtles are state-listed as Threatened in Massachusetts, where their populations are believed to be declining as a result of habitat fragmentation and an increasing amount of roadkill mortality of adults. Individuals are especially sensitive to habitat fragmentation because of their large home range size (up to 63 ha) (Piepgras and Lang, 2000), and their ability to move as much as 3 km in 14 days (Herman *et al.*, 1994). They are sensitive to increases in adult road mortality because of their strongly *k*-selected life history (Gibbs and Shriver, 2002) that includes (1) extreme longevity, with individuals known to survive and be reproductively active to at least 77 years in the wild (Brecke and Moriarty, 1989), (2) delayed sexual maturity, requiring 14 to 20 years (Congdon and van Loben Sels, 1993), (3) low nest success, which can be 0% in some years (Congdon *et al.*, 1993; Congdon and van Loben Sels, 1993), (4) low annual survival of hatchlings (26%) and juveniles (78%) (Congdon *et al.*, 1993), and (5) high annual adult survival (96%) (Congdon *et al.*, 1993). Gibbs and Shriver (2002) examined turtle populations from species with similar life history traits and large home ranges and simulated the effects of road mortality on population viability. They concluded that in fragmented habitats with high traffic densities an increase in adult mortality by 2–3% would significantly reduce population viability. The combination of large home range size, long distance movements, and a *k*-selected life history is likely to restrict this species to landscapes with low levels of development.

Blanding's turtle home range and movement patterns are poorly understood in environments undergoing rapid development, such as eastern Massachusetts. Home range, the area traversed by an individual in its normal activities of food gathering, mating, and caring for young (Burt, 1943), and movement lengths (Home Range Length), the distance between the two most widely separated locations for an individual (Pluto and Bellis, 1988), have received little attention in developing landscapes. Past studies of Blanding's turtle home range and movement patterns have been conducted at large sites, such as in Minnesota (Piepgras and Lang, 2000), and small sites, such as in Illinois, Wisconsin, and Maine (Joyal, 1996; Ross and Anderson, 1990; Rowe and Moll, 1991).

From 2001–2002, we collected radio telemetry data from Blanding's turtles at multiple sites in the suburban environment of eastern Massachusetts, to measure home range size and length in a developing landscape. We examined the effect of sex, year, and activity season on home range size, as estimated by the 95% fixed kernel method, and length. To evaluate the effect of study area size and habitat fragmentation on home range estimates we compared our results to those from other sites, as reported in the scientific literature. Quantifying Blanding's turtle home range size, shape, location, and seasonal changes in the suburban landscape is needed to identify important habitats, movement corridors, core conservation areas, potential threats from development, and lands that should be protected.

Methods

Our study was conducted in eastern Massachusetts during 2001–2002. We examined the movements of animals from 10 sites, located in 9 towns in Middlesex and Essex Counties, Massachusetts (figure 1). Each site was bordered by suburban development and roads having traffic volumes that ranged from 200 to 73,400 vehicles per day. Sites contained roadless areas that ranged from 2.5 to 12.5 km^2 (252–1,246 ha). Habitat types on these sites

