SPATIAL ECOLOGY OF BLANDING'S TURTLES (*EMYDOIDEA BLANDINGII*) IN SOUTHCENTRAL NEW HAMPSHIRE WITH IMPLICATIONS TO ROAD MORTALITY

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Abstract.—Understanding the spatial ecology and habitat requirements of rare turtle species and the factors that threaten their populations is important for the success of long-term conservation programs. We present results from an eight-year field study in which we used radiotelemetry to monitor the activity and habitat use of 22 adult (seven male, 15 female) Blanding's Turtles (*Emydoidea blandingii*) in southcentral New Hampshire. Female turtles had significantly larger home ranges (mean = 19.6 ha ± 3.5 SE) than males (mean = 10.7 ha ± 0.1 SE). Activity patterns varied by season, with activity increasing each month after hibernation until peaking in June, coinciding with the nesting season. Males selected emergent and scrub-shrub wetlands in each season, whereas females selected scrub-shrub wetlands in spring and ponds in summer and fall. We identified road mortality as a potentially important threat for this population because females had greater road densities within home ranges and crossed roads more frequently than males. We attribute differences in road density and road crossings between the sexes to the irregular long distance nest forays and roadside nest site selection among females. The preservation of wetland networks and the implementation of measures to minimize road mortality are important considerations for the long-term persistence of this population.

Key Words.—activity; behavior; compositional analysis; conservation; home range; minimum convex polygon

INTRODUCTION

Turtle populations are declining worldwide due to human activities and associated landscape changes. The slow movement of turtles on land makes them susceptible to collection, harvest, and incidental mortality (Gibbons et al. 2000; Gibbs and Shriver 2002). Turtles generally have a life history characterized by late maturity, high adult survivorship, low hatchling survivorship, and long life spans. These life-history characteristics make populations vulnerable to subtle changes in population structure that might occur as a result of anthropogenic disturbances (Congdon et al. 2008).

Most freshwater turtles select aquatic and wetland environments in response to changes in phenology (e.g., breeding and hibernation periods), prey abundance, temperature, and hydroperiod (Innes et al. 2008; Beaudry et al. 2009; Millar and Blouin-Demers 2011). In addition, freshwater turtles use terrestrial habitats for nesting and making overland migration movements to other aquatic habitats. Therefore, the composition and connectivity of aquatic and terrestrial habitats in the landscape are important factors in maintaining viable turtle populations (Refsnider and Linck 2012). Land cover changes and other human activities fragment and decrease the quantity and quality of habitats in the landscape, increasing the distance turtles must travel to reach suitable habitats. In these altered environments, turtles may be more vulnerable to human collection, predation, and road mortality (Gibbons et al. 2000). For example, road networks near wetlands have resulted in increased mortality among turtles that travel over land (Gibbs and Shriver 2002). In addition, the tendency for sunny, gravel, or sand roadside areas to attract nesting female turtles could create an ecological trap through road mortality of adult females and emerged hatchlings (Aresco 2005; Gibbs and Steen 2005; Steen et al. 2006; Andrews et al. 2008).

Understanding the spatial ecology and habitat requirements of rare turtles is important for the success of long-term conservation programs. Considerable effort has been made to examine the relationships in freshwater turtle spatial ecology across the range of a species (e.g., Steen et al. 2012). However, it is still important to understand habitat use and activity at local scales to identify variation in spatial ecology throughout the range of a species (Congdon et al. 2008). Local studies allow for the identification of important ecological drivers in isolated and disjunct turtle populations (Innes et al. 2008; Beaudry et al. 2009; Millar and Blouin-Demers 2011).

The Blanding's Turtle (*Emydoidea blandingii*) is a North American semiaquatic, freshwater species that is

rare or declining throughout its range as a result of habitat degradation and loss (both wetlands and terrestrial habitats), subsidized predation, and mortality along roadways (Congdon et al. 2008). The species is listed as endangered on the IUCN Red List because of the widespread decline of most of its populations (Rhodin and van Dijk 2011). Disjunct populations occur in the northeastern United States and southeastern Canada in portions of Massachusetts, New Hampshire, Maine, New York, and Nova Scotia (Congdon et al. 2008). The Blanding's Turtle is listed as threatened or endangered by each of the U.S. states within the northeastern portion of the range of the species (MDIFW 2003; MDFW 2007; NHNHB 2012; NYDEC 2014).

Blanding's Turtles use a number of different wetland and terrestrial habitats throughout the year. Both sexes travel over land as they move between wetlands, seek mates, and as females seek nest sites (Rowe and Moll 1991; Beaudry et al. 2009). Blanding's Turtles have been observed to travel > 1 km during terrestrial movements (Congdon et al. 1983; Steen et al. 2012), and these long distance terrestrial movements may make individuals more vulnerable to a variety of potential threats including road mortality (Gibbs and Steen 2005).

The spatial ecology of the Blanding's Turtle has been well documented. Previous studies have used radio-telemetry to monitor activity, home range size, nest site selection, and use of aquatic and terrestrial habitats. Various estimates of home range sizes for this species have been reported, with estimates ranging from < 1 ha to > 90 ha (Ross and Anderson 1990; Piepgras and Lang 2000; Congdon et al. 2008). Sex differences in activity and home range size of Blanding's Turtles have been observed and attributed to different reproductive strategies (Congdon et al. 2008). In addition, activity patterns are dependent on breeding and nesting behavior, which changes seasonally. Males may move great distances to search for reproductively active females during the breeding season, which is generally considered to be the months immediately before or after hibernation (Newton and Herman 2009; Edge et al. 2010). On the other hand, gravid females may move greater distances during the nesting season than at other times of the year as they seek suitable terrestrial nesting sites (Innes et al. 2008; Millar and Blouin-Demers 2011).

