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Red-bellied Mudsnake (*Farancia abacura*) Home Ranges Increase With Precipitation in an Isolated Wetland

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Abstract.—**We radiotracked Red-bellied Mudsnakes (*Farancia abacura*) from April to October 2018 in a small isolated wetland pond in Central Arkansas, USA. Individual *F. abacura* were aquatic, fossorial, and moved within small, well-defined home ranges confined to the pond basin of a wetland system. Individual home ranges of radio-tracked *F. abacura* overlapped extensively. Activity and home range size of *F. abacura* increased following heavy precipitation in August and September. Use of space by *F. abacura* in a small isolated wetland pond in central Arkansas was strikingly different from a previous study in an expansive wetland in southeastern Missouri.**

Key Words.—conservation; habitat structure; movement; radiotelemetry; space use; spatial ecology

Introduction

Environmental space across time and habitats can vary in size, structure, competitor and predator presence, thermal and physiological properties, and availability of resources such as food, water, and shelter. How mobile animals use environmental space has long been recognized as a fundamental property of their ecology (Powell 2000). The way mobile animals use space can reflect on immediate individual needs of the organism in terms of physiology and behavior as well as more extended population processes such as dispersal and gene flow (Blouin-Demers and Weatherhead 2002). A concept that is basic to our understanding of how mobile animals use space is the concept of home range (Spencer 2012). The home range of an animal is most generally defined as the area in which an individual goes about its daily activities but excludes temporary movements out of the home range such as migrations to mating, nesting, basking, and overwintering sites, as well as short-term exploratory forays or sallies (Burt 1943; Brown and Orians 1970; Brown and Parker 1976). A benefit of concentrating activities within a familiar area such as a home range is increased fitness (Bonnett et al. 1999; Spencer 2012). Because the availability of resources in various habitats may differ in time and space, it may be predicted that the use of space by individuals may also vary in time and in different populations of a given species.

The Red-bellied Mudsnake (*Farancia abacura*) is semi-aquatic snake of medium to large size that is an obligate fossorial species, which ranges over the southeastern U.S. (Wright and Wright 1957). The preferred habitat of *F. abacura* seems to be shallow standing water over deep saturated mud and sediment, covered with a growth of obligate wetland plants (Martin 1998; Schepis 2013); however, *F. abacura* occurs in a variety of aquatic habitat types throughout its range in which the use of space might be expected to vary. *Farancia abacura* is a specialized predator, feeding largely on siren (*Siren*) and amphiuma (*Amphiuma*; Wright and Wright 1957), prey that can reach high densities in sympatry with *F. abacura* (Cagle 1948; Gehlbach and Kennedy 1978; Raymond 1991; Frese et al. 2003). In some cases, fish and amphibian larvae are also components of the diet (Carter 2015). *Farancia abacura* may make occasional terrestrial movements (Steen et al. 2013), but it is largely thought to be reluctant to leave a particular aquatic habitat even during drought (Willson et al. 2006; Vogrinc 2018). Quantitative studies have shown that *F. abacura* has high occupancy but low detection probabilities (Durso et al. 2011; Vogrinc 2018), indicating a secretive lifestyle that makes casual detection unlikely. Although *F. abacura* can occasionally be locally abundant (Hellman and Telford 1956; Tinkle 1959), most researchers describe the species as extremely secretive, possibly being rare, and exceedingly difficult to study in the field (Semlitsch et al. 1988; Martin 1998; Schepis 2013; Steen et al. 2013).

Long-term monitoring of wetland snake communities typically report low captures of *F. abacura* (Seigel et al. 1995; Willson et al. 2006; Vogrinc 2018) and field observations of *F. abacura* are largely opportunistic and anecdotal (e.g., Neil 1948; Reimer 1957; Hall and Meier 1993; Semlitsch et al. 1988). Two prior studies targeting use of space by *F. abacura* had little success. A mark-recapture effort in Louisiana yielded no recaptures

(Tinkle 1959) and a three-snake radiotracking study of *F. abacura* in Texas produced limited results (Martin 1998). The most comprehensive field study of the use of space by *F. abacura* is a radio-telemetric study of spatial ecology conducted by Schepis (2013) in the expansive bottomlands of the Mingo National Wildlife Refuge in southeastern Missouri, USA, where the species is of conservation concern due to habitat loss (Missouri Natural Heritage Program 2018).