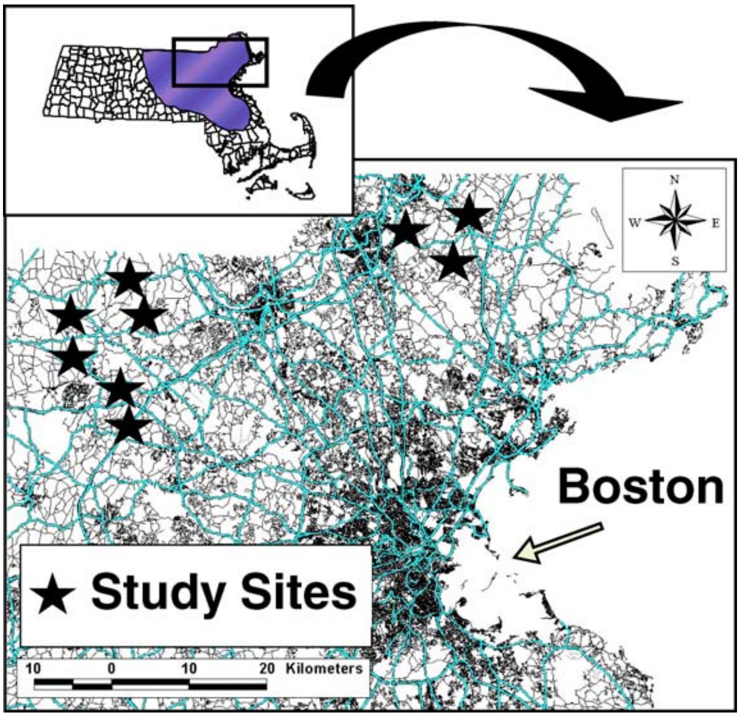

Figure 1. Study sites used for monitoring the movements of Blanding's turtles in eastern Massachusetts during 2001–2002. Shading on the inset map indicates the approximate distribution of Blanding's turtles in Massachusetts.

were a complex matrix consisting of vernal pools, beaver-impounded wetlands, eastern hemlock (*Tsuga canadensis*) seeps, streams, brooks, bogs, scrub shrub wetlands, forested wetlands, emergent marshes, hay fields, residential areas, and mixed coniferous and deciduous forested uplands. Land at these sites was controlled by multiple stakeholders including private landowners, conservation organizations, and the Commonwealth of Massachusetts.

During 2001–2002 we captured turtles with large hoop traps (90 cm diameter, 5 cm mesh, Memphis Net and Twine, Memphis, Tennessee), or opportunistically by hand. Traps were set in wetlands and checked daily for 1–4 months (April–July). All captured Blanding's turtles were uniquely marked using a standard shell notching technique (Cagle, 1939), measured (total carapace length, total plastron length, and total plastron width), aged (by counting plastral humeral laminae), sexed, and 51 turtles were fitted with radio transmitters (MBFT-6, Lotek Wireless, Newmarket, Ontario, Canada). Transmitters were programmed to operate at 12 hour intervals (0800–1600) for a battery life of 2 years, and were attached along the infra-margin of the carapacial scutes using dental acrylic cement (Biocryl Resin, Great Lakes Orthodontic Products, Tonawanda, New York). All turtles were then released at their capture location. The above methods were approved by the Institutional Animal Care and Use Committee of the University of Massachusetts at Amherst (Protocol # 21-02-08).

Turtles were monitored 2–3 times a week between 0800–2000 h during the 2001 and 2002 active seasons (April–October). Locations were recorded using eTrex Global Postitioning Satellite (GPS) units (eTrex, Garmin Inc., Olathe, Kansas), accurate to within a 20 m diameter, and downloaded as a shape file into ArcView GIS (v.3.3, Environmental Systems Research, Inc., Redlands, California).

We calculated home range area for each turtle using ArcView GIS Animal Movement Analysis ArcView Extensions (Hooge and Eichenlaub, 1997). We used the fixed kernel home range utilization distribution (Worton, 1989) as a grid coverage using the default least squares cross validation (LSCV) to calculate a 95% home range area (Seaman and Powell, 1986; Silverman, 1986). The 95% home range estimate eliminates 5% of the positions, which are considered to be outliers. For the home range area analysis, we used data from 41 turtles that had more than 30 locations in a year and were followed for the entire active season (April–October) during that year. We used a cutoff of 30 locations because past studies have determined that this is the minimum necessary for accurate estimates of home range by the fixed kernel method (Seaman and Powell, 1986).

Movement was quantified as home range length (HRL), the distance between the two furthest locations for an individual (Pluto and Bellis, 1988), and was compared between 4 periods of the active season. Activity period 1 consisted of locations beginning at emergence from hibernation and continuing to 31 May. Period 2 extended from 1 June to 30 June and bracketed the nesting season. Period 3 was 1–31 July, representing movements away from ephemeral wetlands, and period 4 lasted from 1 August until hibernation in late October, representing movements to hibernacula. To insure that accurate HRL estimates were used in our analyses, we only conducted seasonal analyses for turtles having at least 5 locations within an activity period. For overall HRL analyses we included turtles having more than 10 locations during the entire active season.

We examined the effect of sex and year on log-transformed home range area using an ANOVA. We also used an ANOVA to test for an effect of the 4 activity periods on log-transformed home range lengths, pooling years. Significant activity period effects were further investigated using Duncan's New Multiple Range Test. We considered results significant if P-values were ≤ 0.05.