In this study, we examined the spatial ecology of a population of the Blanding's Turtle in southcentral New Hampshire, USA, in the northeastern periphery of the range of the species. Over an eight year period, we used radio-telemetry to examine home range size, activity levels, and macrohabitat use of adult turtles and compared our findings to previously published data from other populations. Despite the occurrence of published observations from other portions of the range of the species, it is important to report information on populations in geographic areas that have received little research attention, particularly for rare species such as the Blanding's Turtle, so that regional and range-wide conservation strategies may be better realized. We evaluated the degree of overlap among home ranges to identify habitats of potential population-level importance. We also sought to determine relative sex-based vulnerability to road mortality in this population by examining turtle movement patterns in relation to roadways. Examining the underlying factors that increase risk of mortality allowed us to identify strategies for land management that promoted conservation of this species near the edge of its range.

MATERIALS AND METHODS

Study area.—We conducted this study in and around New Boston Air Force Station (NBAFS), located in southcentral New Hampshire (42.9ºN, 71.5ºW; Fig. 1), between May 2004 and December 2011. NBAFS is a 1,177-ha satellite-tracking station located in an area of hilly and mountainous terrain with elevations ranging between 104 m and 389 m above mean sea level. Over 90% of NBAFS is forested, including coniferous, deciduous, and mixed forest stands. Dominant tree species include White Pine (*Pinus strobus*), Eastern Hemlock (*Tsuga canadensis*), Red Oak (*Quercus rubrum*), Black Oak (*Q. velutina*), American Beech (*Fagus grandifolia*), White Ash (*Fraxinus americana*), Sugar Maple (*Acer saccharum*), and Red Maple (*Acer rubrum*). Most of the forested areas on NBAFS are actively managed to promote wildlife habitat diversity, protect endangered species habitats and rare natural communities, and promote forest health. As a result of this management, NBAFS supports forest stands of various ages and old field habitats at various successional stages. The remaining 10% of the site consists of wetlands, old field, and developed areas.

Much of the area surrounding NBAFS is rural, with interspersed farms, forests, and residential areas. Land cover on the station is consistent with what is found in the surrounding area, and much of the habitat present on the station is represented elsewhere in the county and region. However, residential development of surrounding lands has increased within the past two decades, leaving NBAFS with some of the least disturbed habitats in the region with high ecological value. The base, for example, has some of the greatest biodiversity in the region, with over 20 species and natural communities known to occur at the site that are either listed or considered rare in the state of New Hampshire (LaGory et al., unpubl. report).

Wetlands occupy approximately one-tenth of the study area, and are primarily palustrine emergent or forest-shrub wetlands with a mean size of 0.6 ha (± 0.3 SE). Dominant vegetation associated with these wetlands
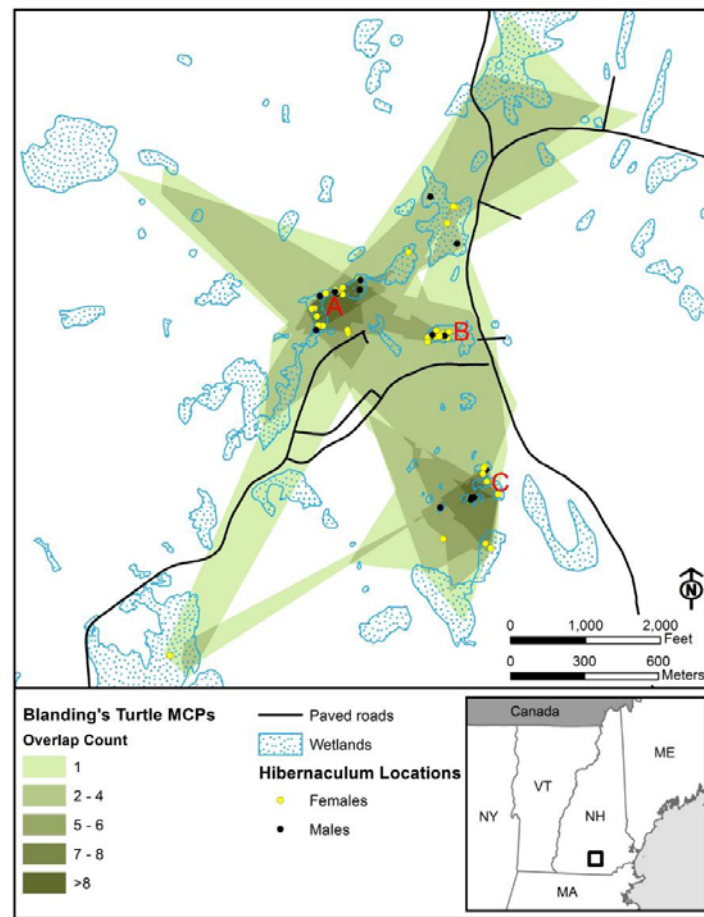
FIGURE 1. Hibernaculum locations and Minimum Convex Polygons for the 22 radio-tracked Blanding's Turtles (*Emydoidea blandingii*) in southcentral New Hampshire (inset) between 2004 and 2011. Wetlands with the greatest overwintering activity are labeled A, B, and C.

include Red Maple, Black Gum (*Nyssa sylvatica*), Highbush Blueberry (*Vaccinium corymbosum*), Meadowsweet (*Spirea alba*), Button-bush (*Cephalanthus occidentalis*), Leatherleaf (*Chamaedaphne calyculata*), Common Winterberry (*Ilex verticillata*), Maleberry (*Lyonia ligustrina*), Sweet Gale (*Myrica gale*), Three-way Sedge (*Dulichium arundinaceum*), and sphagnum moss (*Sphagnum* spp.). The density of paved roadways in the study area was approximately1.1 km/km^2.

