Herpetological Conservation and Biology 14(3):680–690.
Submitted: 2 August 2019; Accepted: 15 November 2019; Published: 16 December 2019.

Habitat Use and Movement Patterns of Butler's Gartersnake (*Thamnophis butleri*) in Southwestern Ontario, Canada

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Abstract.—**Butler's Gartersnake (*Thamnophis butleri*) is listed as Endangered in Canada. Data on its spatial ecology are sparse and information on habitat use, movement patterns, and home range size are needed to prevent further declines. We captured snakes using coverboard refuges and implanted transmitters into 13 individuals (12 females, one male), to track movement and habitat use in southwestern Ontario. Home ranges were distributed non-randomly in the study area, and habitat use at this scale showed a preference for open habitats with few trees and grass as the predominant ground cover. Daily movement rates of tracked snakes were short and localized (about 14 m/day) but increased in length in late summer. Based on the coverboard capture data, maximum distances moved between recapture events of marked individuals were typically < 100 m for males and females, although males made longer movements on average. Female home range size was estimated to be 0.9 ha from the telemetry data. This study is the first to document Butler's Gartersnake hibernacula in Ontario, and likely live-birthing areas from locations of gravid females. Knowledge of the spatial ecology of endangered Butler's Gartersnake obtained from this study will help facilitate habitat management and recovery of this species**.

Key Words.—compositional habitat analysis; conservation; endangered species; habitat selection; hibernacula; spatial ecology; telemetry; wildlife management

Introduction

Habitat use, movement, and home range size are important components of the spatial ecology of a species. Understanding the habitat use of a species can help identify critical habitat that is necessary for the survival or recovery of species at risk (Environment and Climate Change Canada 2016). Data on home range size and movement patterns, such as how often and how far an animal moves, are important for identifying the appropriate spatial scale (e.g., minimum area requirements) and boundaries for protected areas. Knowledge of the spatial ecology of a species is important for conservation and management and can enhance our ability to successfully manage populations that are at risk and make informed ecological management decisions.

Southern Ontario, Canada, is home to seven snake species that are currently listed as either threatened or endangered (Ontario Nature. 2019. Ontario Reptile and Amphibian Atlas. Ontario Nature. Available from www.ontarionature.org/atlas [Accessed 10 May 2019]), and the decline of many snake populations is attributed to habitat loss. Butler's Gartersnake (*Thamnophis butleri*) was designated as Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in November 2010 (COSEWIC 2010) and is also listed as Endangered under Ontario's Endangered Species Act (Committee on the Status of Species at Risk in Ontario [COSSARO] 2011). Ongoing habitat loss and fragmentation are considered threats to the species (COSEWIC 2010; COSSARO 2011) and past habitat loss may have been a major factor leading to the decline in their numbers. Butler's Gartersnake occurs in fragmented populations in small habitat remnants in southwestern Ontario near Windsor, Sarnia, and Luther Marsh Conservation Area (COSEWIC 2010). These three populations are genetically distinct from each other based on genetic structure of microsatellite DNA (Noble et al. 2013). Due to their small size and isolation, these populations may be threatened by negative genetic effects of small population size and by demographic stochasticity. Surveys done prior to the COSEWIC 2010 status assessment did not detect the species at several sites in southwestern Ontario where they were formerly known to occur (COSEWIC 2010; Noble et al. 2013), suggesting that their range may be more restricted than in the past. Published research on Butler's Gartersnake is sparse, and details of their spatial ecology is limited and often anecdotal (Carpenter 1952; Freedman and Catling 1979).

Until recently, it has been difficult to obtain data on habitat use and movement by Butler's Gartersnakes. This is primarily due to a combination of the elusive behavior and small size of the snake, which make it difficult to observe in the field. The miniaturization of very high frequency (VHF) radio transmitters and improvements in digital technology, along with improved surgical techniques for implanting transmitters, have allowed for the collection of detailed data on the spatial ecology and behavior of other snake species (Ujvari and Korsos 2000; Blouin-Demers and Weatherhead 2001; Robson and Blouin-Demers 2013; Goulet et al. 2015). These technological advancements have the potential to provide greater insight into the spatial ecology of Butler's Gartersnake. Previous studies on Butler's Gartersnake habitat use located snakes using visual searches or coverboard refuges (Carpenter 1952; R.J. Planck and Janet Planck, unpubl. report). Habitat of Butler's Gartersnake has been described as open clearings with long grass near drainage ditches or other shallow bodies of water, based primarily on where snakes have been observed and captured (Logier 1939; Carpenter 1952). Movement data for this species have been sparse. Previous studies have reported movement distances between recapture locations of the same individuals (Carpenter 1952; Freedman and Catling 1979). Movement data from these types of studies tend to underestimate home ranges and only provide a coarse estimate of movement because snake locations can be missed. These data can be also be problematic for inferring habitat use because non-detection may not indicate that the habitat is unsuitable, especially if snakes are more difficult to detect in that habitat.