Results

From 2001–2002 we recorded 3,006 individual locations from 51 radio-tracked Blanding's turtles (31 females and 20 males), of which 22 turtles (16 females and 6 males) were tracked during the entire active season during both years. We estimated a total of 63 home range areas using the fixed kernel technique. Home range areas were calculated for 25 individuals in 2001 and 38 individuals in 2002, using data from 41 turtles (27 females and 14 males) having ≥ 30 individual locations (mean = 43 locations; total = 2,768 locations). We estimated 29 HRLs in 2001, and 45 in 2002, using data from 50 turtles (31 females and 19 males) having $\geq$ 10 individual locations (mean = 40).

The 95% fixed kernel home range area, pooling years, was 22.0 $\pm$ 0.06 ha and the HRL was 856 $\pm$ 0.03 m (Table 1). The mean 95% kernel was 14.6 $\pm$ 0.09 ha in 2001 and was 28.9 $\pm$ 0.07 ha in 2002. Home range area for males was 27.5 $\pm$ 0.10 ha and HRL was

Table 1. Home range area (estimated by the 95% kernel method) and home range length for male and female Blanding's turtles during 2001–2002

	Females			Males			Combined			
Home range	Mean (*n*)	Median (*n*)	SE (*n*)	Mean (*n*)	Median (*n*)	SE (*n*)	Mean (*n*)	Median (*n*)	SE (*n*)	Range (*n*)
Area (ha)	19.9	18.2	0.07	27.5	24.5	0.10	22.0	21.5	0.06	0.9–254.7
	(27)	(27)	(27)	(14)	(14)	(14)	(41)	(41)	(41)	
Length (m)	852	888	0.04	866	916	0.05	856	872	0.03	139–3,200
	(31)	(31)	(31)	(19)	(19)	(19)	(50)	(50)	(50)	

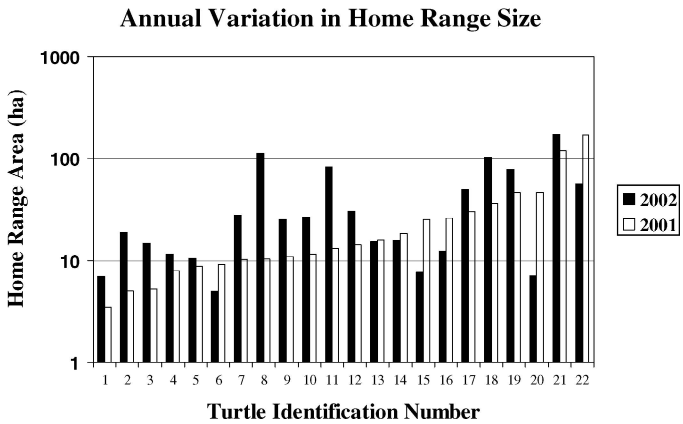

Figure 2. Changes in home range size of 22 individual Blanding's turtles from 2001 to 2002.

866 ± 0.05 m (Table 1). For females, the home range area was 19.9 ± 0.07 ha and HRL was 852 ± 0.04 m (Table 1).

No effects of year, sex, or site on home range area and length were detected in our study ($P = 0.13$ to 0.37). This is likely due to the large variation in home range size between individuals (figure 2) and within individuals between years (figure 2). We also detected large differences in the location of individual home ranges from year to year (figure 3) and little consistency between home range size, shape, and location for individuals at the same study site (figure 4).

We observed unusually long movements of Blanding's turtles over our two-year study period. The longest movement was by an adult male in 2001 (figure 5) that had a 3.2 km HRL (4 km meandering movement) in 46 days (25 April–9 July) and was subsequently killed while attempting to cross a high traffic road (6,400 vehicles per day). This was the only radio-tracked turtle that died during the study. We also observed 20 additional long distance movements (1–2.6 km) by males and females over the active season, and recorded 26 successful road crossings by Blanding's turtles. Eighteen of 26 crossings were by 8