Capture and radiotelemetry.—We captured Blanding's Turtles using 0.75 m long × 0.50 m diameter and 1.68 m long × 0.75 m diameter nylon triple hoop traps (Nylon Net Co., Memphis, Tennessee, USA) that we placed in open pools and channels within wetlands. Trap effort was distributed across all wetland types. We baited traps with an open can of sardines packed in water and oil that we checked every 24 h and re-baited as needed. The lower 2/3 of the trap was submerged under water; the top was left exposed to prevent captured turtles from drowning. We began trapping in early spring and typically ended trapping in early summer of

each year. We also opportunistically collected turtles by hand during each year. Hand captures occurred both by incidental encounters with turtles (e.g., captures along roadways) and by slowly walking in known habitat in search of turtles.

Data we collected from captured turtles included sex, age class, weight, straight-line carapace length and width, shell height, and plastron length. We used the shape of the plastron to identify sex, with male plastrons being strongly concave relative to those of females (Ernst et al. 1994). We assigned turtles to the following three age classes based on carapace length (CL; Congdon et al. 2008): hatchling (< 103 mm CL), non-reproductive juvenile (103–150 mm CL), and adult (>150 mm CL). We measured weight using a Model IN-10 scale (Ametek, Inc., Chatillon Brand Products, Largo, Florida, USA). We permanently marked all turtles by notching the marginal scutes of the carapace with a unique number (Buhlmann and Vaughan 1991), and we implanted adults with PIT tags made by AVID (AVID ID Systems, http//www.avidid.com). We released all

turtles within 2 h of capture at or near the point of capture.

We attached radio transmitters (Model R1860 and R1930, Advanced Telemetry Systems, Isanti, Minnesota, USA) to captured turtles on the right posterior portion of the carapace, approximately midway between the dorsal line and marginal scutes. We affixed transmitters to the turtles using Devcon 5-minute Epoxy (Illinois Tool Works, Danvers, Massachusetts, USA), after the carapace was cleaned with rubbing alcohol. Additional epoxy was applied to the edge of the transmitter to form a smooth shape. We allowed the epoxy to dry before we returned the turtles to the water. The combined weight of the transmitters and epoxy was approximately 30 g and represented < 5% of the body weight of the turtle at time of initial capture. Although we captured and radio-tagged several juveniles weighing between 600 and 800 g and, we only included adult turtles (where CL exceeded 150 mm and transmitters represented < 3% of turtle body weight) in the analysis presented here. We released Radio-tagged turtles immediately after morphometric measurements were recorded and the epoxy hardened (usually within 2 h).

We initially obtained locations of radio-tagged turtles daily for one-two weeks post release, using two models of hand-held receivers (Model R1000, Communications Specialists, Inc., Orange, California, USA and Model FM16, Advanced Telemetry Systems, Isanti, Minnesota, USA) and three-element folding yagi antennas (AF Antronics, Inc., Urbana, Illinois, USA). After this initial tracking, we located turtles at least once per week throughout the year. We located turtles more frequently (every 1–3 d) during the active period of May-September. Despite regular attempts to locate all turtles, some attempts failed to detect the signal of a turtle, likely due to locations that could interfere with signal reception (e.g., buried in wetland bottom sediment) or transmitter failure. For this reason, we separated recorded telemetry observations for some individuals by periods of time when locations could not be determined. In most cases in which a signal was lost, we detected it within two weeks in the same wetland from which the turtle was last observed. Although it is possible that some or all of these turtles could have moved out of range for a period of time and then returned to their original location, we believe it more likely that placement in home wetlands or transmitter failure resulted in a loss or weakening of signal. We made attempts to find turtles whose signal was lost in surrounding areas including offsite areas. We also attempted to recapture turtles to replace weak or failed transmitters.

We tracked radio-tagged turtles during their normal non-hibernation period (typically, March-November) and we obtained all locations during daylight hours. We determined locations of turtles by following the signal of the transmitter to either the exact location of the turtle if it was on land or by triangulating the approximate location of the turtle within the wetland. Based on the size of the wetland, which influenced how close we could get to the approximate location of the turtle, we estimated that the accuracy of most triangulated locations was within 10 m. We included the locations of radio-tagged turtles recaptured in traps with telemetry observations in our analysis. We also made attempts to record hibernacula locations by tracking turtles to final movement destinations in November and December of each year. We captured turtles at different times of the year, and we included full-season and partial-season telemetry observations in our analyses. We collected more than one year of telemetry data for most individuals and we tracked each turtle during at least one spring season when most activity typically occurs. The locations where we trapped individuals and initial post-trap movements were well within the estimated home range of individuals determined from subsequent observations, and many turtle locations were not near the location of active traps. Consequently, we retained the locations where we trapped individuals and immediate post-trap locations in the analysis.

Statistical analyses.—We used a Geographic Information System (GIS) to perform a spatial analysis of turtle locations. Preliminary analyses indicated that home range size did not differ among years for those individuals tracked for more than one year. Therefore, we pooled locations across years to determine home range size. For the radiotagged turtles, we calculated home ranges as 100% minimum convex polygons (MCPs), which are common metrics used to estimate home range size (Plummer and Mills 2000; Powell 2000). We calculated the MCPs using Geospatial Modeling Environment for ArcGIS (Beyer 2012). Based on a preliminary investigation of a scatter plot of MCP area by telemetry observations, we determined that ≥ 25 pooled telemetry observations were needed before MCP area reached an asymptote. Therefore, we included only turtles with ≥ 25 telemetry observations in this study. Using the tool Count Overlapping Polygons for ArcGIS (ESRI 2014), we quantified the degree of home range overlap by counting the number of overlapping polygons and quantifying the area within overlapping polygons. This enabled an identification of habitats or areas that could be especially important at the population level. We examined differences in home range size between males and females using two sample t-tests. We log transformed area measurements of home ranges prior to analysis to conform to parametric assumptions.

