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Home Range Size and Distance Traveled from Hibernacula in Northern Pinesnakes in the New Jersey Pine Barrens

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Abstract: We studied home range size and maximum dispersal distance from hibernacula in Northern Pinesnakes (*Pituophis m. melanoleucus*) at a 1418-ha preserve in Cumberland County, New Jersey, USA, between 1993 and 2003. We discovered 22 different winter hibernacula that were used by 39 Northern Pinesnakes. Of the 10 snakes monitored in hibernacula for 3–5 yr, shifting was observed by 8 individuals, and 2 females showed hibernacula philopatry for five consecutive years. The average minimum convex polygon home range of 14 radio-tracked Northern Pinesnakes was 105.51 ha (located 30–108 times/snake), whereas the average kernel density estimator home range was 50% isopleth = 38.99 ha and 90% isopleth = 133.15 ha. There were no differences in home range as a function of sex, but the number of years snakes were radio-tracked affected home range size. An adult male had the largest home range of 258 ha. The average distance traveled by radio-tracked Northern Pinesnakes from their winter hibernacula was 1321.05 m, with a maximum distance of 2146.91 m. Of all snakes followed, 27.3% (n = 3) traveled <1000 m, 18.2% (n = 2) traveled 1000–1100 m, 18.2% (n = 2) traveled 1100–1200 m, and 36.4% (n = 4) traveled >1200 m. The average number of hibernacula available per home range was 3.2. Snakes that were monitored for ≥2 yr had larger home ranges than snakes that were only radio-tracked for 1 yr. Thus, radio-tracking several adult snakes over a 3–5-yr period is the most effective method to determine home ranges, locate hibernacula sites of meta-populations, and reveal an understanding of their ecology, behavior, and conservation requirements.

Key words: Distance from hibernacula; Home range size; Philopatry; *Pituophis melanoleucus*; Radio-tracking

Snakes are affected by habitat loss and fragmentation (Reinert 1994), yet their responses to such alterations have received less attention than in other vertebrates (Gibbons et al. 2000; Bury 2006). Snakes are in need of conservation strategies (Dodd 1993), especially strategies that are species specific (Himes et al. 2006; Burger et al. 2007; Burger and Zappalorti 2011a). For example, populations of Florida Pinesnakes (*Pituophis melanoleucus mugitus*) are declining, largely caused by habitat loss (Frantz 1991, 1992, 2005), and populations of Louisiana Pinesnakes (*Pituophis ruthveni*) are declining throughout their range in Louisiana and Texas, USA (Rudolph and Burgdorf 1997; Himes et al. 2002). With habitat loss, snakes may attempt to move to other nearby areas, suffer local extinctions, or rarely be located by biologists. Thus, translocation or shifting of snakes within their home range also deserves careful consideration and efficacy studies (Reinert 1991; Tuberville et al. 2000; Teixeira et al. 2007).

New Jersey, USA, is a densely populated state and has experienced dramatic habitat loss over the past 30 yr, with an annual loss of 0.27% per year (Hasse and Lathrop 2008). The habitat requirements and home range sizes of threatened and endangered snake species is crucial information for management and conservation planning. Northern Pinesnakes (*Pituophis m. melanoleucus*) are listed as a state threatened species in New Jersey; their overall range and critical habitat have declined, with annual habitat loss of about 0.29% (Golden and Jenkins 2003; Burger and Zappalorti 2011a,b). Northern Pinesnakes are important predators within the Pine Barrens ecosystem; therefore, understanding the distance they travel from their hibernacula has important conservation implications. Snake species that are distributed at higher latitudes must have appropriate places to survive freezing winter temperatures. Snakes that move great distances are more likely to experience mortality because of many factors (Bonnet et al. 1999), and they are often intentionally run over while crossing paved or sand roads (Burger and Zappalorti 2011a). Thus, examining home range sizes and maximum seasonal migration distances away from winter hibernacula for Northern Pinesnakes is important, particularly as an example of a large snake species surviving within a highly urbanized and densely populated region (Kauffeld 1957; Zappalorti and Mitchell 2008).

In this paper, we examine variations in home range sizes and distances that Northern Pinesnakes travel from hibernacula to areas of available habitat. We conducted a radiotelemetry study over a 10-yr period at The Nature Conservancy plant and wildlife preserve in Cumberland County, New Jersey. We determined (1) the mean and greatest dispersal distances traveled by Northern Pinesnakes away from their winter hibernacula; and, (2) the average minimum convex polygon and average kernel density estimator values for the home range of 26 adult radio-tracked Northern Pinesnakes. We were also able to examine philopatry to hibernation sites, and shifts among hibernation sites for 10 snakes followed for 3–5 yr. We have previously examined the question of philopatry to hibernation sites in a 26-yr study of pinesnakes, where hibernacula were excavated each year (Burger et al. 2012), and in a 6-yr study where some snakes were translocated and could choose to hibernate in natural hibernacula or hibernacula we constructed (RZ, personal observation). In the present study, we examine home range size over a 10-yr period, although no individual snake was followed for more than 5 yr.

Protecting populations of threatened species such as pinesnakes requires information on home range size, hibernaculum use, and distance traveled to reach a hibernaculum; such information has important implications for conservation by aiding in (1) maintaining habitat patches that are large enough to support viable populations; (2) ensuring adequate habitat diversity and space for numerous