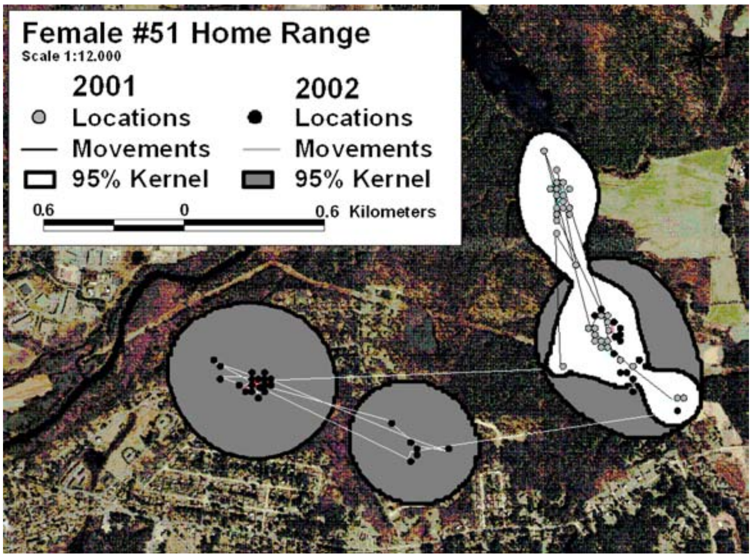

Figure 3. Annual change in the home range location for a female Blanding's turtle.

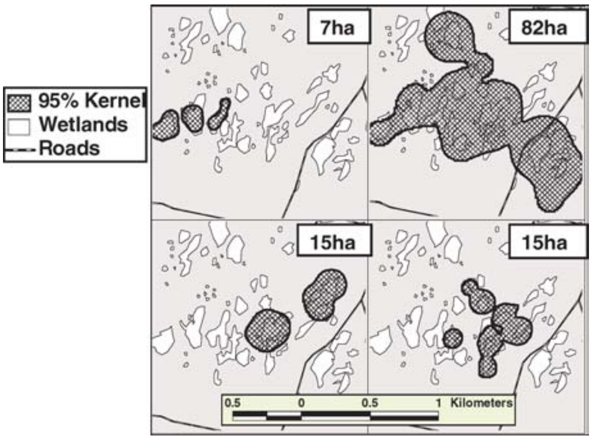

Figure 4. Variation in home ranges of Blanding's turtles at the same study site.

females, of which 10 were the result of traveling to nest sites, and 8 were movements to ephemeral wetlands. Turtles successfully crossed roads with traffic densities that ranged from 200 to 4,800 vehicles per day (mean = 550).

For the activity period analysis we estimated a total of 278 individual HRLs from 51 turtles (31 females, 20 males) having ≥5 locations per period (mean = 11 locations). The number of HRL estimates for periods 1–4 were 67, 69, 70, and 72, respectively. The mean HRL for periods 1–4, pooling years, were 501±0.05 m, 309±0.05 m, 317±0.04 m, and 284 ± 0.04 m,

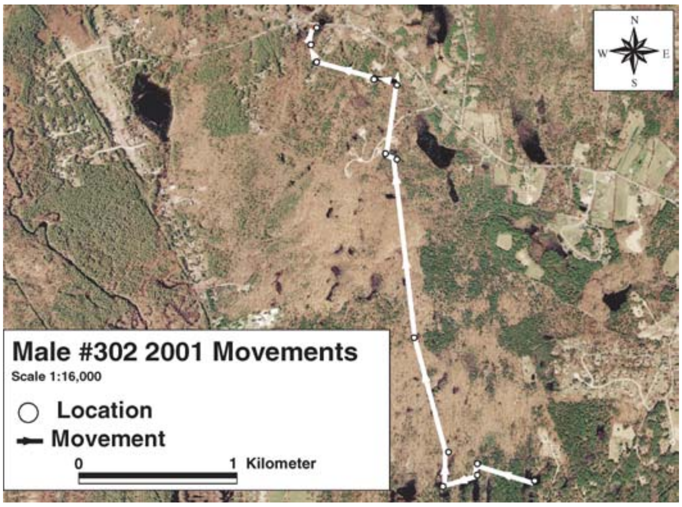

Figure 5. Movement of an adult male Blanding's turtle over a 46-day period. The individual traveled a straight line distance of 3.2 km before being killed while attempting to cross the road at the top of the picture.

respectively. Activity period had a significant effect on HRL, with movements being greatest during period 1 (Table 2). During active period 1 in 2001 and 2002, we observed 11 males and 23 females with large home range lengths (>500 m) resulting from movements from permanent wetlands to ephemeral wetlands. Ephemeral wetlands appeared to serve as areas for feeding, mating opportunities, and as staging habitats for nesting females. Nesting sites for females were often in close proximity to ephemeral wetlands and were located in predominately anthropogenic habitats, such as lawns, gardens, mulch piles, and power line right-of-ways. Although most females moved long distances to ephemeral wetlands in period 1, we observed three females make extensive movements, in excess of 1 km, while traveling to nesting sites during period 2. For most animals, movements during periods 2–4 represented return trips to permanent wetlands, and eventually to wetlands they used for over-wintering the previous year.