To evaluate seasonal turtle activity, we determined the total monthly distance travelled for each individual (determined as the monthly sum of distances between consecutive points), averaged across all years in which

the individual was tracked. We recognized that turtle activity varies among years, and some females may not nest each year (e.g., Congdon et al. 1983); however, we believe that averaging across years is an appropriate approach to evaluate activity of turtles that were tracked in different seasons and years. Because we measured activity at fixed intervals over time (monthly), we performed a two-way repeated measures analysis of variance, using turtle ID in the calculation of the error term, to determine if total distance moved was affected by month or sex.

We determined macrohabitat selection of radio-tagged Blanding's Turtles by investigating whether turtles used wetland types in proportion to their availability in the study area. We defined the study area by using a 1-km buffer surrounding all telemetry observations (total area 1,451 ha). We then obtained and field-verified wetland spatial data using results from previous wetland characterization projects on the site and data from the National Wetlands Inventory (NWI; U.S. Fish and Wildlife Service 2012). We categorized these wetlands into the following five wetland types: emergent, forested, scrub-shrub, freshwater pond, and lake/lacustrine. Emergent wetlands were relatively shallow (typically < 2 m maximum depth), and dominated by emergent herbaceous vegetation. Forested wetlands were relatively shallow, and dominated by woody vegetation $\geq$ 6 m in height. Scrub-shrub wetlands were relatively shallow wetlands, and dominated by woody vegetation < 6 m in height. We defined ponds as any open-water (i.e., with limited emergent vegetation) wetland < 8 ha in size. We defined lacustrine habitats as any open-water wetland $\geq$ 8 ha in size. Both ponds and lacustrine habitats were deeper (> 2 m maximum depth) than emergent, forested, and scrub-shrub wetlands. There were some wetlands on the site that had not been previously mapped or characterized by NWI, and in those cases, we used field observations of vegetation characteristics and hydrology to classify the wetland using the NWI wetland types.

For each turtle, we determined the total number of wetland observations and used Geospatial Modeling Environment for ArcGIS (Beyer 2012) to identify an equal number of random wetland points in the study area. The study area is defined here as the area that incorporated all home ranges of study turtles surrounded by a 1 km buffer. We used this distance because it represents the approximate maximum observed distance from the center of the home range of a turtle and the edge of its home range. We then calculated the proportion of used and random wetland types observed for each turtle. We used compositional analysis (Aebischer et al. 1993) to determine whether wetland type selection differed from random. Compositional analysis uses a multivariate analysis of variance (MANOVA) that avoids pseudoreplication problems by

accounting for within-individual variability (Aebischer et al. 1993; Pita et al. 2011). Observations of zero proportion are problematic for this analysis. Therefore, as recommended by Aebischer et al. (1993), we substituted a value of 0.01 in all cases in which the proportion would have been zero. The MANOVA was used to rank wetland types in order of selection. For significant effects detected with the MANOVA, we used post-hoc two-sample t-tests to determine which wetlands were statistically selected or avoided. We interpreted overuse relative to random availability as selection for a particular wetland type; we interpreted underuse as avoidance. We performed separate compositional analyses to examine habitat selection between sexes and among seasons.

Each fall, we made attempts to track each turtle to the wetland in which overwintering occurred (hibernaculum wetland). In a few cases, we could not locate the hibernaculum wetland of a turtle due to weak transmitter signal. For those hibernaculum wetlands that we could locate, however, we determined whether their classification was statistically different from other wetlands in the study area. Due to the limited or missing number of observations for some individuals, we could not perform a compositional analysis for hibernaculum use. Instead, we pooled hibernaculum counts under each habitat type and compared that to the availability of different wetland types in the study area (note that all hibernacula were located in wetlands). We determined availability of wetland types in the study area by randomly selecting wetland points (selecting the same number of points as hibernaculum points) in the study area and characterizing the wetland type for each random point. We selected random wetland points within a GIS using Geospatial Modeling Environment for ArcGIS (Beyer 2012). The frequency of random points in each wetland type served as the test distribution in a Pearson's chi-square goodness-of-fit test. We also used a similar chi-square goodness of fit test (using the frequency of each wetland type in the study area as the test distribution) to determine whether hibernaculum wetland types differed between males and females.

We also used the GIS to quantify road densities within home ranges (MCPs) as well as the number of turtle road crossings. We determined road crossings by counting intersections between the straight-line path of turtles between consecutive locations and road GIS layers. Our goal was to evaluate road crossings with greatest risk to turtles. Therefore, we only included paved roadways in this analysis because the unpaved roads in the study area serviced relatively few vehicles and were for official use only where vehicle speeds were minimized. In addition, many of the vehicle operators traveling unpaved roads were instructed to detect and avoid turtles and other wildlife crossing the roadways. We therefore assumed that the unpaved roadways at NBAFS represented a

TABLE 1. Turtle identification (ID) number, year of initial capture, weight (kg) and carapace length (CL in cm) recorded at initial capture, number of telemetry observations (n), and Minimum Convex Polygon (MCP) area in ha for 22 Blanding's Turtles (*Emydoidea blandingii*) tracked in southcentral New Hampshire between 2004 and 2011.