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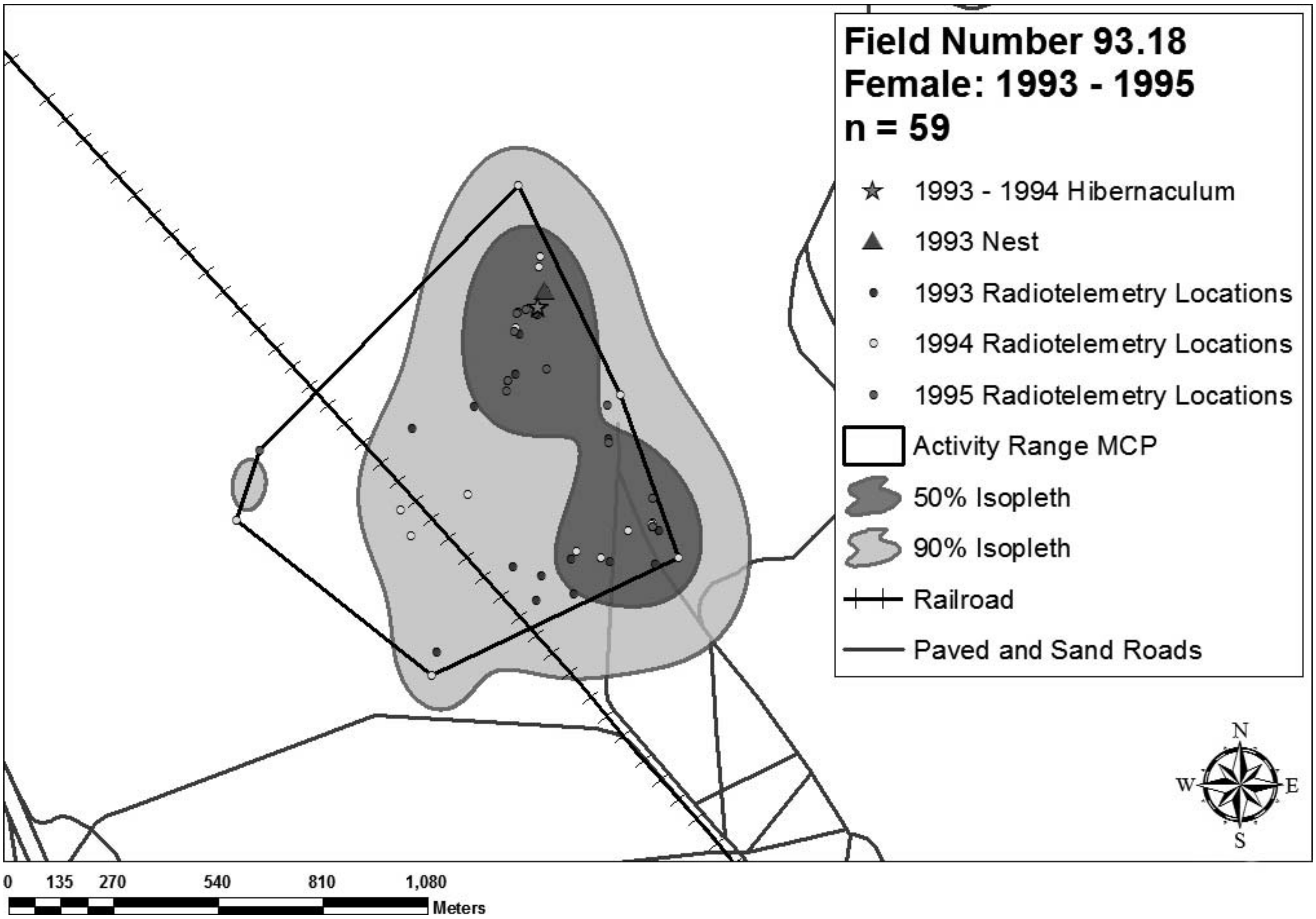

FIG. 1.—Home range of adult female Northern Pinesnake (*Pituophis m. melanoleucus*) 93.18, radio-tracked for 3 yr in southern New Jersey.

overlapping home ranges; (3) determining protected area size, which cannot be determined without information on site-specific home range sizes (particularly for pinesnakes in New Jersey that are separated from others farther south by 450 km); and, (4) determining the space required for habitat protection, which is influenced by the distance individual pinesnakes will travel. If large enough habitat patches are maintained, but they do not contain nesting or hibernation sites, or are not those habitats actually used by pinesnakes, the snakes will move to their preferred critical habitat (e.g., nesting areas and hibernacula), even if it means crossing a road. With increased development in the New Jersey Pine Barrens, it is critical to understand how far pinesnakes will move to reach a hibernaculum, and whether they bypass other natural hibernacula.

MATERIALS AND METHODS

Description of Study Area

This study was conducted between 1993 and 2003 at a 1417.5-ha Nature Conservancy sanctuary in Cumberland County, New Jersey. The study area is located between a river and a creek, has three paved roads and five sand roads, and is bisected by a semi-active railroad (one train per week). The New Jersey Pine Barrens represents a post-Pleistocene sand ridge area with unique geomorphic features that support an assortment of plant and animal communities adapted to dry, nutrient-poor conditions (McCormick 1970; McCormick and Forman 1979; Boyd 1991). The plant communities include Short Leaf Pines (*Pinus echinata*), Pitch Pines (*Pinus rigida*), Virginia Pines (*Pinus virginiana*), and hardwoods such as Scrub Oaks (*Quercus ilicifolia*), Post Oaks (*Quercus stellata*), and Blackjack Oaks (*Quercus marilandica*).

Frequent wildfires have historically shaped the landscape of the Pine Barrens (Forman and Borner 1981). According to McCormick (1970) and Boyd (1991), forests of Pitch Pines typically have an understory consisting of Scrub Oaks, Blackjack Oaks, Lowbush Blueberries (*Vaccinium pallidum*), Black Huckleberries (*Gaylussacia baccata*), Dangleberries (*Gaylussacia frondosa*), and Mountain Laurels (*Kalmia latifolia*). In forest areas where the canopy is fairly open, however, especially sections that were formerly disturbed, the understory is dominated by Pennsylvania Sedges (*Carex pensylvanica*), Heathers (*Hudsonia ericoides*), Staggerbushes (*Lyonia mariana*), Switchgrasses (*Panicum virgatum*), Broom Sedges (*Andropogon virginicus*), Little Blue Stems (*Schizachyrium scoparium*), and Sweet Ferns (*Comptonia peregrina*). The oak species associated with Oak–Pine forests consist of White Oaks (*Q. alba*), Chestnut Oaks (*Q. prinus*), Black Oaks (*Q. velutina*), Post Oaks, and Scarlet Oaks (*Q. coccinea*).