Table 2. Mean home range length (HRL) during 4 activity periods for Blanding's turtles in Massachusetts. Data were pooled for 2001 and 2002, and analyzed using Duncan's New Multiple Range Test

Activity Period	Number of HRLs	Mean HRL (m)	Duncan's NMRT*
1 (15 Apr–31 May)	67	501	a
2 (1–30 Jun)	69	309	b
3 (1–31 Jul)	70	317	b
4 (1 Aug–15 Oct)	72	284	b

*Activity periods sharing the same letter were not significantly different.

Discussion

Accurate home range estimates are especially important for rare species since protection of adequate areas is critical to the maintenance of viable populations. Seaman *et al.* (1999) concluded that accurate home range estimates can be obtained with a least squares cross validated fixed kernel estimator when $\geq$30 individual locations are used to calculate home range area. All of our home range estimates met this sample size criterion, so we feel that our estimates are robust. We did not detect significant differences in home range size between years, probably as a result of the large amount of variation in home range size between and within individuals (figure 2). Due to this large amount of variation, future studies should be carried out for more than 2 years to more adequately test for annual effects on home range size.

Home range size did not vary between study sites, even though sites ranged from 252 ha to 1,246 ha in size. Once again, this is likely the result of the high variation in home range size between and within individuals. Comparison of our mean home range estimates with those from other studies is complicated by the diversity of estimation methods used (Table 3). We calculated a mean annual home range area of 22 ha for Blanding's turtles in Massachusetts, a value that falls in the midst of estimates of home range size for animals on large study areas (21,500 ha) in Minnesota (Piepgras and Lang, 2000). Estimates of female home range size in Minnesota have been estimated to be 7.8 ha using the Grid Summation (GS) method, 35.4 ha using the Minimum Convex Polygon (MCP) method, and 63.0 ha using the Adaptive Kernel (AK) method (Table 3). Piepgras and Lang (2000) believe that the GS method underestimates home range size because it excludes upland habitat corridors that turtles use when moving between wetland activity centers. Home range size has also been estimated at smaller study sites in Illinois (25 ha and 125 ha; Rowe and Moll, 1991),

Table 3. A summary of Blanding's turtle home range estimates from across their geographic range

Location	Number and sex	Area (ha; mean)	Length (m; mean, range)	Method*	Reference
Massachusetts	27 F, 14 M	20.0, 27.4	N/A	FK	This study
Massachusetts	31 F, 19 M	N/A	856 (139–3200)	HRL	This study
Minnesota	13 F, 6 M, 6 J	7.8, 7.8, 5.9	835 (208–2700)	GS	Piepgras and Lang, 2000
Minnesota	13 F, 6 M, 6 J	35.4, 38.4, 12.8	906 (243–2987)	MCP	Piepgras and Lang, 2000
Minnesota	13 F, 6 M, 6 J	63.0, 53.4, 15.1	985 (292–3100)	AK	Piepgras and Lang, 2000
Wisconsin	6 F, 2 M	0.56, 0.57 & 0.94	N/A	MPM	Ross and Anderson, 1990
Illinois	5 F, 6 M, 1 J	1.3**	−(630–800)	MPM	Rowe and Moll, 1991
Maine	6 F, 3 M	0.91**	680 (90–2050)***	MPM	Joyal, 1996

*Home range area was calculated using the 95% fixed kernel (FK) method with least squares cross validation. Home range length (HRL) was estimated by measuring the maximum distance between the furthest locations. Others have calculated home range area and length using either 95% grid summation (GS), adaptive kernel (AK), and/or the minimum convex polygon (MCP), which is analogous to the minimum polygon method (MPM).
**Estimate derived by summed activity centers.
***Distance between activity centers.

two fragmented study sites in Maine, each 9 km^2 in area, with 5.0 km of roads in one, and 12.3 km of roads in the other (Joyal, 1996), and a 281 ha site in Wisconsin (Ross and Anderson, 1990) (Table 3). Home ranges in these studies were calculated using the Minimum Polygon Method (MPM), a method analogous to MCP, and estimates were all less than 1.3 ha in size (Table 3). Thus, if we disregard home range estimates calculated using the conservatively biased GS method, home range estimates for Blanding's turtles on moderate-sized study sites in Massachusetts (252–1,246 ha) appear to be intermediate to those estimated for large and small study sites.