Turtle ID	Year	Sex	Weight	CL	n	MCP
B002	2004	F	1.7	22.6	266	37.32
B003	2004	M	1.4	21.3	241	6.65
B004	2004	M	1.2	20.3	170	6.59
B005	2004	F	1.6	21.8	220	11.13
B006	2004	F	1.6	23.0	39	6.22
B007	2005	F	1.6	22.0	103	6.89
B008	2005	F	1.0	19.2	142	8.00
B009	2005	F	1.5	22.0	64	13.85
B012	2005	M	1.2	21.0	59	4.59
B013	2005	M	1.7	23.3	51	26.75
B014	2006	M	1.8	23.4	68	3.69
B015	2006	F	1.3	20.9	79	5.78
B016	2006	F	1.4	21.0	94	38.45
B018	2006	F	1.0	19.0	117	16.29
B019	2006	F	1.5	22.0	73	19.70
B022	2007	M	1.6	22.0	71	24.87
B024	2007	F	1.4	20.8	51	33.77
B026	**2007**	F	1.6	20.4	44	47.13
B028	2008	F	1.3	20.3	102	26.99
B030	2008	F	1.7	22.5	67	5.87
B032	2009	M	1.9	23.0	62	2.08
B033	2011	F	1.5	22.4	27	16.19

minimal, if not negligible, risk of vehicle mortality to Blanding's Turtles. To standardize road crossings across individuals, we calculated frequency of road crossing for each turtle (i.e., the proportion of road crossings divided by the total number of telemetry observations for each individual turtle). We used two-sample *t*-tests to determine if MCP road density and the frequency of road crossings differed between females and males. In both analyses, we used a Satterthwaite correction to account for unequal variances. We conducted all statistical analyses using SAS version 9.3 (SAS Institute, Inc. 2002); and we considered *P*-values ≤ 0.05 statistically significant. We used the code provided by Ott and Hovey (1997) to perform the compositional analysis (MANOVA and *t*-tests).

RESULTS

We included 22 radio-tagged adult Blanding's Turtles (seven male, 15 female) in our spatial analyses (Table 1). Although we considered a minimum of 25 observations necessary for inclusion, we recorded more than 50 telemetry observations for most turtles (Table 1). The mean weight and carapace length of radio-tracked turtles was 1.5 kg ($\pm$ 0.1 SE) and 21.6 cm ($\pm$ 0.3 SE), respectively (Table 1). There were no morphometric differences between males and females at the time of initial capture (weight: $t = -0.85$, $df_{adj} = 9.45$, $P = 0.545$, carapace length: $t = -1.28$, $df_{adj} = 11.78$, $P = 0.266$).

We recorded 63 hibernation locations among the 22 turtled we tracked in this study (Fig. 1). We identified each hibernaculum location to the wetland used, not the specific location in the wetland. Frequently, more than one turtle hibernated in the same wetland in a given winter. The number of hibernaculum observations for each turtle varied from zero to seven, with most turtles having at least two hibernaculum records over the study period. The number of hibernaculum locations was a function of the number of years a turtle was tracked (i.e., turtles tracked for several years generally had a greater number of hibernaculum records than turtles tracked for fewer years). In a few cases, we could not determine a hibernaculum wetland of a turtle due to loss of the signal of the transmitter. We observed high wetland site
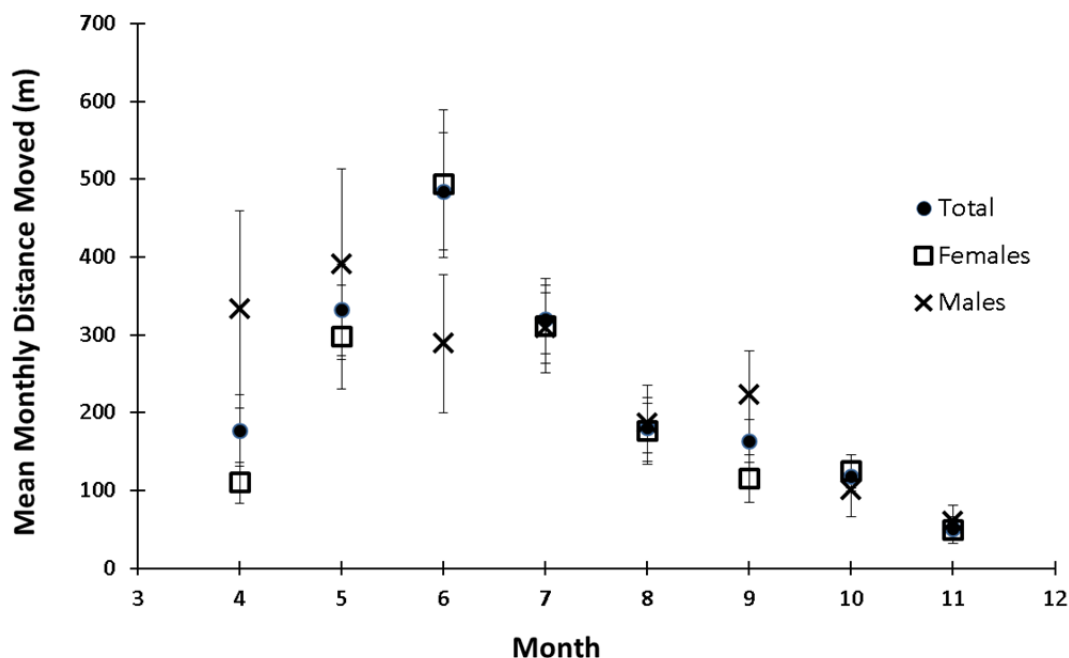
FIGURE 2. Mean (± SE) monthly movement distances of the 22 radio-tracked Blanding's Turtles (*Emydoidea blandingii*) in southcentral New Hampshire.

fidelity among the turtles having multiple hibernaculum wetland observations. For example, one female turtle (B002) used the same hibernaculum wetland in seven consecutive years. Forty-nine hibernacula (77.8% of the total hibernacula observations) were located within three wetlands on NBAFS (Fig. 1).

Home ranges.—Overall, mean home range size (MCP) of radio-tracked Blanding's Turtles was 16.8 ha (± 2.8 SE). Females occupied home ranges 19.6 ha (± 3.5 SE) in size, whereas males occupied home ranges 10.7 ha (± 4.0 SE) in size. Female home ranges were significantly larger than male home ranges (MCP, $t =$ 2.18, df = 20, $P = 0.029$).