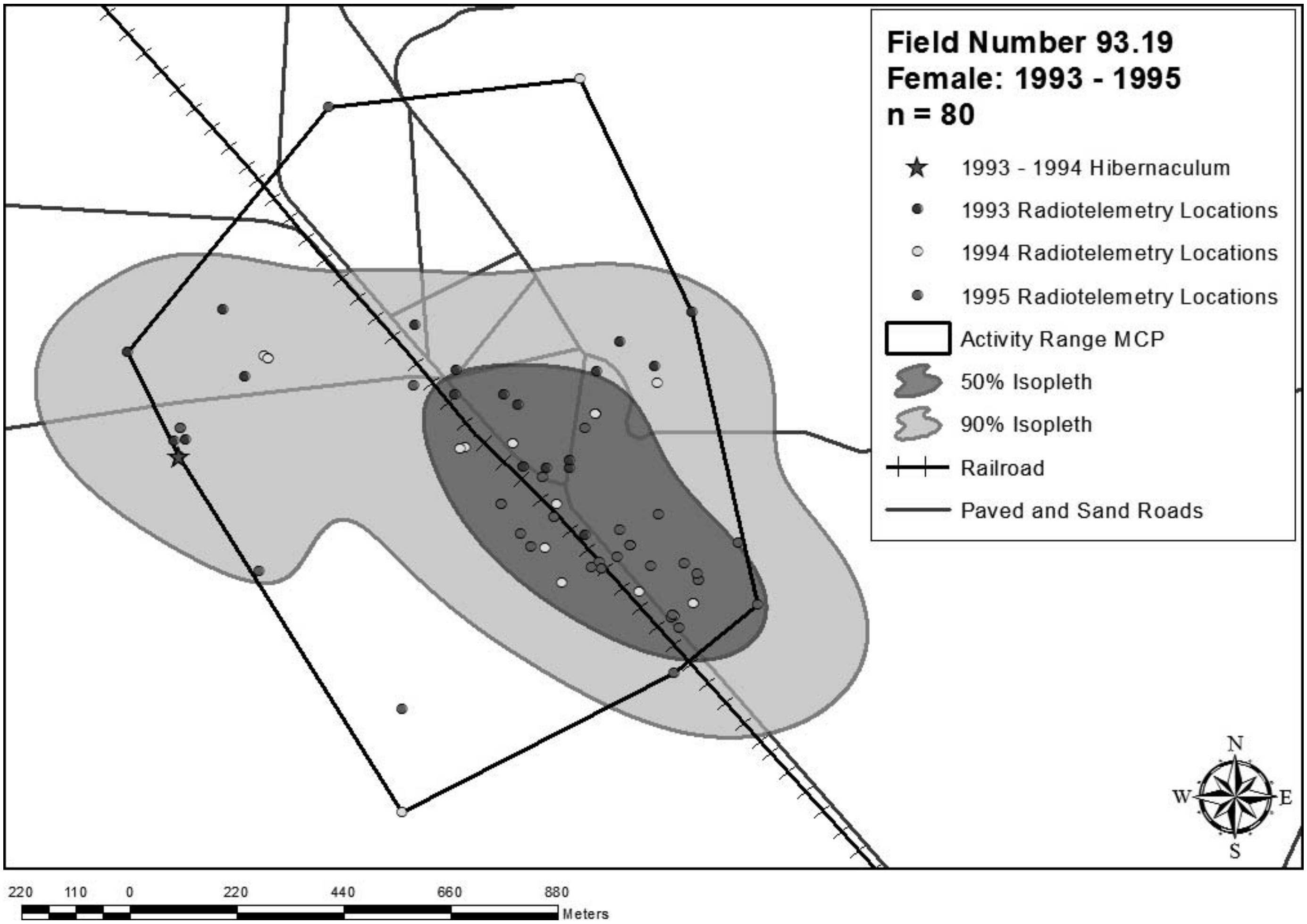

FIG. 2.—Home range of adult female Northern Pinesnake (*Pituophis m. melanoleucus*) 93.19, radio-tracked for 3 yr in southern New Jersey.

Protocol

Our overall protocol was to locate snakes and use radiotelemetry to determine the maximum distance traveled from a hibernaculum and the home range size of each subject. We defined a hibernaculum as the place where each snake spent the winter (November–March). Because Northern Pinesnakes are secretive and difficult to locate in the forest, we used several sampling techniques that took into account different aspects of their biology, which resulted in the best capture results (Campbell and Christman 1982; Vogt and Hine 1982; Enge 1997; McDiarmid et al. 2012). Four standard survey methods were used to find Northern Pinesnakes: random opportunistic sampling, time-constrained searching, diurnal and nocturnal road cruising, and drift fence trapping (Campbell and Christman 1982; Karns 1986; Enge 1997). We used 1.7-m-high wire hardware cloth fence or 1-m nylon silt fencing in lengths that varied from 50 to 1000 m, in conjunction with 29 wooden snake funnel traps. Three drift fences were positioned in the habitat to capture snakes as they traveled or foraged (one fence along the edge of a sand road [300 m in length], one fence in the center of a grassy field [400 m], and one fence in the Pine–Oak forest [500 m]). Leaves and moss were placed in each trap to provide a suitable retreat, and a plywood board was placed over the top to provide shade and reduce exposure to the sun (Enge 2001). Snake funnel traps were checked every 24–48 h, depending upon weather.

Individual Identification and Marking

Body measurements were taken upon initial capture using a squeeze box; mass was determined using an Ohaus triple beam balance (± 0.5 g); and sex was determined by probing, counting subcaudal scales, or noting sexually dimorphic characteristics. Initially, snakes were marked by branding dorsal scales in a specific pattern with a fine-tip soldering iron; but thereafter, implantable AVID tags were used for individual identification (Elbin and Burger 1994). The AVID tags were small (14×2.1 mm, 0.08 g), thereby allowing their use in neonate Northern Pinesnakes.

Radiotelemetry

Radio transmitter R1535 or R1520 units (Advanced Telemetry Systems, Inc., North Isanti, MN) were used; they have a battery life of 12 or 24 mo. Therefore, several of the snakes had their radio transmitters replaced every 1 or 2 yr. Transmitter mass was <5% of snake body mass. The typical reception range of the transmitters was 400–1000 m, depending on the snake's location. Transmitters were surgically implanted in the coelomic cavity following the procedure of Reinert and Cundall (1982), with additional

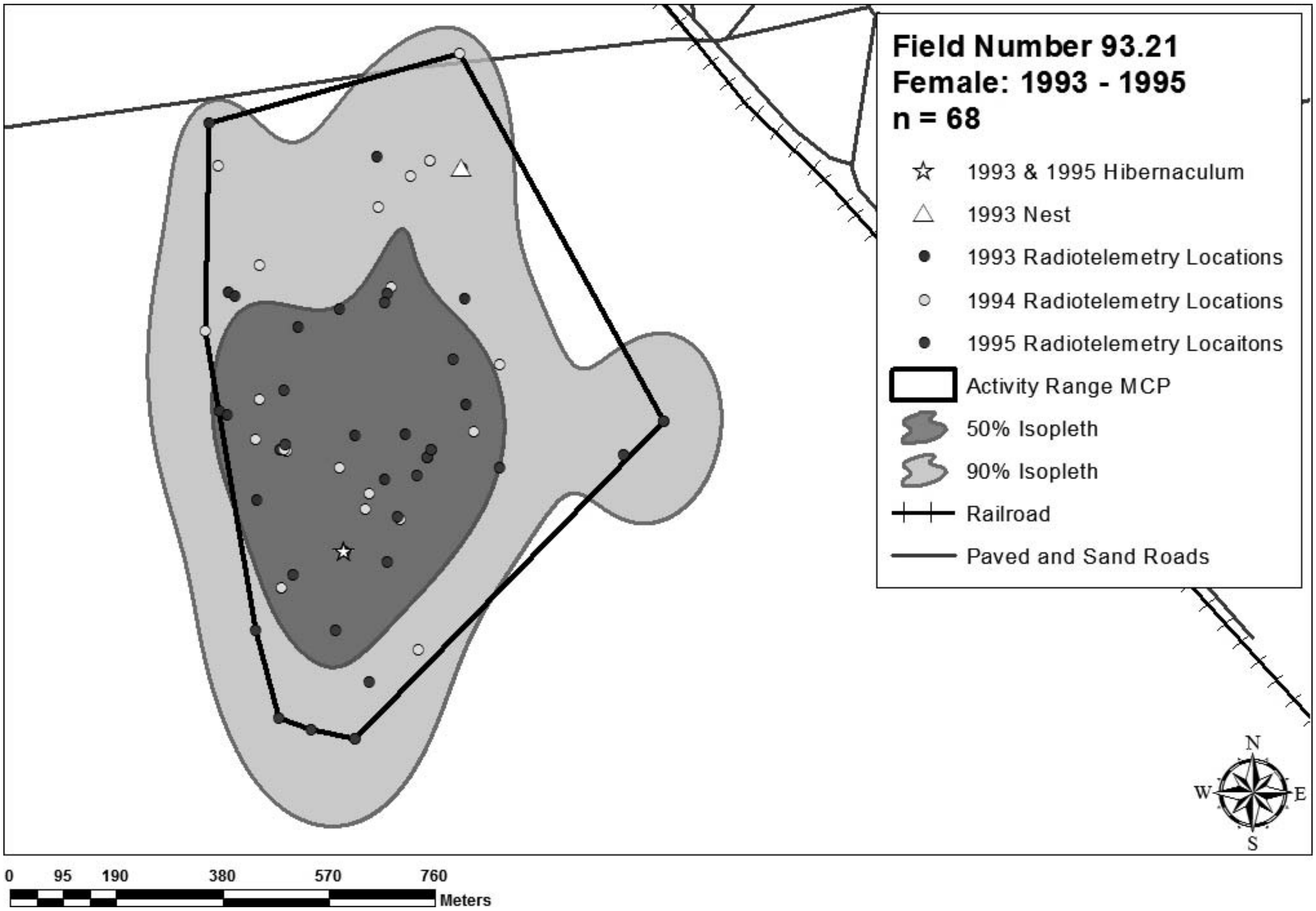

FIG. 3.—Home range of adult female Northern Pinesnake (*Pituophis m. melanoleucus*) 93.21, radio-tracked for 3 yr in southern New Jersey.