Knowledge of how a species uses space is critical in designing conservation and management plans for species at risk (Semlitsch and Bodie 2003; Kapfer et al 2010). Indeed, the success of conservation efforts can be greatly affected by sufficient access to biological knowledge of the target species (Dodd 1987; Reinert 1993). Because *F. abacura* occupies a wide variety of wetland types, Schepis (2013) suggested the need for a comparative study of *F. abacura* in an isolated wetland to understand possible variability in how space is used in different populations of the species, thus providing a better foundation from which to design conservation measures for the species.

Habitat structure and resource availability are important variables affecting movements and home range size in snakes (Gregory et al 1987; Reinert 1993). For example, the activity of wetland snakes is influenced by changes in precipitation and water level (Dalrymple et al. 1991; Bernardino and Dalrymple 1992). Our goal is to describe activity and home range of *F. abacura* in a small isolated wetland pond and to document its response to a large increase in precipitation over the course of the study. We also compare our activity and home range results from a small isolated pond with similar data from a large expansive wetland (Schepis 2013) < 350 km from our study site.

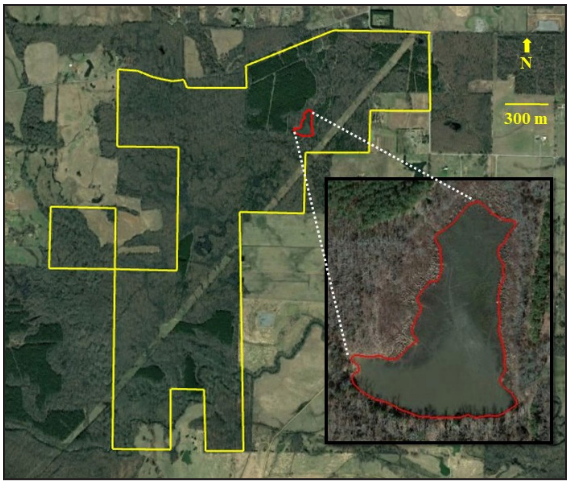

Figure 1. Aerial view of the 280 ha Gilliam Biological Research Station, White County, Arkansas, USA, (outlined in yellow) and the 1.2 ha Gilliam Pond basin (outlined in red). (Image from Google Earth, March 2016).

Materials and Methods

Study area.—The Gilliam Biological Research Station (GBRS) of Harding University is a 280-ha tract of primarily bottomland hardwood forest and seasonal wetland located in White County, Arkansas, USA. Gilliam Pond, a human-constructed 1.2 ha shallow pond basin, is located in the northern portion of the GBRS (Fig. 1) at an elevation of about 75 m. The basin was constructed in Leadville silt loam on land with a 1–3% slope. The water surface area of Gilliam Pond can vary up to 60%, with maximum water levels in spring and minimum levels in late summer through early fall as it recedes from north to south. Annual rainfall averages 127 cm (www.usclimatedata.com). The basin receives input from several small drainage channels at its northern end. A 160 m long human-constructed earthen dam borders the southern end and a small spillway on the west end of the dam drains the pond to a small southeast flowing stream. The largest pool within 100 m of the pond basin is a 0.09 ha pool adjacent to the south slope of the dam. In addition to human modifications to this wetland habitat, habitat modifications by Beaver (*Castor canadensis*) and Nutria (*Myocastor coypus*) are evident. A Beaver lodge sits in the southeastern portion of the pond and burrows are dug into the earthen dam along its length. Smaller diameter (5–10 cm) burrows, presumably constructed by *Farancia*, *Amphiuma*, *Siren*, crayfish, and small mammals, permeate the steep shoreline of the dam and in the shallowly sloping shoreline toward the pond. A network of ditches maintained by Beaver and Nutria activity channel water flow through the pond. The pond basin has an open canopy and is surrounded by bottomland hardwood forest and planted Shortleaf Pine (*Pinus echinata*) tracts to the west and east (Fig. 1). Numerous old stumps, downed logs, and coarse woody debris occur throughout the basin. Obligate wetland herbaceous vegetation in the pond basin include spatterdock (*Nuphar*), grasses (*Andropogon*, *Dichanthelium, Echinchloa, Panicum*, *Tridens*), and sedges (*Carex*). A dense mat of smartweed (*Persicaria*) covers extensive shallow areas of the middle and upper portions of the pond. Outward from the shoreline are narrow bands of shrubs and vines including blackberry (*Rubus*), greenbrier (*Smilax*), honeysuckle (*Lonicera*), and rose (*Rosa*). A thick stand of buttonbush (*Cephalanthus*) occurs at the upper end. Outward from the shrub zone are various bottomland hardwoods including oaks (*Quercus*), hickories (*Carya*), persimmon (*Diospyros*), sweetgum (*Liquidambar*), elms (*Ulmus*), sycamore (*Platanus*), maple (*Acer*), juniper (*Juniperus*), and pine (*Pinus*).