There was considerable overlap among the home ranges of the 22 turtles. The composite area of all 22 MCPs was 183 ha, of which 112 ha (61.2%) contained overlapping home ranges of two or more turtles. A maximum of 14 overlapping MCPs (63.6% of the turtles evaluated in this study) occurred in the study area, with more than eight overlapping MCPs occurring within an area of approximately 2.8 ha (Fig 1). Areas of greatest home range overlap (> eight overlapping MCPs) intersected two of the three prominent hibernaculum wetlands on NBAFS (Fig. 1), indicating the relative importance of specific wetland complexes. One of these wetland complexes (A in Fig. 1) is a series of impoundments controlled by Beaver (*Castor canadensis*) activity. The other wetland (C in Fig. 1) is an emergent wetland dominated by Highbush Blueberry.

Activity.—Activity levels, defined as the total (sum) monthly distance moved by each turtle, varied throughout the year (Fig. 2). There was a significant effect of month on turtle activity ($F_{10,166} = 11.81$; $P < 0.001$); however, there was no difference in activity between sexes ($F_{1,166} = 0.60$; $P = 0.440$), nor was there a significant interaction between month and sex on turtle activity ($F_{10,166} = 1.80$; $P = 0.080$). Following emergence from hibernation (March-April), turtle activity increased each month to peak levels in June when females were moving, on average, a cumulative total of approximately 500 m during the month (Fig. 2). There was a relatively steady decrease in activity following the June peak. By November, turtles were moving < 100 m per month.

Habitat use.—Wetland use differed from availability within the landscape (Wilks' λ = 0.15; $F_{4,18} = 21.48$; $P = 0.001$). Overall, turtles selected ponds and scrub-shrub wetlands and avoided lacustrine wetlands (Table 2). The generalized rank order of habitat selection was pond > scrub-shrub > emergent > forested >> lacustrine (where a > denotes a non-significant rank order, and a >> denotes that the rank order is significantly different between two consecutive wetland types based on post-hoc *t*-tests at α = 0.05). Males and females exhibited differences in wetland selection by season. Males generally selected emergent and scrub-shrub wetlands in each season, whereas females generally selected scrub-shrub and emergent wetlands in spring and ponds in

TABLE 2. Results of the compositional analysis to determine Blanding's Turtle (*Emydoidea blandingii*) use of wetlands relative to availability in southcentral New Hampshire between 2004 and 2011.

Season[a] and Sex	MANOVA Results		Rank Order of Habitat Selection[b]
Overall Total	Wilks' $\lambda = 0.152$	$F_{4,18} = 21.48$ $P < 0.001$	Pond > Scrub-Shrub > Emergent > Forested > >Lake
Overall Females	Wilks' $\lambda = 0.192$	$F_{4,11} = 11.57$ $P = 0.001$	Pond > Forested > Scrub-Shrub > Emergent >> Lake
Overall Males	Wilks' $\lambda = 0.004$	$F_{4,3} = 14.87$ $P = 0.001$	Emergent > > Scrub-Shrub > Pond > Forested > > Lake
Spring Total	Wilks' $\lambda = 0.147$	$F_{4,18} = 26.02$ $P < 0.001$	Scrub-Shrub > Emergent > Forested > Pond > > Lake
Spring Females	Wilks' $\lambda = 0.194$	$F_{4,11} = 11.40$ $P = 0.001$	Scrub-Shrub > Emergent > Forested > Pond > > Lake
Spring Males	Wilks' $\lambda = 0.003$	$F_{4,3} = 288.0$ $P < 0.001$	Scrub-Shrub > Emergent > Forested > Pond > > Lake
Summer Total	Wilks' $\lambda = 0.177$	$F_{4,18} = 19.82$ $P < 0.001$	Pond > Emergent > Scrub-Shrub > Forested > > Lake
Summer Females	Wilks' $\lambda = 0.253$	$F_{4,11} = 7.37$ $P = 0.005$	Pond > Forested > Scrub-Shrub > Emergent >> Lake
Summer Males	Wilks' $\lambda = 0.006$	$F_{4,3} = 126.51$ $P = 0.001$	Emergent > Scrub-Shrub > Pond > Forested >> Lake
Fall Total	Wilks' $\lambda = 0.356$	$F_{4,18} = 8.12$ $P = 0.001$	Emergent > Pond > Forested > Scrub-Shrub >> Lake
Fall Females	Wilks' $\lambda = 0.467$	$F_{4,11} = 3.14$ $P = 0.050$	Pond > Emergent > Forested > Scrub-Shrub >> Lake
Fall Males	Wilks' $\lambda = 0.054$	$F_{4,3} = 13.15$ $P = 0.030$	Emergent > Scrub-Shrub > Pond > Forested >> Lake

[a] spring = 1 March through 31 May; summer = 1 June through 31 August; fall = 1 September through 31 December.
[b] ">>" indicates a statistically significant difference between 2 consecutively ranked variables (based on pairwise *t*-test results).

summer and fall (Table 2). Forested and lacustrine wetlands were never the most-selected wetland type by any sex in any season.

We characterized the 63 hibernaculum wetlands to determine whether their use differed from availability. The frequency of hibernaculum wetland types differed from random wetlands ($\chi^2 = 9.79$; df = 4, $P = 0.044$). In general, turtles hibernated in forested wetlands and ponds and generally avoided scrub-shrub wetlands and lakes. However, there was no difference in the proportion of hibernaculum wetland types used by males and females ($\chi^2 = 7.15$; df = 4, $P = 0.130$; Fig. 1).