improvements (Mech 1983; Reinert 1992). Within any given year, implantations were performed only from 15 April to 15 August, allowing snakes ample time to heal from the surgery (Lutterschmidt 1994; Rudolph et al. 1998). We surgically implanted 26 Northern Pinesnakes with radio transmitters, but only 14 snakes had ≥30 radiolocations. Snakes with <30 locations were not included in the analysis, even though we generated a distribution map of all radio-tracked snakes. At the end of the study, all transmitters (except for those that had malfunctioned) were removed successfully before final release of the snakes (Reinert 1992).

Transmitter-equipped snakes were located in the field once every 48-h period by using a TRX 2000S receiver (Wildlife Materials, Murphysboro, IL), except during unfavorable weather (e.g., fog, rainstorms, or lightning). Equipment malfunctions (either transmitter or receiver) also affected the radio-tracking intervals. Each snake's location, activity, behavior, and habitat were recorded in the field using a GeoExplorer 3 GPS unit (Trimble, Sunnyvale, CA). We also recorded habitat structure at snake locations, temperature, humidity, and weather conditions.

Home range analysis.—A home range is defined by Gregory et al. (1987) as an integrated expression of an animal's location and movements over a specific time interval. The range and total distance traveled provide a quantitative expression of the area required to complete all biological activities (hibernation, mating, foraging, oviposition). The minimum convex polygon (MCP) method was used in this study to plot locations of transmitter-equipped snakes to scale and to calculate home range boundaries (Southwood 1966). This method was chosen for its simplicity, historic prominence, and ease of comparison with existing data on reptilian activity (Jenrich and Turner 1969; Brown and Parker 1976; Reinert 1992, 1994). The MCP method uses the outermost points plotted on a map (connected to form a polygon), which includes 100% of the subject locations. The area of the polygon is then calculated to arrive at the MCP home range.

We also calculated home range using the kernel density estimator (KDE), via a fixed range of animal habitat utilization distributed equally within 50% and 90% isopleths (Worton 1995). The KDE uses nonparametric statistical procedures to calculate probabilities of a snake being in various locations in two-dimensional space, and adjusts the home range boundaries for local variation in frequency. We used a bivariate normal-density kernel in our analyses of home range (Worton 1995) and used a smoothing factor, H (Row and Blouin-Demers 2006), in a geospatial modeling environment (Beyer, 2012). We used multiple regression techniques to identify the factors affecting variation in home ranges (SAS Inc. 2005). A probability of $\alpha < 0.05$ was considered significant.

Hibernation philopatry.—Philopatry was examined at five communal hibernacula that were each encircled with

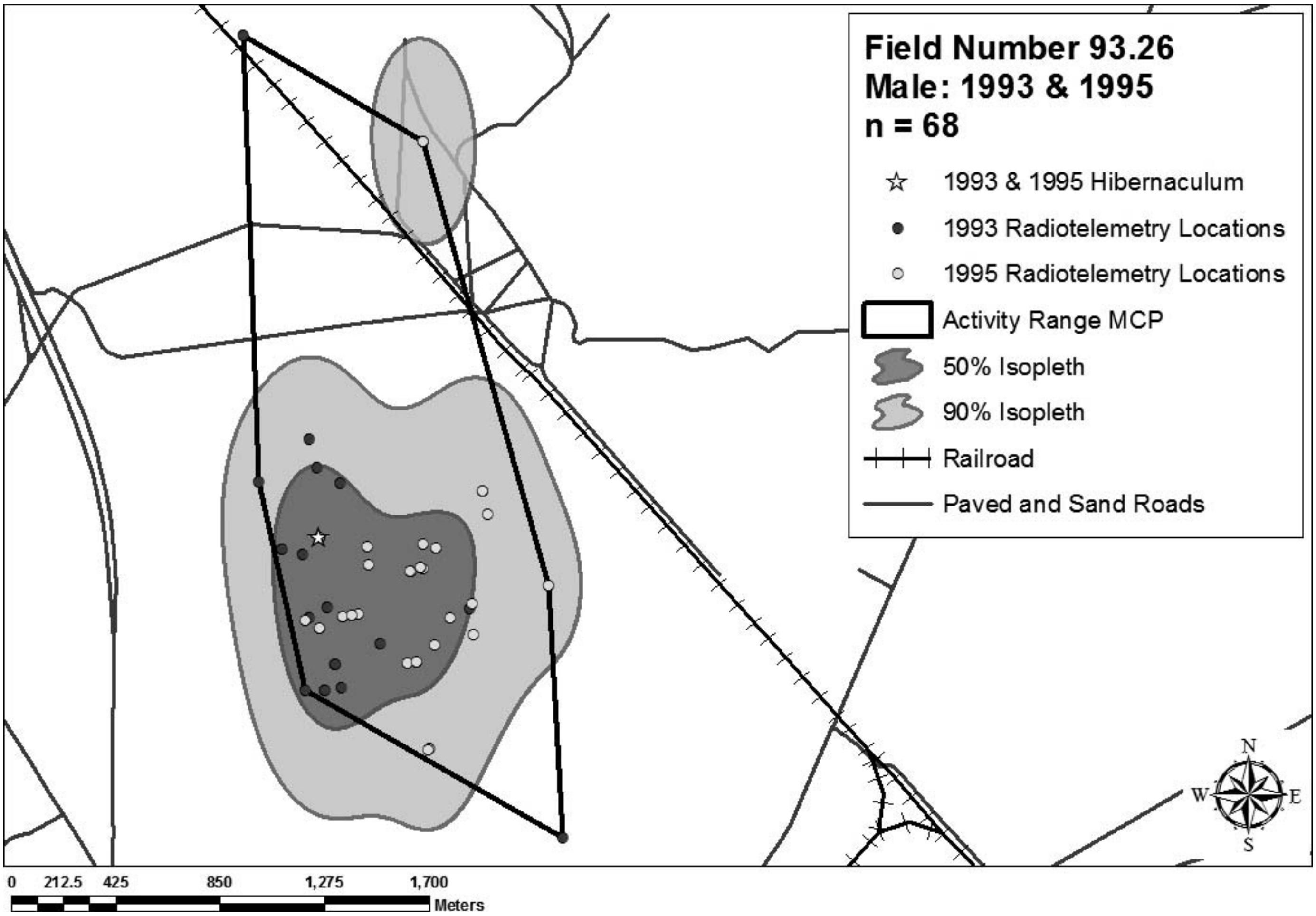

FIG. 4.—Home range of adult male Northern Pinesnake (*Pituophis m. melanoleucus*) 93.26, radio-tracked for 2 yr (1993 and 1995) in southern New Jersey.