Snake and data collection.—We captured *F. abacura* opportunistically by hand, in unbaited wire mesh funnel traps, and under tin coverboards placed at the shoreline. We transported snakes to the laboratory where we determined sex with a cloacal probe and measured snout-vent length (SVL, mm) and body mass (g). We surgically implanted snakes with either Model LF1 (L.L. Electronics, Mahomet, Illinois, USA) or Model SI-2T (Holohil Systems Ltd., Ontario, Canada) transmitters under isoflurane anesthesia following widely accepted procedures for snakes (Reinert 1992). Transmitter mass was < 10% of body mass. We released implanted snakes at their original capture location ≤ 24 h after implantation and tracked them three non-consecutive days a week from April to October 2018. We use the term relocation to describe the location of a snake following a voluntary movement. At each relocation we recorded transmitter frequency, date, time, GPS coordinates, habitat (substrate, vegetation, cover, distance from shoreline), visibility, and behavior. Local precipitation data were obtained from U.S. Climate Data (www.usclimatedata.com).

Data analysis.—Upon relocation, we considered a snake to have moved if it was at least 5 m from its previous location. We estimated home ranges for snakes with at least 35 telemetry relocations over a minimum of 90 d. We excluded a temporary sojourn made by one snake into a feeder channel at the north end of the pond because this activity was not in alignment with home range constraints (Brown and Orians 1970). We incorporated a GPS location error of ± 5 m when estimating home ranges. We estimated a 95% Minimum Convex Polygon (MCP) home range for each snake. Although the MCP has the disadvantages of including areas not used by individuals and not incorporating repeated use of specific sites, it still is widely used for snakes and has been recommended as a good overall indicator of home range size (Row and Blouin-Demers 2006). For analysis of home range use, we estimated 95% and 50% Fixed Kernel home ranges (KDE). Because KDE areas are heavily dependent on the value of the smoothing factor (h) used in KDE calculation, we followed Row and Blouin-Demers's (2006) recommendation for objectively determining h by adjusting h until the 95% KDE area equaled that of the 95% MCP area of an individual. For a wide-ranging predator such as *F. abacura*, the 95% KDE can be conceived as the area in which foraging, mate-searching, and similar activities would occur whereas the 50% KDE is a core area in which shelter would be taken for activities such as escape and thermoregulation associated with digestion and shedding (Silva et al. 2018). To further characterize home ranges of *F. abacura*, we calculated relative home range shape complexity as the ratio of home range perimeter to home range area (Silva et al. 2018). Estimating both MCP and KDE home ranges, commonly done among snake researchers (Row and Blouin-Demers 2006), can be viewed as an optimization procedure between making a Type I error (not including areas known to be used; e.g., KDE) and a Type II error (including areas known not to be used; e.g., MCP; Silva et al. 2018). Home range estimates were calculated with Biotas™ (Ecological Software Solutions LLC, Version 1.03.1a, Hegymagas, Hungary).

We used SYSTAT 12 (SYSTAT Software Inc., Richmond, California, USA) for statistical analyses. We examined data for normality with Kolmogorov-Smirnov tests and equality of variances with Bartlett's tests. The variables home range size and log-transformed distance moved met the assumptions for parametric tests. We used ANOVA to compare log-transformed distance moved by month and a paired *t*-test to compare home range size between May-July and August-October periods. We used Mann-Whitney tests to compare movement per day between the sexes and home range complexity between methods. We used a Chi-square test of association to examine the relationship between month and locations relative to the dam. Directionality of movements was determined by Rayleigh's test. Alpha was set at 0.05 for all tests.