Road densities and crossings.—We found significant differences in MCP road densities and crossings between sexes (densities: $t = 2.50$, $df_{adj} = 19.92$, $P = 0.023$; crossings: t, $df_{adj} = 17.80$, $P = 0.014$). On average, road densities within female home ranges were approximately five times greater than those for males. We also observed, based on the proportion of road crossings from our telemetry results, that females crossed roads four times more frequently than males (Fig. 3).

DISCUSSION

Home ranges.—Understanding population-level home range size and activity patterns of rare species is important for identifying population risks and developing conservation guidelines to ensure that all habitats important for the persistence of a species in the area are protected. Previous studies have demonstrated that home range sizes for Blanding's Turtle vary widely, from < 1 ha to over 90 ha (Table 3). Our observations of Blanding's Turtle home range size fall within this reported range. Variation in home range size may depend on turtle size and age class, geography, climate, habitat composition and availability, and population density (Congdon et al. 2008). In particular, the composition and availability of refugia and hibernacula is a primary influence of home range estimates (Innes et al. 2008; Millar and Blouin-Demers 2011; Pettit et al. 1995; Piepgras and Lang 2000). Based on previous studies (Table 3), there does not appear to be a consistent relationship between geography and home range size. We found no influence of morphometric variables on home range size, which indicates that other factors such as landscape composition of resources, climate, and
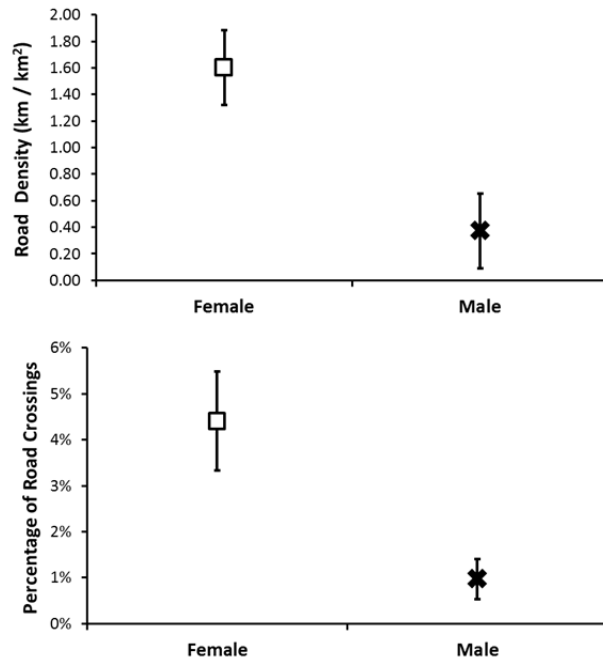
FIGURE 3. Average MCP road density and percentage of road crossings (relative to total number of telemetry observations) for male and female Blanding's Turtles (*Emydoidea blandingii*) in southcentral New Hampshire between 2004 and 2011. Error bars represent ± 1 SE.

population density may be among the primary drivers of home range size among turtles in our study.

On average, females in our study occupied home ranges that were nearly twice as large as the home ranges for males (Table 3). Sex-based differences have been observed in Blanding's Turtle populations and have been attributed to biological and physiological factors that influence activity and habitat use, such as nest site selection among females (Congdon et al. 2008; Millar and Blouin-Demers 2011). For example, in a study in Ontario, Canada, Millar and Bouin-Demers (2011) found that gravid females had larger home ranges than males and non-gravid females, presumably due to the inclusion of long-distance nesting forays of gravid females. Although we did not determine whether the female turtles we tracked during the spring months were gravid, all were of reproductive age (based on carapace length; Congdon and van Loben Sels 1993), and we did observe nesting behavior of some tracked females on several occasions.

The degree of overlap in use of a few areas on our study area, despite the abundance of other wetland habitats and individual use of a greater diversity of wetland areas, suggests that certain wetland complexes may have greater importance than others for maintaining the population at the local scale. We did not conduct a detailed investigation of the characteristics of these more heavily used wetlands, and they appear to be quite different in terms of type (Beaver impoundment vs Highbush Blueberry wetland). It is likely that these

areas are favored because of specific wetland characteristics (depth, water temperature, and water quality) as well as characteristics of surrounding habitats that affect movement patterns and the ability of individuals to meet life-history needs. There is no evidence that these areas of overlap are a result of trap placement because approximately 70% of traps were set elsewhere on the station, and outside of the study area.

Activity.—Similar to previous studies, activity patterns of Blanding's Turtles in our study varied by season (Beaudry et al. 2008; Innes et al. 2008; Millar and Blouin-Demers 2011). Turtles became active in March and April of each year following their emergence from hibernation. Overall, movement distances by turtles in our study increased each month during the spring and peaked in the month of June, which is the month that generally coincides with the nesting period (Innes et al. 2008; Beaudry et al. 2009; Refsnider and Linck 2012). In New Hampshire, Innes et al. (2008) found that female Blanding's turtle activity peaked in late spring and early summer during the nesting period, whereas males increased activity in August and September. In Maine, activity of both sexes also peaked during the late spring / early summer period (Beaudry et al. 2009).

Our findings on Blanding's Turtle activity are consistent with those of other populations in the northeastern United States (Innes et al. 2008; Beaudry et al. 2009). Although we did not detect a significant sex-based difference in movements, activity peaked in May and June for males and females, respectively. The peak in male activity in early spring could be attributed to greater distances moved in the months immediately following emergence from hibernation as they seek to mate with females (Edge et al. 2010). Our observations of female activity are similar to previous studies that found that Blanding's Turtle activity peaked with the nesting season of late spring to early summer (Beaudry et al. 2009; Refsnider and Linck 2012). During the months of peak activity, female Blanding's Turtles in our study area moved approximately 500 m/mo and males moved approximately 400 m/mo. These observations are slightly lower than the extrapolated monthly distances reported by Innes et al. (2008), who found that female and male Blanding's Turtles in New Hampshire traveled approximately 50 m/d (1500 m/mo) and 28 m/d (840 m/mo), respectively, during the nesting period. After the nesting season, Blanding's Turtle activity patterns at NBAFS decreased steadily until turtles arrived at hibernacula in November. The regular decline in activity between the nesting and hibernation periods has been reported in previous studies (Grgurovic and Sievert 2005; Beaudry et al. 2009; Refsnider and Linck 2012).