13 m of 1.7-m-high hardware cloth fence. Three funnel traps were also positioned at each den site. Snakes were trapped on the outside of the fence as they egressed in the spring, or on the inside of the fence when they ingressed in the fall. We trapped snakes at dens for 5 yr. This effort allowed the recapture of marked Northern Pinesnakes that were not fitted with radio transmitters, gaving us a total of 13 additional non-radio–tracked Northern Pinesnakes. For analysis, we divided a snake's distance from a hibernaculum into four categories based on what we previously believed was the maximum distance traveled (1000 m; Burger and Zappalorti 1988).

RESULTS

Radio-tracked Northern Pinesnakes, located from 30 and 108 times between April and October of any given year, led us to 22 different natural hibernacula within the study area. In total, 39 Northen Pinesnakes occupied these natural dens. Generally, home range size tended to increase with an increased duration of telemetry (Figs. 1–6). The composite distribution map generated from locations of all 39 adult Northern Pinesnakes tracked over the 10-yr study indicates a combined area used by this population of 980 ha (Fig. 7). The home ranges of most snakes were centered around a railroad track.

We used multiple regression analysis to identify the factors that affected home ranges, including one model that excluded water features (Table 1). At least 70% of the variation in the home ranges was explained by maximum distance to the hibernacula; sex did not enter as a significant variable. The number of years radio-tracked also entered as a significant variable. Some snakes were radio-tracked for only 1 yr, whereas others were tracked for 3–5 yr. Most snakes that were monitored for >2 yr had larger home ranges than those individuals that were radio-tracked for only 1 yr (Table 2).

The average 100% MCP home range size of 14 radio-tracked Northrn Pinesnakes (each located >30 times) was 105.51 ha. Home ranges calculated from MCPs did not vary as a function of sex (Table 3). The average KDE home range was 38.99 and 133.15 ha for the 50% and 90% isopleths, respectively (Table 4). The largest home range of 258.0 ha was used by an adult male.

The maximum distance traveled from a winter hibernaculum (den) by an adult male subject was 2146.91 m, whereas the maximum distance traveled from a hibernaculum by an adult female was 1171.75 m. The mean maximum distance traveled by radio-tracked snakes from their winter hibernacula was 1320.05 m. Of the 11 tracked snakes with known winter den locations in a given year, 27.3% traveled <1000 m from their hibernacula (n = 3), 18.2% traveled 1000–1100 m

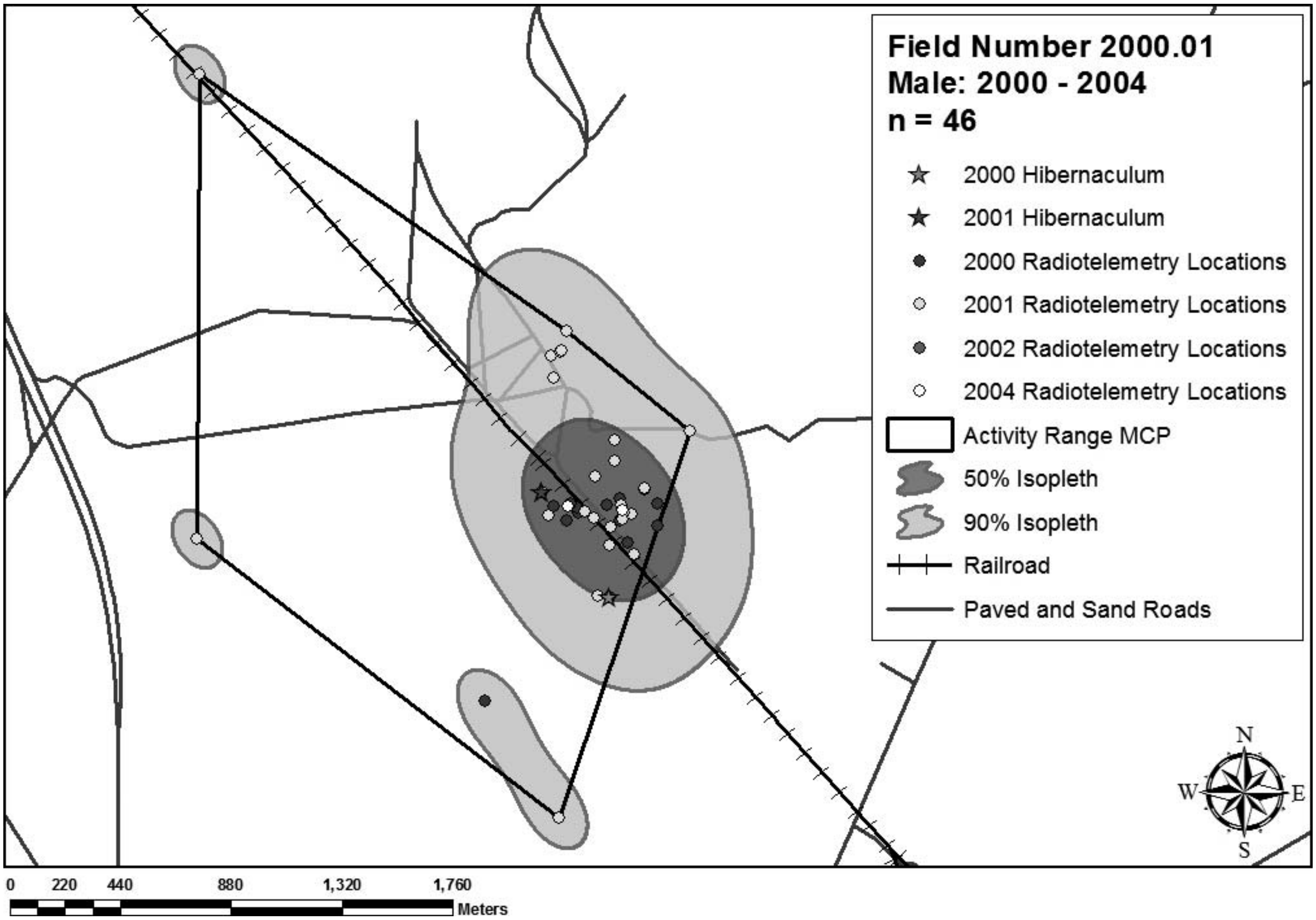

FIG. 5.—Home range of adult male Northern Pinesnake (*Pituophis m. melanoleucus*) 2001.01, radio-tracked for 4 yr (2000–2002 and 2004) in southern New Jersey.

(n = 2), 18.2% traveled 1100–1200 m (n = 2); the remaining snakes (n = 4; 36.4%) moved >1200 m from their winter hibernacula. Maximum distance from the den was related to activity range (Fig. 8). The maximum distance from a den did not vary as a function of the number of years that a snake was tracked (Table 2).