Results

We radio-tracked eight adult (Robinette and Trauth 1992; Lutterschmidt et al. 2006) *Farancia abacura* from April through October 2018 (Table 1). Snakes were exceptionally difficult to visually detect; we observed snakes swimming, outstretched, coiled, and mating only 7% (37/521) of relocations. Eighty percent (388/487) of snake relocations were within 5 m of the shoreline. Fifty-nine percent (285/487) of relocations were at the edge of the water, where snakes were buried in mud in 86% (246/285) of cases. On land, we made 97% (161/166) of relocations on unseen snakes in underground burrows. Individual snakes tended to use specific sites multiple times. We tracked all snakes to the Beaver lodge for 68 times, 46 of which were accounted for by three individuals. We tracked all snakes to ditches 87 times and to stumps and logs 90 times. Unfortunately, as revealed by Google Earth's historical imagery during drier years, numerous stumps and logs were hidden under water and a mat of herbaceous vegetation during much of our tracking period. Thus, our estimate of stump and log use by snakes is likely underestimated. Coarse woody debris was typically found within 2–3 m of all snake relocations.

Snakes were active (i.e., moved at least 5 m from their previous location) on 70% (351/500) of tracking

Table 1. Identification number, sex, snout-vent-length (SVL), mass, tracking dates, relocation data, and fate of eight Red-bellied Mudsnakes (*Farancia abacura*) radiotracked at Gilliam Biological Research Station, Arkansas, USA, in 2018. Overwintered indicates that snake successfully entered into its overwintering site in November.

ID	Sex	SVL (mm)	Mass (g)	Start track	End track	No. days	No. fixes	Fate
020	F	875	286	19 April	31 October	195	69	Overwintered
122	M	760	209	04 April	04 August	100	37	Transmitter failed
208	M	680	170	19 April	31 October	195	68	Overwintered
233	M	750	217	19 April	31 October	195	69	Overwintered
516	M	770	271	03 May	31 October	181	78	Overwintered
560	M	590	095	05 May	31 October	179	77	Overwintered
932	M	770	218	03 May	31 October	181	57	Overwintered
970	F	1260	663	01 Aug	31 October	092	36	Overwintered

days. Annual activity, as determined by movement per tracking day excluding days with no movement, was statistically uniform across months ($F_{5,203}$ = 1.83, P = 0.108; Fig. 2). Movement per day, exclusive of days with no movement, averaged 39.6 ± 1.80 (standard error) m and did not differ between males (38.2 ± 1.88 m) and females (45.9 ± 5.22 m; U = 8129.5, df = 1, P = 0.401). Although directionality of movement was not statistically different from random for any snake (Table 2), snake relocations on the dam increased in September and October (X^2 = 95.02, df = 5, P < 0.001; Fig. 3) where seven of the eight snakes overwintered within the man-made earthen dam at the southern end of the pond.

Mean 95% MCP home range areas averaged 55 ± 8.2% of the pond basin area resulting in extensive home range overlap (mean overlap = 65 ± 3.2%; Fig. 4). The only area of the pond basin not included in a MCP of any snake was a 0.17 ha area at the north end. This area was the shallowest part of the basin and was the first to dry as water levels dropped. Ninety-five percent MCP home range areas of the eight snakes averaged 0.66 ± 0.10 ha. Although the overall 95% KDE area was calculated to equal the 95% MCP area for each snake, the overall shape complexity of 95% KDE home ranges (1.09 ± 0.18) was two times greater than the overall complexity of 95% MCP home ranges (0.55 ± 0.09 ha; U = 58.5, df = 1, P = 0.005; Fig. 5). The 50% KDE core areas were ≤ 0.1 ha for all snakes (Table 2).

Annual precipitation was at long-term average values from April through July 2018 and the pond decreased in size during this period as is typical most years. By early July the pool below the dam was devoid of standing water and the stream had little flow. In contrast, precipitation in August and September was 18.4 cm, which was three times the long-term average of 6.1 cm. The increased precipitation rendered the pond full, the stream fast flowing, and the low-lying areas south of the pond a series of interconnected flooded pools and ditches. With the major changes in the wetland habitat, activity (X^2 = 19.79, df = 1, P < 0.001) but not distance moved (U = 15549.5, df = 1, P = 0.870,) increased between early (May-July) and late (August-October) periods. Furthermore, grouping locational data for each snake into May-July and August-October periods confirmed that mean MCP home range area increased 67% with the August–October precipitation (MCPMay-