TABLE 3. Home range sizes of male and female Blanding's Turtles (*Emydoidea blandingii*) from this study and throughout its range.

Study	Geographic Location	Method[a]	Mean Home Range Size (ha)	
			Males (n)	Females (n)
Current Study	New Hampshire, USA	MCP	10.7 (7)	19.6 (15)
Edge et al. 2010	Ontario, Canada	MCP	57.1 (5)	61.2 (16)
Schuler and Thiel 2008	Wisconsin, USA	MCP	26.1 (9)	20.7 (9)
Innes et al. 2008[b]	New Hampshire, USA	MCP	3.7 (4)	1.5 (3)
Innes et al. 2008[b]	New Hampshire, USA	MCP	-	6.8 (3)
Grgurovic and Sievert 2005	Massachusetts, USA	FK	27.5 (14)	19.9 (27)
Millar and Blouin-Demers 2011	Ontario, Canada	MCP	8.5 (20)	gravid: 20.3 (12) nongravid: 7.3 (5)
Piepgras and Lang 2000	Minnesota, USA	MCP	94.9 (8)	60.7 (16)
Rowe and Moll 1991	Illinois	MPM	1.4 (4)	1.2 (3)
Ross and Anderson 1990	Wisconsin, USA	MPM	0.8 (2)	0.6 (4)

[a] MCP = Minimum Convex Polygon; FK = Fixed kernel (95%); MPM = Minimum Polygon Method (equivalent to MCP).
[b] Study of two populations; median values reported instead of averages.

Habitat use.—Similar to reports from other studies, Blanding's Turtles in our study area avoided larger lacustrine wetlands and selected smaller and shallower wetlands throughout the year (Rowe and Moll 1991; Joyal et al. 2001; Beaudry et al. 2009). However, we found that wetland use also varied by sex and season. Males generally selected emergent and scrub-shrub wetlands in each season, whereas females selected scrub-shrub wetlands in spring and ponds in summer and fall. The seasonal selection of different wetlands by females could be due to selection of certain wetlands near nest sites during the nesting period. However, we were unable to reliably detect when females were actually nesting to perform any analysis to statistically evaluate this hypothesis. Although we did not analyze sun exposure or other microhabitat variables in used wetlands, previous studies have suggested that the use of shallower scrub-shrub and emergent wetlands in spring aids in turtle thermoregulation as these wetlands and associated basking locations are warmed more quickly by the sun (Beaudry et al. 2009).

We expected turtles of both sexes to select deeper waterbodies as hibernaculum sites that would provide more stable ice-free habitat for overwintering. Indeed, we did not detect any differences in hibernaculum site selection between sexes. In general, turtles of both sexes overwintered in forested wetlands and ponds. We were unable to evaluate microsite conditions to determine what habitat qualities were selected by turtles for hibernation. Most hibernaculum locations that we observed were within wetlands that remained inundated throughout the winter period (however, we did note that one individual successfully overwintered in a pool that dried out prior to its emergence).

Road densities and crossings.—Vehicle collisions represent a source of mortality that may exceed sustainable levels for many turtle species (as modeled in Gibbs and Shriver 2002). The increasing density of road networks impacts turtle populations through the loss and fragmentation of aquatic and terrestrial habitats and the direct mortality of individuals, particularly reproductive adults (Andrews et al. 2008). Life-history traits or behaviors may increase the likelihood of an individual encountering a roadway, such as the seasonal long-distance nest forays and selection of nest sites exhibited by female turtles, and road mortality of females has been linked as a primary factor affecting turtle populations (Steen and Gibbs 2004; Gibbs and Steen 2005). Road densities within the home ranges of females in our study areas were higher and females crossed roads more frequently than males as they moved between wetlands and selected nest sites. Female Blanding's Turtles in our study area, therefore, may be more vulnerable to road mortality than males.

Previous studies have observed the selection of roadsides by nesting female Blanding's Turtles. Refsnider and Linck (2012) found that road shoulders and trails were the most commonly used land cover type by nesting Blanding's Turtles. They also found that most female turtles crossed roadways at least once during the nesting season, with a mean of 2.4 road

crossings per female. We observed Blanding's Turtle nesting activity along roadsides at NBAFS on several occasions during the study period. Hatchlings have also been observed (both alive and dead) on the portions of these roadways near known roadside nest sites. Hatchlings emerging from roadside nests are at increased risk of vehicle mortality compared to those emerging from nests farther away from roadways.

Studies such as ours that examine spatial ecology and habitat selection of species in disjunct populations or at the edge of their geographic range are needed to ensure that they are sufficiently understood to promote the conservation of the species. These populations can exhibit distinct adaptations to conditions that are atypical of the same species near the center of its range. Populations near the periphery of the range are often smaller and less robust, and therefore more vulnerable to risk factors such as habitat loss or road mortality. The preservation and management of wetland complexes, which include wetlands of various types, depths, and hydroperiods, will be important to provide optimum year-round habitat for the species at all life stages. Peak activity levels coincided with the nesting season in spring and early summer, and females may be more vulnerable to road mortality during this time. Recognizing that this source of mortality to females may represent a significant impact to structure and long-term viability of the population, NBAFS has implemented a turtle awareness program and began implementation of low-angle curbing and drain-cover modifications along road segments to minimize the risk of road mortality. Additional measures, such as exclusion fencing and the consideration of turtle movement corridors between wetlands in the siting of new road projects, should be considered in turtle conservation.

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