The positive relationship between the area of roadless habitat and the home range size of Blanding's turtles has not been noted previously. This relationship is potentially a reflection of differences in the methods used for calculating home range, or perhaps represents a true ecological phenomenon. We strongly recommend the FK method described in this paper when sample sizes are appropriate. Traditionally, the MCP method has been commonly used, but it appears to be highly biased and inaccurate unless 100–300 locations are available for each individual (Bekoff and Mech, 1984; Harris *et al.*, 1990; Laundre and Keller, 1984). In addition, we feel that the smaller home range estimates for Maine and Illinois animals may be the result of adding activity centers, versus calculating home range estimates from all locations, and therefore excludes the area between the summed activity centers. Assuming a positive relationship between roadless block size and home range area exists, several ecological explanations are possible. One possibility is that sites fragmented by roads only contain animals with small home ranges because those having large home ranges suffer higher rates of roadkill mortality. It is also possible that fragmentation of habitat occurs more rapidly in landscapes that have a higher density of resources for Blanding's turtles, and thus turtles move less in these landscapes. Further studies should attempt to confirm the trend we have noted and proceed to test biological explanations if necessary.

We found that Blanding's turtles have significantly longer HRLs from 15 April to 1 June than at other times during the active period (Table 2). The only other study to examine seasonal movements of Blanding's turtles found that the longest movements occurred for females during the nesting period, and the shortest movements occurred in the spring (Piepgras and Lang, 2000). The long distance movements we observed for both males and females during the spring activity period resulted from frequent use of ephemeral wetlands. These ephemeral wetlands contain large numbers of invertebrates and amphibian egg masses which serve as an important seasonal food resource for Blanding's turtles. In addition, our observations also indicate that vernal pools are used as mating sites and staging areas for females during the nesting season. Other studies have reported ephemeral wetland use by Blanding's turtle adults (Ernst *et al.*, 1994; Joyal, 1996) and hatchlings (Butler and Graham, 1995), but ours' is the first to document long distance movements to these habitats during the spring.

Sex was not a significant predictor of home range size in our study, as in others (Table 3). Both males and females made long trips to ephemeral wetlands, and apparently the long nesting trips of females were matched by long trips of males, possibly made in search of mates. Mean home range length of Blanding's turtles across their range varies from 680 to 985 m (Table 3). Maximum home range length for the species has been recorded as 3.1 km in Minnesota (Piepgras and Lang, 2000), 800 m in Illinois (Rowe and Moll, 1991), >2 km in Maine (Joyal, 1996) and 3.2 km in this study.

Conservation of Blanding's turtles in Massachusetts is extremely challenging due to the species' long overland movements, and the high rate at which their habitat is being fragmented by roads. Long overland movements, and spatial shifts in home range from year to year, imply that large landscapes are needed to support even single animals. In our 2-year study of Blanding's turtle home ranges we found a low amount of home range overlap for the same individuals followed in both 2001 and 2002, indicating that our calculations greatly underestimate lifetime home ranges for single animals. Because individuals show little spatial overlap in their use of the environment, large areas are required to sustain high adult survival. Even small increases in adult mortality can lead to rapid decline of Blanding's populations due to their extreme *k*-selected life history (Condgon *et al.*, 1993). For a conservation program to be successful, viable populations of Blanding's turtles must be maintained into the foreseeable future, and future modeling efforts should address population sizes and accompanying land area necessary for these populations. Establishing Blanding's turtle conservation areas in eastern Massachusetts will require working with a diverse set of stakeholders that includes landowners, town conservation commissions, politicians, non-government and government organizations, developers, and biologists. Because of the rapid rate of development across the range of Blanding's turtles in Massachusetts, these actions should be initiated without delay.

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