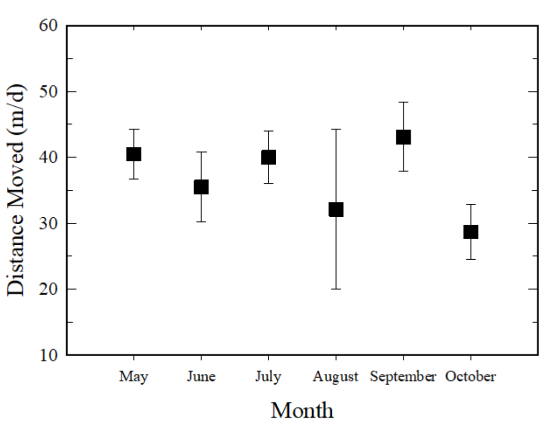

Figure 2. Mean distance moved per tracking day by month for eight Red-bellied Mudsnakes (*Farancia abacura*) at the Gilliam Biological Research Station, White County, Arkansas, USA. Error bars indicate ± one standard error.

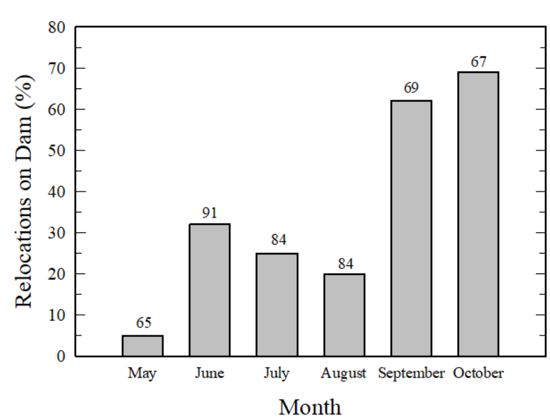

Figure 3. Percentage of relocations of radio-tracked Red-bellied Mudsnakes (*Farancia abacura*) in 2018 on the Gilliam Pond earthen dam by month at the Gilliam Biological Research Station, White County, Arkansas, USA. Numbers above bars indicate sample sizes.

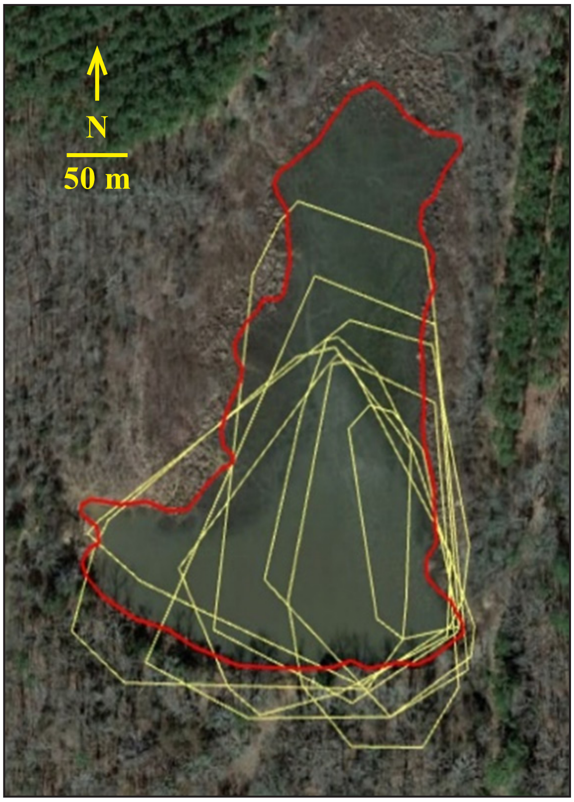

Figure 4. Overlapping MCP home ranges (yellow polygons) of eight Red-bellied Mudsnakes (*Farancia abacura*) at the Gilliam Biological Research Station pond, White County, Arkansas, USA. The pond basin is outlined in red. (Image from Google Earth, March 2016).