In this study we investigated habitat use, movement patterns, and home range sizes of Butler's Gartersnakes. This research is the first to study Butler's Gartersnake spatial ecology using implanted transmitters, which provide more detailed and finer resolution data on habitat use and movements compared to previous capture-recapture studies that relied on visually detecting snakes. Based on earlier research, we predicted that Butler's Gartersnakes would use open grassland habitats most frequently, but we were also interested in quantifying the importance of other habitats where snakes may not have been frequently sighted in previous studies. By studying the habitat use and movement of Butler's Gartersnake, this study provides empirical data necessary for the management and protection of this species near their northern range limit.

Materials and Methods

Study species and study area.—Butler's Gartersnakes are stout, viviparous, small to medium-sized striped snakes in the Family Colubridae. We conducted the research in 2009 and 2010 during the active seasons from emergence in April until hibernation in October, in an area southwest of Windsor, Ontario, Canada, approximately 2 km east of the Detroit River. The study area is 45 ha in size and bordered by a multi-lane divided highway to the north and residential streets along the east, west, and south sides. It consisted of a mosaic of natural habitats (deciduous forest, deciduous swamp, meadow marsh, and tallgrass prairie) and human-altered habitat types (conifer plantation, old field meadow, savannah, woodland, and thicket). Due to the endangered status of this species, we are not providing a map of the study area and habitat types.

Snake capture and handling.—To capture snakes, we laid out 185 cover boards (60 × 90 × 1.27 cm) 20 m apart in a grid pattern in open habitats throughout the study area. The cover boards were made of chipboard, and we painted them black to make them weather resistant. We checked the boards once a week from 1 April to 29 October in 2009 and 2010 during 3-h periods before dusk. We individually marked and determined the sex of each snake we captured, and measured the mass, snout-vent length (SVL), and total length of each. If captured snakes were < 20 g, we clipped ventral scutes in recognizable patterns (Brown and Parker 1976). If they weighed > 20 g, we marked individuals by subcutaneous injection of a passive integrated transponder (PIT) tag (BIOMARK, Boise, Idaho, USA). We determined the sex of young snakes (< 10 g) by manually everting the hemipenes by manipulation of the tail base. We gently probed larger snakes using a sterilized and lubricated ball-tipped metal snake probe (Niagara Reptiles, Beamsville, Ontario, Canada) to determine the presence or absence of hemipenes. We checked the reproductive statuses of adult females by palpating along their ventral surface. Individual bumps or lumps, where fetuses were developing, could be felt while palpating. We released all snakes at the point of capture after handling.

Implanting telemetry transmitters.—We used specially designed very high frequency (VHF) radio transmitters, Pisces Model TX-P5-I-28-S (Sigma-eight Inc., Newmarket, Ontario, Canada) to track snake habitat use and movement in 2010. The transmitters consisted of two 1.5 V type 377 silver oxide batteries connected in series with a chipboard in an elongated shape to conform to the body of the snake. We placed each transmitter in a vacuum sealed container and encapsulated it in epoxy, then coated it with a thin layer of Parylene to protect the transmitter from reacting with the body fluids of the snake. Each transmitter measured 30 × 8 × 3 mm and weighed 1.8 g, with a 120-mm long flexible antenna. The transmitters could be programmed with a specific pulse pattern, time interval between pulses, and time of day when signals would be transmitted. The small sizes of Butler's Gartersnakes constrained the size of the transmitter we could use, so to maximize transmitter life span, we programmed the transmitters to transmit during specific periods. We could change these parameters while the transmitter was in the snake using the computer software program PISCES and a specially designed box where data could be transmitted to and from the transmitter.

An experienced herpetological veterinarian examined adult snakes (females weighing at least 35 g and males weighing at least 40 g) to determine whether they would be suitable candidates for transmitter implants. We measured snakes chosen for implants and snakes were anesthetized with an isoflurane inhalant before and during surgery (Blouin-Demers et al. 2000). The mass of transmitters was approximately 2–6% of snake body masses. Sterile technique and instruments were used, and heart rate and breathing were monitored throughout the implanting procedure. The veterinarian surgically implanted each transmitter into the peritoneal cavity and attached it to the ribs of the snake. The antenna extended through the peritoneal cavity in the posterior third of the body of the snake alongside the subcutaneous tissue ahead of the cloaca. We held snakes for 72 h after surgery to give them time to recuperate before releasing them at the point of capture.

If the battery in a transmitter became weak, we attempted to recapture the snake to remove the transmitter while it could still be found using the radio signal. If the snake was deemed to be in good health by the veterinarian and showed no ill effects of the transmitter implant, a new transmitter was implanted. By replacing transmitters prior to battery exhaustion, we extended data collection from an individual beyond normal battery life. If the snake did not appear healthy, we removed the original transmitter and released the snake after the recuperation period. We made every effort to recapture snakes and remove transmitters at the end of the study.