Philopatry to Hibernacula

Of the 22 hibernacula identified during our study, we focused on five den sites over a 5-yr monitoring period; at these sites, 10 snakes demonstrated varying degrees of philopatry. Seven snakes shifted from one hibernaculum to another at least once during the 5 yr of observation. One adult male overwintered in hibernaculum 3 for three consecutive years, then shifted to hibernaculum 2 the following winter, and shifted again to hibernaculum 9 the subsequent winter. In contrast, two adult female Northern Pinesnakes that were radio-tracked showed philopatry to the same hibernacula for five consecutive years.

DISCUSSION

Home Ranges

Home ranges can vary within and among closely related species as a function of resources, habitat variability, habitat suitability, predator pressures, and other factors. Understanding variation in home range of the same species in different places can provide some indication of resource differences, as well as site-specific information about spatial requirements of individuals within a given population. The mean MCP home range of the Northern Pinesnakes in our study (105.51 ha) was greater than that reported for populations in Tennessee (79.1 ha; Gerald et al. 2006a,b) and Mississippi, USA (47.5 ha for Black Pinesnakes [*Pituophis melanoleucus lodingi*]; Duran and Givens 2001). Snakes in the latter population used old stump holes for shelter and avoided using burrows of Gopher Tortoises (*Gopherus polyphemus*) for refugia. The smaller home range sizes reported by Duran and Givens (2001) might reflect a more diverse and higher quality habitat. In contrast, the home ranges of Black Pinesnakes at DeSoto National Forest in Mississippi ranged from 91.0 to 395.0 ha (Baxley 2007; Baxley and Qualls 2009). A study of Florida Pinesnakes in southern Georgia, USA, found a mean MCP home range of 59.2 ha (Miller et al. 2012). Home ranges of Florida Pinesnakes differed seasonally, with the size during fall and winter being smaller than the size during spring and summer, and this pattern was driven by differences in the home range sizes of male snakes (Miller et al. 2012). The number of years of study might also account for some of these differences, as we found a significant effect of telemetry duration on home range size.

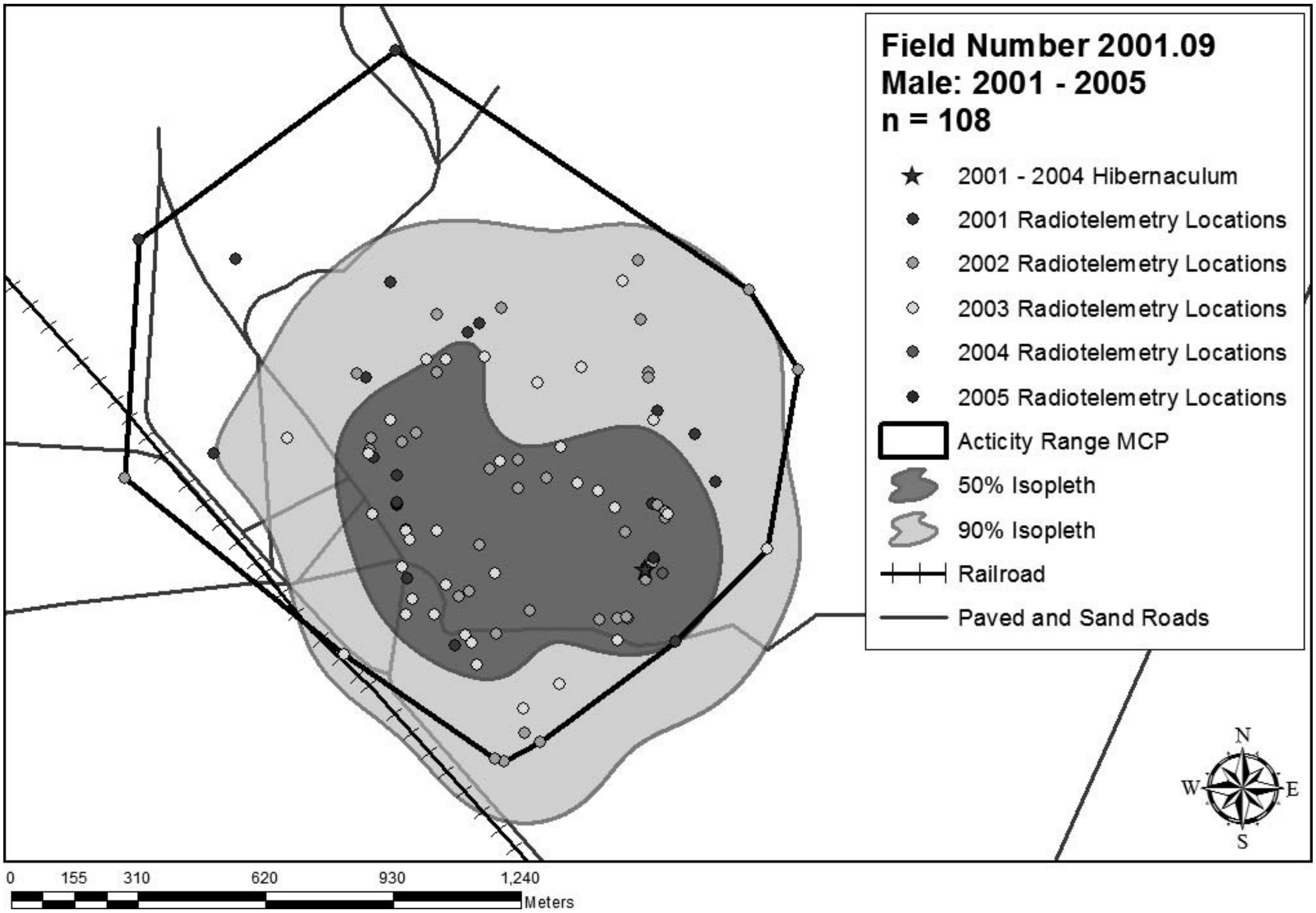

FIG. 6.—Home range of adult male Northern Pinesnake (*Pituophis m. melanoleucus*) 2001.09, radio-tracked for 5 yr (2001–2005) in southern New Jersey.

Comparing our results to other studies of congeners, the mean MCP of six Louisiana Pinesnakes was larger (118.0 ha; Himes et al. 2006) than that of the telemetered snakes in the current study. Using Bullsnakes (*Pituophis catenifer sayi*) near the northern limit of its geographic range, Kapfer et al. (2008) reported a mean home range of 41.0 ha for males ($n = 15$) and 23.0 ha for females ($n = 12$). The home ranges of Great Basin Gophersnakes (*Pituophis catenifer deserticola*) in British Columbia, Canada, averaged 10.5 ± 1.7 ha (Williams et al. 2012), which was considerably smaller than that of the New Jersey Northern Pinesnakes. As suggested above, differences in MCP values between these studies might also relate to duration of tracking.

Large movements by male snakes are associated with courtship and mating behavior, whereas large movements by females are associated with migration to nesting areas and nest site selection (Zappalorti et al. 1983; Burger and Zappalorti 1991, 1992, 2011b). During the spring at our study site (April and May), males moved greater distances in search of females. Indeed, the largest movement made by any of our snakes within 24 h was 2146.91 m—this snake was an adult male found mating with a telemetered female, and he remained with her for 2 d. Aside from mating and nesting, foraging behavior during the summer also appeared to trigger distant movements by pinesnakes to areas with abundant prey (Burger and Zappalorti 1988, 2011b).