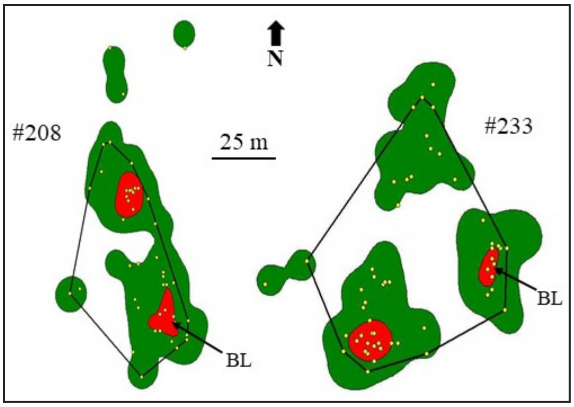

Figure 5. Representative Minimum Convex Polygon (MCP) and fixed kernel (KDE) home ranges of two Red-bellied Mudsnakes (*Farancia abacura*) at Gilliam Biological Research Station, White County, Arkansas, USA. Yellow dots indicate snake relocations. Single dots may represent multiple relocations at the same site. Black line outlines the 95% MCP home range, green indicates the 95% kernel home range, and red indicates the 50% core kernel home range, two of which centered around a Beaver lodge (BL). Note that the KDE home ranges have greater shape complexity and reveal areas within the MCP home ranges that were not used by snakes.

July = 0.48 ± 0.10 ha; MCPAugust-October = 0.80 ± 0.06 ha; t = -3.80, df = 5, P = 0.006; Fig. 6).

Discussion

Use of space by *F. abacura* inhabiting the small isolated pond at GBRS consisted of almost totally aquatic movements within restricted, clearly defined, overlapping home ranges, whereas terrestrial movements were limited to movements to and from burrows within a few meters of the shoreline. We documented a significant positive association between the use of space and precipitation as substantial increases in rainfall during August-October, a time when annual water levels typically were at their lowest, resulted in increased movement frequency and home range size compared to May-July. We can only speculate as to why activity and home range size increased. Potential reasons include increased availability of habitat within the pond basin, increased activity of siren and amphiuma prey following precipitation (Cagle 1948; Schalk and Luhring 2010), and possibly stimulation from the influx of fresh water.

The home ranges we found in our small wetland habitat contrast sharply with home range descriptions

Table 2. Identification number, sex, Minimum Convex Polygon (MCP), and Fixed Kernel (KDE) home range areas (ha) and complexity (comp.), frequency of tracking days in which snakes moved, movement per tracking day (m) in which snakes moved, and Rayleigh's test for directionality of movements for eight Red-bellied Mudsnakes (*Farancia abacura*) radio-tracked at Gilliam Biological Research Station in Arkansas, USA, in 2018.

ID	Sex	95% MCP	95% MCP comp.	95% KDE	95% KDE comp.	50% KDE	Move frequency (%)	Move per day	Rayleigh probability
020	F	0.82	0.4	0.80	0.7	0.1	59.3	50.2	0.798
122	M	0.16	1.1	0.20	2.2	< 0.1	77.8	40.3	0.692
208	M	0.46	0.6	0.50	1.0	< 0.1	67.7	36.4	0.946
233	M	0.59	0.5	0.60	1.1	0.1	74.2	37.5	0.890
516	M	0.93	0.4	0.90	0.8	< 0.1	79.2	48.4	0.859
560	M	0.50	0.6	0.50	1.3	< 0.1	61.8	32.9	0.856
932	M	0.95	0.4	0.90	0.9	0.1	70.4	50.8	0.815
970	F	0.84	0.4	0.80	0.7	0.1	63.6	38.0	0.738

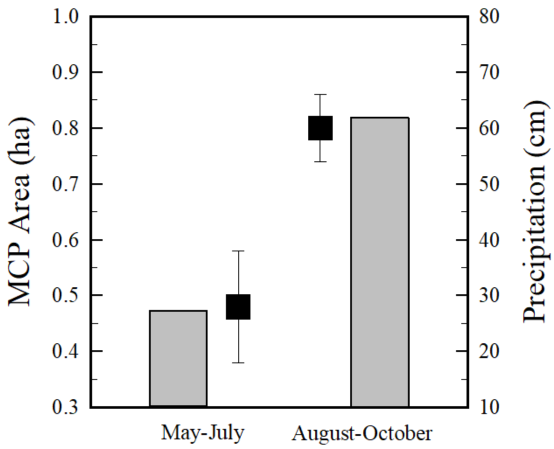

Figure 6. Mean Red-bellied Mudsnake (*Farancia abacura*) MCP home range area (black symbols) and precipitation (gray bars) between May-July and August-October 2018 at the Gilliam Biological Research Station, White County, Arkansas, USA. Error bars indicate ± one standard error.