Telemetry field tracking.**—**We staggered the daily start time for transmitters, but each was programmed to run 7 h per day. Considering all the snakes combined, we collected data on their movements between 0700 and 2100. We programmed a shut-down period into some of the transmitters to occur the first two weeks of August and the first two weeks of September to further extend battery life into the period when snakes would be moving to hibernacula. We did not program a shut-down period in transmitters implanted into snakes later in the summer because the battery was expected to last until snakes moved to their hibernacula. We also programmed transmitters to shut down from 29 October to mid-March of the following year. This was intended to preserve battery life so that transmitters could turn back on when snakes emerged the following year. We tracked snakes tracked using a 3-element folding Yagi antenna (ATS, Inc., Isanti, Minnesota, USA) attached to an Icom model IC R-20 communication receiver (ICOM Inc., Osaka, Japan). We determined the locations of snakes by following the signal until the snake could be seen or pinpointed. To minimize disturbance to the snake, field observers maintained as much distance as possible on approach. We tracked and located each snake 1–4 times a day and 4–6 d a week, weather permitting.

Home range size and habitat use analysis.**—**We characterized the study area using the Ontario Ecological Land Classification system for southern Ontario (Lee et al. 1998). We identified 16 ecosite types; however, these were consolidated into nine habitat types at the community series level of the ecosite types in our final analyses. Four of these habitat types were natural and included Deciduous Forest (> 60% tree cover, deciduous trees > 75% canopy), Deciduous Swamp (standing water or vernal pools with > 25% tree cover), Mineral Meadow Marsh (seasonally flooded and dominated by grasses and sedges), and Tallgrass Prairie (dominated by prairie grasses). The other five habitat types were human-altered and included Conifer Plantation, Cultural Meadow (old field meadow and roadside verge), Cultural Thicket (tree cover ≤ 25%, shrub cover > 25% and dominated by deciduous shrubs), Cultural Savannah (tree cover 25–35%), and Cultural Woodland (tree cover 35–60%).

We estimated the home range size of each snake tracked over the active season using two methods. We calculated the Minimum Convex Polygon (MCP) for each snake by drawing the smallest possible convex polygon from all its telemetry locations. MCPs are a common method to estimate home ranges (e.g., Plummer and Mills 2000; Gardner-Santana and Beaupre 2009; Vanek and Wasko 2017). Kernel density estimators are another method to calculate a home range by considering the use distribution of an animal, i.e., patterns of habitat use based on frequency. The home range size deduced from a use distribution is the minimum area within which the probability of relocating an animal is equal to a specified value (e.g., 95% kernel density is the smallest area in which probability of relocation is equal to 0.95). We calculated home range size in R version 3.5.3 (R Core Team 2019) using package adehabitatHR (Calenge 2006), based on 100% MCP and 95% and 50% kernel density, for comparison purposes.

We used a compositional analysis (Aebischer et al. 1993) to determine whether habitat use by snakes differed from the habitat available in the study area using the adehabitatHS package (Calenge 2006) in R version 3.5.3 (R Core Team 2019). This analysis approach has been applied previously in studies of snake habitat selection (Goulet et al. 2015; Buchanan et al. 2017). An advantage of this technique is that it uses individual snakes as the sample units, as opposed to individual telemetry locations, and compares proportional habitat use with proportional habitat availability (Aebischer et al. 1993). We conducted this analysis at two scales, at a larger landscape scale to evaluate second order habitat selection (i.e., where individuals establish their home ranges), and at a smaller scale to evaluate third order habitat selection (i.e., habitats used within a home range; Johnson 1980). At the larger landscape scale, the available habitat was delineated as the study area, and habitat use was the habitat composition of each individual home range. For the analysis at the smaller scale within a home range, we grouped the habitat types based on similarity of vegetation into five types to deal with the issue of some habitat types being available to only a few snakes. We collapsed Cultural Woodland, Conifer Plantation, Deciduous Swamp and Deciduous Forest into a single habitat type labelled Cultural Woodland/Forest. We collapsed Cultural Meadow and Mineral Meadow Marsh into a single habitat labeled Cultural Meadow/Mineral Marsh. At this smaller scale, we measured availability as the proportion of each habitat type within an MCP home range of an individual and use as the percentage of telemetry locations within each habitat type. We evaluated nonrandom habitat use using Wilks' lambda (Λ) test statistic.

***Analysis of snake movements.*—**We calculated the maximum distance between all recapture events from the capture data from weekly coverboard checks in 2009 and 2010 for each individually marked snake as a measure of the maximum spatial extent of activity for snakes during the active season. We analyzed the difference in maximum spatial extent of activity of males and females using Welch's two sample *t*-test ($\alpha = 0.05$). Maximum spatial extent of activity was not normally distributed and distances were log(x + 1)-transformed prior to analysis; we added 1 m to all distances to allow transformation when the maximum spatial extent was 0 m, which occurred if a snake was only ever caught under the same coverboard.