Use and Philopatry of Hibernation Sites

Pinesnakes, and other members of this genus, use occupied and abandoned mammal burrows, or subterranean tunnels, for summer shelter or winter hibernacula (Stull 1940; Kauffeld 1957; Burger et al. 1988; Reichling 1995). They also use stump holes or burrows that they excavate themselves (Carpenter 1982). Burger et al. (2012) have shown that pinesnakes might occupy the same winter hibernacula for up to 26 consecutive years. Kapfer et al. (2010) reported that Bullsnakes largely remain near their hibernacula year-round, which might explain their smaller home ranges and shorter travel distances to hibernacula. When a hibernaculum is not used, it is usually because it has been discovered by a predator, or the snakes shifted to other hibernacula within their home range (Burger et al. 2012).

The factors guiding a snake's selection of particular hibernacula are poorly understood. We documented 22 hibernacula at our study site; thus, Northern Pinesnakes have a choice as to which hibernacula they will use. Because two to five hibernacula are available within the home range of each telemetered snake, the hibernacula used were not always at the center of those areas. As the temperatures decrease in the fall, a snake might move to a particular hibernaculum, bypassing others within its home range, or the individual might use the closest den site that it had used

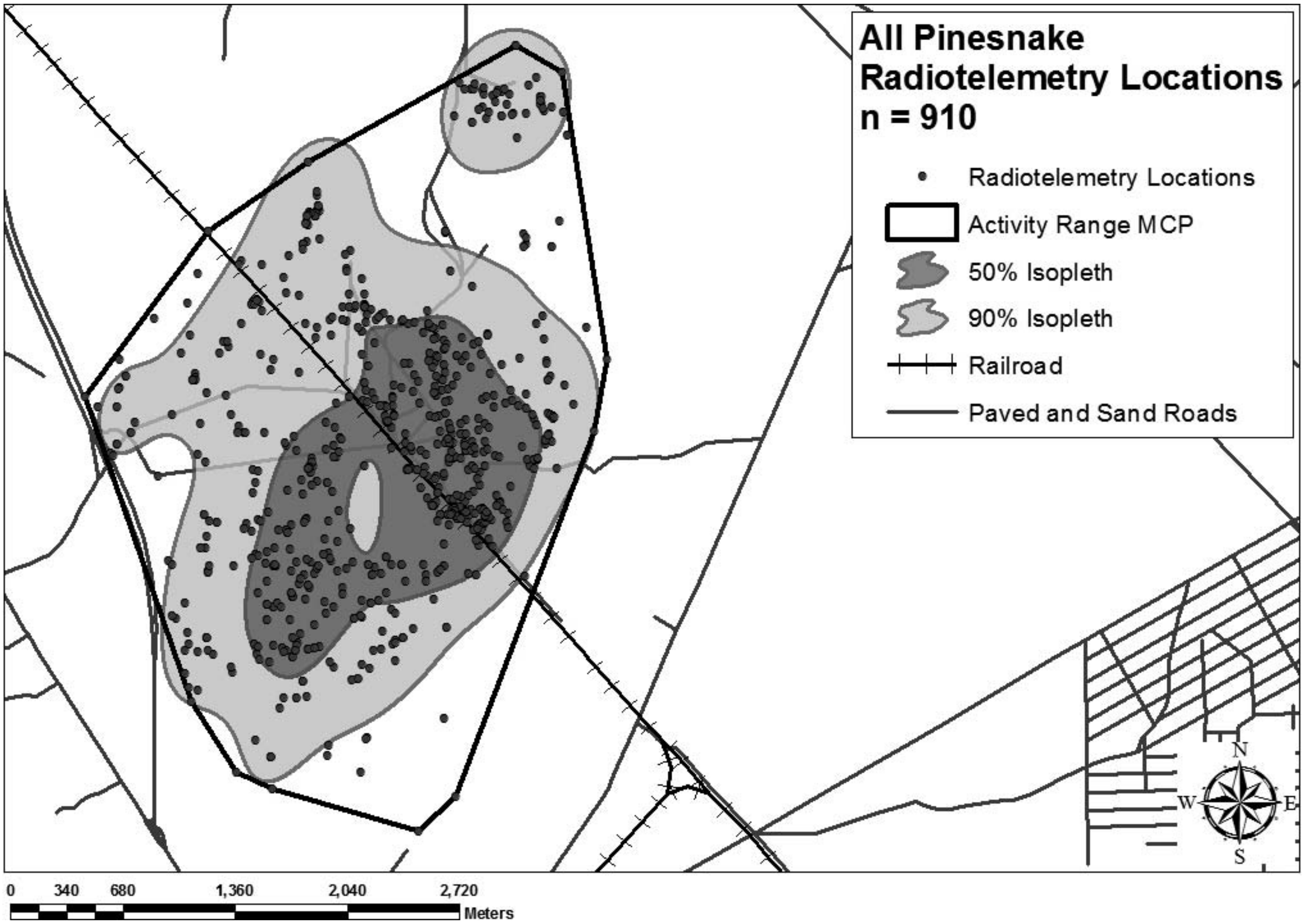

FIG. 7.—Composite distribution of locations from all radio-tracked Northern Pinesnakes (*Pituophis m. melanoleucus*; $n = 14$) over a 10-yr period (between 1993 and 2005) in the New Jersey Pine Barrens.

TABLE 1.—Models explaining variations in home range of Northern Pinesnakes (*Pituophis m. melanoleucus*; $n = 26$) in New Jersey between 1993 and 2003. We also developed a model based only on the area of land excluding water, because Northern Pinesnakes do not forage in water.

		Home range (km^2)	
		All areas	Area excluding water
Model			
F (P)		6.2 (0.001)	4.4 (0.007)
df		5	5
r^2		0.61	0.52
Factors entering; F (P)			
	Sex	0.03 (0.85)	1.6 (0.22)
	No. of locations	1.5 (0.24)	0.64 (0.43)
	Maximum distance from den	9.2 (0.007)	3.7 (0.07)
	Years radio-tracked	0.86 (0.36)	5.1 (0.04)
	No. of dens in area	0.96 (0.34)	2.4 (0.14)

TABLE 2.—Effect of years tracked on home range and maximum distance to a den for Northern Pinesnakes (*Pituophis m. melanoleucus*) in New Jersey Pine Barrens between 1993 and 2003.Values are reported as means ± 1 SD.

	Random capture	1 yr	2 yr	3 yr
No. of snakes	6	8	6	6
Mean no. of locations	7.5 ± 2.4	27.0 ± 10.0	50.3 ± 21.4	65.3 ± 26.6
Home range (km^2; all areas)	0.37 ± 0.43	0.64 ± 0.29	1.09 ± 0.79	1.07 ± 0.49
Home range (km^2; ponds excluded)	0.32 ± 0.40	0.59 ± 0.30	0.98 ± 0.49	0.77 ± 0.37
Maximum distanced from den (km)	1.13 ± 0.42	1.28 ± 0.57	1.34 ± 0.62	1.10 ± 0.21
No. of dens in home range	3.5 ± 1.4	1.88 ± 1.13	4.5 ± 2.74	3.17 ± 1.94

TABLE 3.—Values (mean ± 1 SE) for parameters generated from telemetry of female (n = 13) and male (n = 13) Northern Pinesnakes (*Pituophis m. melanoleucus*) in New Jersey Pine Barrens between 1993 and 2003.