in existing radiotelemetry studies of *F. abacura* in more extensive habitats. At GBRS, *F. abacura* moved shorter distances, had smaller home range and core areas and greater home range overlap compared to *F. abacura* in an expansive (8,000 ha) wetland 350 km north of our study site in southeastern Missouri (Schepis 2013; Table 3). Martin (1998) found the largest home range (9 ha) among three *F. abacura* was located in the largest area of suitable habitat (10,500 ha). Habitat structure and resource availability are generally considered to be important factors influencing movements and home range size in snakes (Gregory 1984; Gregory et al. 1987; Reinert 1993), and comparative use of space in different habitats has been reported for several snake species (e.g., Shine 1987; Plummer and Congdon 1994; Moore and Gillingham 2006; Carfagno and Weatherhead 2008). Comparing our movement results with those of Martin (1998) and Schepis (2013) suggests that aquatic habitat structure influences use of space in *F. abacura*.

Understanding the use of space of a species is fundamental in determining conservation measures that may be needed for species at risk (Dodd 1987, 1993); however, it is becoming apparent that home range size can be highly variable within a species in different systems. Thus, the use of home range data from one population when making conservation and management decisions in other areas should be done with caution. Because sirens make up a large portion of *F. abacura* diet (Wright and Wright 1957), the availability of sirens may also play a critical role in home range size and distribution within aquatic habitats. The density of sirens at the site in southeastern Missouri (Schepis 2013) is the highest reported in the scientific literature (Frese et al. 2003); unfortunately, the density of sirens at GBRS is unknown.

Table 3. Wetland type, distance moved, and home range sizes (95% MCP, 50% Fixed Kernel) and overlap of Red-bellied Mudsnakes (*Farancia abacura*) in a small isolated wetland pond at the Gilliam Biological Research Station, Arkansas, USA, and in an expansive wetland (Mingo National Wildlife Refuge) in Missouri, USA (Schepis 2013).

	Arkansas	Missouri
Study area (ha)	Isolated pond (1.2)	Expansive wetland (8K)
Distance moved (m/d)	38 (M), 46 (F)	87 (M), 223 (F)
MCP (ha)	Small (0.6–0.8)	Large (11–22)
Core Kernel (ha)	Small (0.1)	Large (6–9)
HR Overlap (%)	High (65)	None (0)

In our study, we used time-tested MCP and KDE models to describe home range size and shape of *F. abacura* to facilitate direct comparisons to previous studies on the species. As expected, the KDE models revealed high-use areas such as the Beaver lodge and other clusters of relocations mostly associated with stumps, logs, and coarse woody debris. The KDE models also revealed areas within the MCP home ranges, principally deep-water areas, that were not used by snakes. For further refinement of internal home range use by *F. abacura*, future researchers should consider using newer statistical models that incorporate data on time and habitat (Walter et al. 2015; Silva et al. 2018).

Particularly as a result of habitat deterioration and loss, reptiles in general (Gibbons et al. 2000; Saha et al. 2018), and snakes in particular (Dodd 1987, 1993; Reading et al. 2010), are known to be declining on a global scale. As a result of wetland habitat requirements, dietary specialization, and apparent reluctance to leave a deteriorating wetland (Willson et al. 2006; Vogrinc 2018), the maintenance of *F. abacura* populations likely hinges on the maintenance of appropriate wetlands and an appropriate terrestrial buffer zone (Gibbons 2003; Semlitsch and Bodie 2003; Roe et al. 2006). Small isolated wetlands, similar to our *Farancia* study site, may be especially vulnerable to loss (Gibbs 1993; Semlitsch and Bodie 1998). Unfortunately, the world has lost over 50% of its wetlands since 1900 (Davidson 2014) and human-caused loss of wetlands continues to be an important issue in the loss of reptilian biodiversity (Semlitsch and Bodie 1998; Gibbs 2000; Roe and Georges 2007; Attum et al. 2008). Our data emphasize the home range plasticity of *F. abacura* in response to the effects of precipitation on availability of adequate aquatic habitat. Future precipitation is predicted to increase within the geographic range of *F. abacura* due to climate change (Trenberth 2011; Blunden and Arndt 2019). While an increase in precipitation would seem promising in the conservation of wetland snakes like *F. abacura*, increased wetland stewardship should not be ignored.

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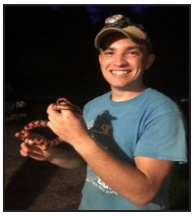

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