From the 2010 telemetry data, we calculated several movement metrics: (1) the maximum spatial extent between all telemetry locations for each individual snake; (2) distance and time between successive location fixes; and (3) percentage of location fixes with no movement since the previous fix. For calculations between successive fixes, we excluded those that overlapped with when snakes were hibernating in October and those that spanned time periods when the transmitter was shut off in either early August or early September. In summary, these calculations were based on 810 snake movements. We analyzed movement behavior across the active season by dividing it into semi-monthly periods. We excluded all movements in early August and early September from this analysis because of low sample size since most of the functioning transmitters were shut off during these periods. Our final dataset for this analysis included 782 snake movements. Distances moved between successive location fixes were not normally distributed and were log(x + 1)-transformed prior to analysis. We added 1 m to all distances to allow transformation when the distance moved was 0 m. We analyzed movement rates across semi-monthly periods using a one-way Analysis of Variance (ANOVA) with log(distance moved) as the response variable and semi-monthly period as the explanatory variable. Subsequently, we used post-hoc Tukey HSD (honestly significant difference) tests with significance level at α = 0.05 for pairwise multiple comparisons. We performed ANOVA and Tukey HSD tests using R version 3.5.3 (R Core Team 2019) in RStudio version 1.1.456 (RStudio Team 2018).

Results

In total, we caught and marked 346 individuals across both years during 1,245 capture events, with 55 individuals caught in both 2009 and 2010. In 2009, there were 561 capture events at 105 coverboards of 182 individual snakes. In 2010, there were 684 capture events at 132 coverboards of 217 individual snakes. In total, we caught and marked 158 females and 188 males. A coverboard was used by up to 15 Butler's Gartersnakes during the active season in either year. The mass of individual snakes caught for the first time each year ranged from 4–82 g, mean female mass = 24.1 ± (standard error) 0.8 g and mean male mass = 12.6 ± 0.3 g. Snout-vent length (SVL) of individual snakes ranged from 173 mm to 480 mm, mean female SVL = 290.4 ± 3.4 mm and mean male SVL = 252.6 ± 2.3 mm.

We implanted transmitters into 13 adult snakes (12 females and one male) in 2010. Only one male caught in 2010 met the minimum size requirements for a transmitter implant and did not reach this size until mid-June. This was because female snakes were larger on average and females over 35 g were large enough for a transmitter implant, whereas males of similar mass were longer and thinner. All females tracked were gravid, and the transmitters of eight females functioned through the birthing season in early July.

Tracked individuals used the coverboards frequently as refuge or basking sites and were located on or beneath the coverboards daily. We tracked individual snakes from 27 April to 29 October 2010, over an average span of 85 d during the active season. The shortest tracking period was 20 d and the longest tracking period was 185 d. Shorter tracking periods for some individual snakes were due to transmitter failures (three snakes), deaths from predators (five snakes) and vehicles (one snake), and later capture dates (some snakes of appropriate size for transmitter implant were not captured until