	All snakes	Females	Males
Mean no. of locations	36.7 ± 27.2	33.9 ± 24.1	39.6 ± 30.6
Mean no. of years tracked	1.5 ± 1.1	1.6 ± 1.3	1.3 ± 0.9
Home range (km^2; all areas)	0.78 ± 0.57	0.65 ± 0.42	0.91 ± 0.68
Home range (km^2; ponds excluded)	0.66 ± 0.44	0.53 ± 0.41	0.79 ± 0.44
Maximum distance from den (km)	1.22 ± 0.47	1.06 ± 0.24	1.38 ± 0.59
No. of dens in home range	3.2 ± 2.0	2.6 ± 1.7	3.7 ± 2.2

in a prior winter. We also suggest that their selection of hibernacula may be associated with chemical scent (pheromone) trails deposited by conspecifics entering a hibernaculum (Ford 1978, 1986; Burger 1989, 1991; Gehlbach et al. 1971). Another possible explanation for choice of hibernacula might simply be related to the snake's location within its home range when the weather turns consistently cold in late fall.

One adult male hibernated in the same hibernaculum for three consecutive years and then shifted to a different hibernaculum the next winter. When located the following winter, the snake had shifted again to a den site 400 m away from where it hibernated the previous year. In contrast, two adult females showed philopatry for five consecutive years. These observations compare favorably with studies we conducted previously at 45 different hibernacula in Burlington and Ocean counties, New Jersey, where snakes often shifted from one hibernaculum to another, whereas others showed philopatry for several years (Burger and Zappalorti 2011a; Burger et al. 2012).

Implications of Home Range and Hibernation Data

In contrast to smaller species of snakes, large species such as Northern Pinesnakes are particularly vulnerable because their populations are generally smaller, their home ranges are larger, and they suffer higher rates of persecution by the general public (Burger and Zappalorti 2011a). The task of conserving large-bodied snakes in heavily populated areas is thus challenging, particularly in the face of continued development and habitat destruction, and the disregard for biological constraints (Zampella 1986).

Knowing the approximate home range and the mean distance snakes will travel away from hibernacula is useful information for conservation biologists when determining the minimum area of habitat necessary to protect pinesnakes throughout their range. Once a hibernaculum location is known, based upon the maximum distance a snake will travel away from it, conservation biologists might be able to encompass all known hibernacula within a preservation area. The more hibernacula that are included in a planned conservation area, the greater the chance are that a population will survive. Pinesnake habitat, including nesting and hibernation sites, occurs at a low frequency in the Pine Barrens (Burger and Zappalorti 1986, 1991, 2011a). Including critical nesting habitat within the conservation area ensures recruitment into the target population, but the nesting area should be contiguous with hibernacula preservation areas because both are necessary to maintain a healthy population.

For a large-bodied snake species occurring in temperate climates, we suggest that radio-tracking several adults for a minimum of 3–5 yr is necessary to locate hibernacula and understand the ecology and habitat requirements of the species. Although this study focused on home range size and hibernacula use, confirmed nesting areas and connected wetlands should also be included in a proposed snake conservation area to ensure habitat diversity (Burger and Zappalorti 2011a). If possible, such proposed areas for preservation should not be traversed by paved roads (or improved dirt roads) because of the high probability of road mortality incurred by snakes and other wildlife (Saunders et al. 1991; Andrews and Gibbons 2005; Burger et al. 2007; Andrews et al. 2008).

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TABLE 4.—Maximum distance traveled from dens and values for minimum convex polygon (MCP) and kernel density estimator of home ranges for radio-tracked Northern Pinesnakes (*Pituophis m. melanoleucus*) in New Jersey Pine Barrens between 1993 and 2003.

Snake field no.	Sex	Years radio-tracked	No. of locations	MCP home range (km^2)	Kernel home range (km^2)	Maximum distance traveled from den (km^2)
93.26	Male	1993, 1995	68	2.58	50% = 0.64; 90% = 2.40	4.24
2000.01	Male	2000, 2002, 2004	46	0.78	50% = 0.46; 90% = 1.56	4.61
2001.09	Male	2001–2005	108	1.83	50% = 0.51; 90% = 1.52	2.02
93.18	Female	1993–1995	59	0.79	50% = 0.29; 90% = 1.0	0.97
93.19	Female	1993–1995	80	1.25	50% = 0.26; 90% = 1.10	1.28
93.21	Female	1993–1995	68	0.65	50% = 0.27; 90% = 0.84	0.65
93.20	Male	1993–1994	50	1.0	50% = 0.47; 90% = 1.44	1.14
93.23	Female	1993, 1995, 1996	42	1.34	50% = 0.56; 90% = 1.94	1.15
93.102	Male	1993, 1995	35	0.98	50% = 0.41; 90% = 1.60	No den location[a]
94.145	Male	1994–1995	31	0.83	50% = 0.27; 90% = 0.92	3.15
95.61	Male	1995–1996	30	0.84	50% = 0.46; 90% = 1.43	No den location[a]
97.17	Female	1997, 2001, 2003	38	0.60	50% = 0.16; 90% = 0.65	0.80
2001.15	Female	2001–2003	35	0.55	50% = 0.25; 90% = 0.72	1.37
2002.01	Female	2002	39	0.78	50% = 40.46; 90% = 1.56	No den location[a]

[a] Snake captured during late spring, away from its den. Distance traveled is unknown.

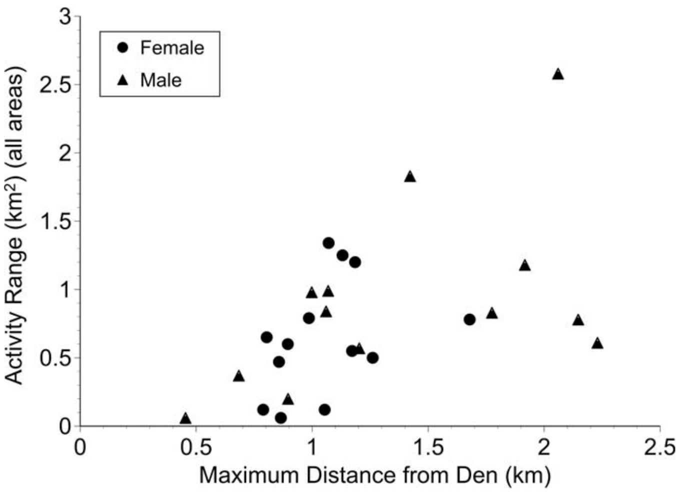

Fig. 8.—Relationship of home range to the maximum distance from a hibernaculum for male and female Northern Pinesnakes (*Pituophis m. melanoleucus*) in the New Jersey Pine Barrens.

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