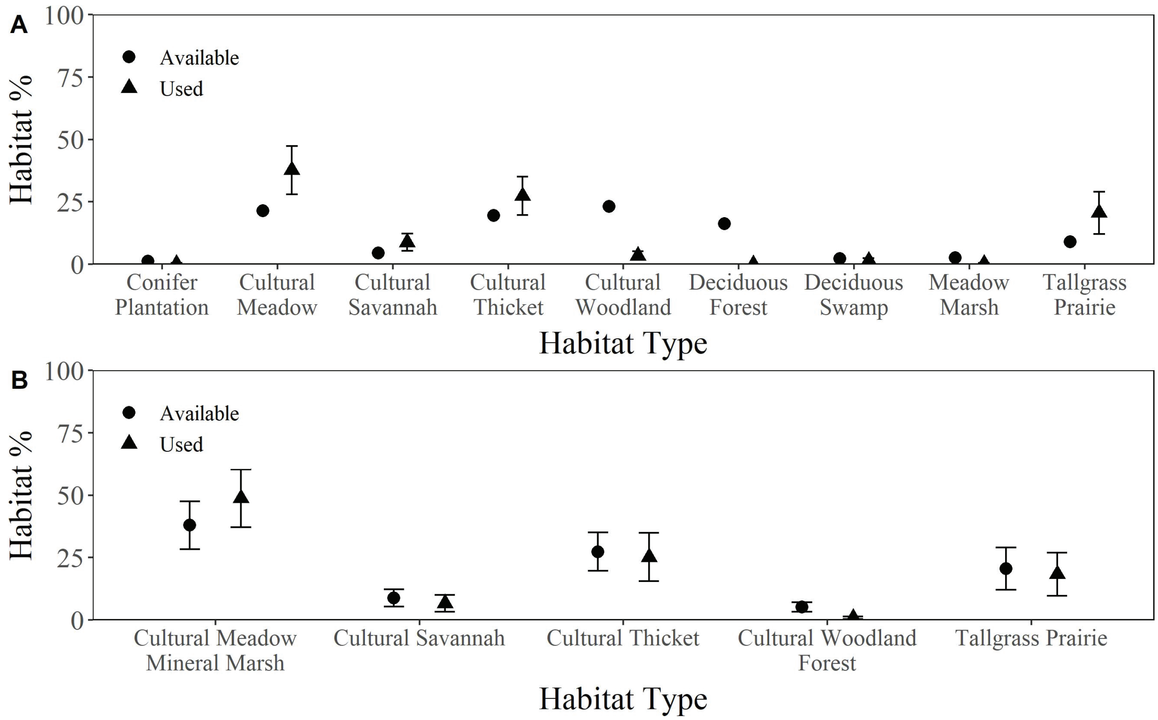

Figure 1. Habitat selection by Butler's Gartersnakes (*Thamnophis butleri*) in southwestern Ontario, Canada, (n = 13 tracked snakes) at two spatial scales: (A) At a larger landscape scale, where available habitat is the percentage of each of nine habitat types within the study area, and used habitat is the mean percentage (± standard error [SE]) of habitat types within a home range; (B) At a smaller scale within the home range, where available habitat is the mean percentage (± SE) of five habitat types within the home range, and used habitat is the mean percentage (± SE) of telemetry locations of snakes within each habitat type.

late June and late July). The longer tracking periods of some individuals were due to the programmed cycles of transmitters, which enabled some to function for over 4 mo. In addition, we implanted two consecutive transmitters in two individuals, with the second transmitter implanted about a month and a half after the first transmitter, allowing data to be collected over 5–6 mo. The transmitters of four snakes functioned into late September and October and three were tracked to their hibernaculum. Unfortunately, none of the transmitters were functional the following spring. We tracked snakes in the field during 120 tracking days, and we took an average of 67 location fixes per individual snake (range, 21–137 fixes per snake). Transmitter signals were detected up to approximately 300 m away.

Home range size.—The average home range size for a female based on 100% MCP was estimated to be 0.90 ± 0.2 ha (n = 12). The single male that we tracked had a home range estimate of 0.26 ha. All but one individual had overlapping MCP home ranges with one or more other tracked snakes. Female home range size was estimated at 2.72 ± 0.93 ha based on 95% kernel density and was 0.52 ± 0.17 ha based on 50% kernel density. The single tracked male had an estimated home range size of 0.45 ha based on 95% kernel density, and 0.10 ha based on 50% kernel density.

Habitat use.—At the larger home range scale, the 13 tracked Butler's Gartersnakes used habitats non-randomly relative to availability in the study area ($\Lambda = 0.022$, $P < 0.001$), indicating that snakes did not establish their home range in random locations and selected particular habitats. A ranking matrix indicated that Cultural Thicket, Cultural Meadow, Cultural Savannah, and Tallgrass Prairie habitat were used most frequently, and there was no detectable difference in use between these top four habitats (Table 1). Cultural Meadow accounted for 37.7% of snake home ranges on average (Fig. 1), followed by Cultural Thicket (27.4%), Tallgrass Prairie (20.6%), and Cultural Savannah (8.8%). Cultural Woodland accounted for 3.5% of snake home ranges on average (Fig. 1), and its proportional use was significantly less than Cultural Thicket and Cultural Meadow (Table 1). Deciduous Swamp and Conifer Plantation were infrequently used (accounting for 1.5% and 0.28% of home ranges, respectively) and their proportional use was significantly less than Cultural Thicket, Cultural Meadow, and Cultural Savannah (Table 1). The proportional use of Meadow Marsh habitat was significantly less than all the top four ranked habitats (Table 1) and was only used by a single snake. Deciduous Forest was ranked the lowest in the ranking matrix and was used significantly less than all other habitats (Table 1); this habitat type was not

Table 1. Home range selection by 13 tracked Butler's Gartersnakes (*Thamnophis butleri*) in Southwestern Ontario based on compositional analysis. Ranks are from most selected (1) to least selected (9) relative to availability. Signs (+ or -) indicate greater or lesser use of the habitat in the row relative to the habitat in the column. Triple signs indicate a significant difference at $P < 0.05$. Habitat abbreviations are CT = Cultural Thicket, CM = Cultural Meadow, CS = Cultural Savannah, TP = Tallgrass Prairie, CP = Conifer Plantation, DS = Deciduous Swamp, CW = Cultural Woodland, MM = Meadow Marsh, DF = Deciduous Forest.

Habitat type	Rank	CT	CM	CS	TP	CP	DS	CW	MM	DF
CT	1		+	+	+	+++	+++	+++	+++	+++
CM	2	-		+	+	+++	+++	+++	+++	+++
CS	3	-	-		+	+++	+++	+	+++	+++
TP	4	-	-	-		+	+	+	+++	+++
CP	5	---	---	---	-		+++	+	+++	+++
DS	6	---	---	---	-	---		+	+	+++
CW	7	---	---	-	-	-	-		+	+++
MM	8	---	---	---	---	-	-	-		+++
DF	9	---	---	---	---	---	---	---	---	

incorporated into the home ranges of any of the tracked snakes (Fig. 1).

Within home ranges, habitat use was statistically indistinguishable from random ($\Lambda = 0.259$, $P > 0.1$). The proportions of used and available habitat at this scale were similar (Fig. 1). We found no evidence that snakes selected certain habitat types within their home range and there was no detectable preference among the five reclassified habitat types (Cultural Meadow/ Mineral Marsh, Tallgrass Prairie, Cultural Thicket, Cultural Savannah, and Cultural Woodland/Forest).

Movement behavior.—From the capture data from the coverboard refuges, we calculated maximum distance moved between recapture events to estimate maximum extent of spatial activity for 276 individual snakes: 126 individuals in 2009 and 150 individuals in 2010. The maximum extent of spatial activity averaged across individuals was 75 ± 4 m. This ranged widely among individuals (Fig. 2): 0 m was the shortest distance (indicating that some individuals were always caught under the same coverboard, even though we checked coverboards at weekly intervals) and the largest maximum extent of spatial activity was 444 m for a female and 380 m for a male (Fig. 2). Note that for these calculations, this is not distance between successive recapture events, but between all recapture events of an individual within a single year. For most individuals (73% of individuals recaptured), their maximum extent of spatial activity was < 100 m (Fig. 2). In 2009 we recaptured 53 females and 73 males at least once, and in 2010 we recaptured 68 females and 82 males at least once. Males had larger maximum spatial extent of activity than females ($t = -2.39$, df = 241.51, $P = 0.017$). The average maximum extent of spatial activity was 65.3 ± 6.5 m for females and 82.2 ± 5.4 m for males.

For the 13 individuals tracked by telemetry, the maximum spatial extent between location fixes during the active season was 174 ± 32 m. If we remove the single male tracked, the maximum spatial extent by females was 182 ± 34 m. It was not possible to evaluate differences in movement between sexes from the telemetry data because we only tracked one male. Ninety-eight percent of movements between successive fixes for all 13 tracked snakes were < 100 m, though there were a few longer distance movements (Fig. 3). The longest movements recorded between successive fixes were 326 m and 337 m, and both occurred in July. The time lag between successive fixes was 24.8 ± 1.0 h on average, and the average distance that snakes travelled was 13.9 ± 1.0 m between successive fixes, which is likely a good proxy for the average daily distance moved. The percentage of location fixes with no movement since the previous fix was 23.5% during the active season; however, 47% of these no movement events had a time lag of < 12 h between location fixes. If we exclude no movement events < 24 h, only 5% of all movements during the active season were no movement events with a time lag of 24 h or more between fixes.

Average distance moved between successive fixes was significantly different across semi-monthly periods during the active season ($F_{7,774} = 10.69$, $P < 0.001$). Movements in late August (16–31 August) and late July (16–31 July) were significantly longer than during all other semi-monthly periods (Tukey HSD, all $P \leq 0.05$; Fig. 4). These results are based on the movements of all 13 tracked snakes, but the results are the same if the single male is excluded from the analysis. Note that we did not analyze data from early August and early September, because most transmitters were off during this period, so we do not know how movement rates during those periods compared to late August and late

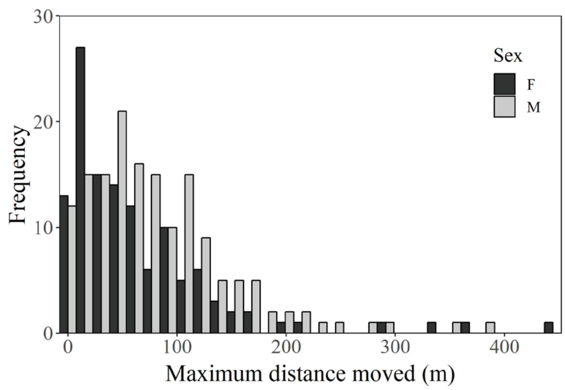

Figure 2. Maximum spatial extent of activity of individual Butler's Gartersnakes (*Thamnophis butleri*) in southwestern Ontario, Canada (n = 276 individuals, 121 females and 155 males), measured as the total distance moved by individual snakes between all recapture locations within an active season. Snakes were captured using coverboard refuges checked at weekly intervals in 2009 and 2010.

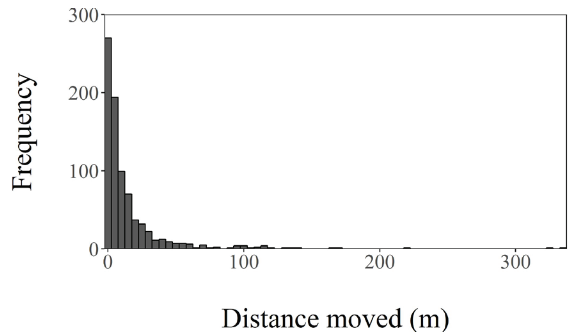

Figure 3. Distances moved by 13 tracked Butler's Gartersnakes (*Thamnophis butleri*) in southwestern Ontario, Canada, between successive telemetry locations, excluding successive fixes that overlapped with periods when snakes were hibernating in October, and successive fixes that spanned time periods when the transmitter was shut off in either early August or early September (n = 810 movements). Mean time lag between successive telemetry fixes was 24.8 h.

July. However, it is worth noting that mean movement rates in early July (13.3 m; Fig. 4) were significantly shorter (Tukey HSD, $P < 0.05$) than late July (24.6 m; Fig. 4).

Birthing area evidence.—On 7 July, we discovered the first Butler's Gartersnake neonates of 2010 in the study area: we found a female without a transmitter under a coverboard with four neonates. On 14 July, we found more neonates: 11 neonates beneath two boards in an area with Cultural Savannah and Deciduous Swamp habitat and eight more under boards in an area with Cultural Meadow and Cultural Thicket habitat. The areas where we found neonates overlapped with locations of six tracked females from 6–14 July. These six females were gravid prior to this period, and after this likely parturition period, we re-examined their physical conditions. At this later stage, the females appeared thin, had lost body mass, and palpation revealed that they were no longer gravid, suggesting that parturition occurred in these likely birthing areas. We investigated the soil characteristics of the areas where the neonates were found and measured moisture using a soil moisture probe. This revealed a shallow clay layer creating imperfect drainage with higher soil moisture than the surrounding habitats.

Hibernacula.—For the three Butler's Gartersnakes tracked to hibernacula, one was in a group of Chimney Crayfish (*Fallicambarus fodiens*) burrows, one was beneath a wood pile and one was along a creek drain. These three snakes moved into their hibernacula on 21, 23, and 27 September 2010. After those dates, we tracked these individuals to the same locations on multiple days until 28 October 2010, the last day the transmitters were functional. We tracked a fourth snake to a potential hibernaculum at an underground location in chimney crayfish burrows from 8–10 September but it re-emerged and was located aboveground on 14 September. We attempted to locate this snake on 20 September, but we did not detect a signal.

Discussion

We used telemetry data from this study to document movement patterns, home range sizes, and habitat use by Butler's Gartersnakes on a finer temporal timescale than previous studies using only capture techniques. We estimated average home range size of female snakes from the telemetry data from our study to be about 0.9 ha using the 100% MCP method, which is comparable to the maximum activity range of 1 ha reported for Butler's Gartersnake in the most recent report from COSEWIC (COSEWIC 2010). The estimated home range size (<

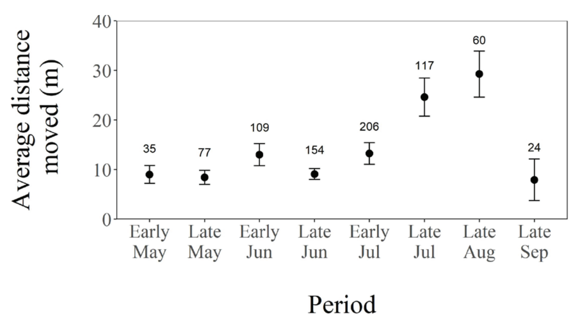

Figure 4. Average distance moved (± standard error) by 13 tracked Butler's Gartersnakes (*Thamnophis butleri*) in southwestern Ontario, Canada, during semi-monthly periods across the active season. The numbers in each bar refer to the number of successive telemetry locations (i.e., sample size). Early August and early September are excluded because most functioning transmitters were turned off during these periods.

1 ha) was supported by the maximum extent of activity by snakes during the active season being generally < 100 m based on coverboard surveys. The 2.7 ha home range size estimated from the 95% kernel density was about three times the area estimated by MCP. The home range size estimated by 50% kernel density, which is often interpreted as the core area of the home range, was 0.5 ha. These estimates are for female snakes. The sole male snake tracked had an estimated home range in the lower end of the range of values, and we do not know whether this is typical of the home range size of males. Based on the recapture data from coverboard surveys, the average maximum extent of activity was larger for males than females, hinting at possibly larger home ranges than females. Thus, more research is needed to determine how home range sizes of males compare to females. To our knowledge, our study is the first to track Butler's Gartersnakes by telemetry and will provide a useful baseline for future studies.

Butler's Gartersnake home ranges were distributed non-randomly in the study area, and habitat use at this scale showed selection for more open habitats with few trees. Selected habitat types included Cultural Meadow, Cultural Thicket, Cultural Savannah, and Tallgrass Prairie habitat types. This aligns with previous studies that suggested Butler's Gartersnakes have an affinity for open habitats with grass as the dominant ground cover type (Logier 1939; Carpenter 1952; Catling and Freedman 1980a). Deciduous Forest was avoided and none of the tracked snakes incorporated this habitat type into their home ranges or were located in this habitat. Conifer Plantations made up small proportions of a few of the home ranges of individuals as determined by the MCP method, but we did not locate individuals in this habitat type. In at least one previous study, researchers searched forested areas but did not locate any Butler's Gartersnakes in this habitat type (Carpenter 1952). Our results indicate that forested areas with substantial canopy cover are avoided; however, snakes in our study did frequently use cultural savannah habitat. Cultural Savannah is characterized as having 25–35% canopy cover, which suggests that habitats with low amounts of tree cover are suitable for this species.

The capture data we collected using coverboard refuges provided supplementary and less complete data on movement patterns by Butler's Gartersnakes. From these data, we found the average maximum extent of activity was larger for males than females, which agrees with an earlier report that stated that males moved more than females (R.J. Planck and Janet Planck, unpubl. report) based on fewer male than female recaptures at their original capture locations. Movements from both our capture and telemetry data indicated that snake movements were typically < 100 m. The telemetry results showed that daily movements were over short distances and localized (about 14 m/day) but increased in length later in the active season in late July and late August. The longest movements recorded during our telemetry study were over 300 m, and the longest distances between recapture locations were 444 m for a female and 380 m for a male. The telemetry data also revealed that snakes did not move between GPS fixes about 24% of the time, though this was primarily when the time between GPS fixes was within 24 h. The telemetry data suggests Butler's Gartersnakes move mostly short distances but do so frequently during the active season. Previous results of Butler's Gartersnake movements based on capture data found movements were highly localized with the occasional record of longer distance movements: 433 m by a male and 517 m by a female (Freedman and Catling 1979), and 125 m by a male and 161 m by a female (Carpenter 1952). Because of temporal gaps in the documented locations of the marked snakes, results from that methodology did not regularly document daily movements. Longer distance movements documented during this study were comparable to movements reported by Freedman and Catling (1979). These longer movements during summer may be associated with females moving to habitats required to successfully give birth or for survival of new-born snakes, and in early autumn, for snakes moving to their hibernacula.

We tracked three snakes, and potentially a fourth, to their hibernacula. We located two of the snakes in burrows of Chimney Crayfish, and we located many of these types of burrows throughout the study area. We located the other two snakes hibernating beneath a wood pile and along a creek drain. Butler's Gartersnakes in Michigan have been reported to use Chimney Crayfish burrows, small mammal burrows, and ant mounds as hibernacula (Carpenter 1952); however, no hibernacula have previously been documented in Ontario. Autumn tracking of individual Butler's Gartersnakes in our study revealed that snakes moved longer distances in the second half of August when compared to the second half of September. This suggests that snakes may be making longer movements in late summer to be close to their hibernacula, but with gaps in the telemetry data in the first half of August and the first half of September it is difficult to determine how movement patterns change over this period. Red-sided Gartersnakes (*Thamnophis sirtalis parietalis*) have been found to disperse long distances to reach their hibernacula in autumn in the Interlake Region of Manitoba, Canada (Gregory and Stewart 1975). Winterkill of snakes in hibernacula can be high depending on environmental conditions; for example, Red-sided Gartersnakes hibernating in communal dens in Manitoba suffered high mortality in years when snow cover was unusually light (causing freezing) or unusually heavy (causing flooding; Shine and Mason 2004). Thus, suitable hibernacula may be a limiting resource for temperate-zone snake populations.

Movements by oviparous snakes to more suitable aggregation sites to lay eggs have been documented in other species (Bonnet et al. 1999; Brown et al. 2005). Aggregations of gravid females and communal egg-laying are common behaviors in many oviparous snake species (Doody et al. 2009), but aggregations are less common in viviparous snakes (Graves and Duvall 1995). From 6–14 July, six gravid female Butler's Gartersnakes aggregated in three small areas with moist soils, which we suspect was to give birth to neonates. These areas may have more abundant and accessible food sources for the neonates. Earthworms are the most common prey of Butler's Gartersnakes (Carpenter 1952; Catling and Freedman 1980b). Neonates, independent at birth, do not receive any form of food provisioning and will begin to feed within a few hours after birth (Carpenter 1952), and therefore, need access to food sources to ensure their survival. We suspect that neonates born in the birthing areas used during this study would have a readily accessible food source, and likely a better chance of survival than in drier upland areas.

Conservation management programs require information on habitat use and movement patterns for successful protection and management of threatened and endangered species. Studying the movements and habitat use by Butler's Gartersnakes made it possible to identify important habitat types and quantify movement patterns and home range size for this species in Ontario. In addition, we located the hibernacula of several snakes and birthing areas of some of the gravid females. The knowledge obtained from this study contributes to the understanding of the spatial ecology of Butler's Gartersnakes and will be useful in facilitating management of habitats for the recovery of this endangered species in Ontario.

Acknowledgments.—We thank the Ministry of Transportation in Ontario (MTO), particularly Joel Foster and Barbara MacDonell, for their financial support on this project and reviewing numerous reports prior to this paper. We also thank the Ontario Ministry of Natural Resources and Wildlife Animal Care Committee who authorized the permits and the newly designed transmitters needed to conduct the research. We thank Cam Grant of Sigma-eight Inc. who developed the transmitters and Tony Braithwaite, DVM, who performed the surgical implants on the snakes. We thank Spatial Ecologist Ted Elliot and GIS Analyst Karen Chung at LGL Limited for their assistance. Finally, many thanks to the field assistants who helped with snake captures and telemetry tracking. All handling methodologies were approved by the Wildlife Animal Care Committee under the 2010 Ontario Ministry of Natural Resources Annual Research Protocol #10-146 and capture was authorized under the Scientific Collectors Permit (Authorization #1056302, Local Reference #CH-10-41).

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