Herpetological Review, 2019, 50(4), 709–712.

Annual and Diel Activity of Spiny Softshell Turtles (*Apalone spinifera*) and Snapping Turtles (*Chelydra serpentina*) in an Urban Minnesota Lake

Understanding both annual and diel activity patterns of organisms is important for conserving and managing wildlife populations (Litzgus and Mousseau 2004; Lowe and Bray 2006). Temporal activity patterns can influence the competitors and predators that individuals encounter, as well as the resources available to them (Smith and Iverson 2004). Many studies have examined the activities of freshwater turtles (e.g., Ernst 1971; Rowe 2003; Smith and Iverson 2004). One of the most widely used techniques, radio-telemetry, has been an integral tool for understanding turtle movements. However, radio-telemetry data are largely limited to the frequency and distance of turtle movements and collecting finer scale activity data can be challenging.

Spiny Softshell Turtles (*Apalone spinifera*) and Snapping Turtles (*Chelydra serpentina*) are relatively common and widespread freshwater turtle species in the United States (Ernst and Lovich 2009). Snapping Turtles and Spiny Softshell Turtles are semi-aquatic and have limited surface and terrestrial activities (Holman 2012; Moriarty and Hall 2014). Despite being common species, researchers face many challenges to obtaining data regarding aquatic and nocturnal activity. Data loggers have been used as a potential solution to these challenges for Painted Turtles (*Chrysemys picta*; Gutowsky et al. 2017), Eastern Musk Turtles (*Sternotherus odoratus*; Gutowsky et al. 2017), and European Pond Turtles (*Emys obicularis*; Dall'Antonia et al. 2001); however, activity loggers are still not widely used for many turtle species.

Research indicates that Snapping Turtles and Spiny Softshell Turtles are most active from April to October (Brown and Brooks 1994; Galois et al. 2002; Tornabene et al. 2017, 2018) and are primarily diurnal, with Snapping Turtles sometimes being categorized as crepuscular (Obbard and Brooks 1981; Smith and Iverson 2004). Some nocturnal activity has been inferred for both species (Wade and Gifford 1965; Bancroft et al. 1983)—however, Smith and Iverson (2004) found no indication of nocturnal activity for Snapping Turtles and Spiny Softshell Turtles. Additionally, diurnal, nocturnal, and crepuscular rates of activity have never been continuously measured at a fine scale for either species.

The purpose of this study was to examine the annual and diel activity patterns of Snapping Turtles and Spiny Softshell Turtles using activity loggers to overcome some of the traditional challenges related to collecting these data. Specifically, we sought to 1) quantify and examine activity levels for each month of the year, 2) quantify and examine diurnal, crepuscular, and nocturnal activity levels, 3) quantify and investigate basking behavior for the two species, and 4) assess the effectiveness of activity loggers to better inform temporal activity patterns alongside traditional telemetry methods.

Materials and Methods

Study site.—Field work took place at Medicine Lake, in Plymouth, Minnesota, USA. Medicine Lake is a 364-ha metro-area lake surrounded by over 300 residential properties. The lake is eutrophic and the surrounding landscape is classified as primarily developed (Homer et al. 2015). The northern shoreline (part of Clifton E. French Regional Park managed by Three Rivers Park District), small portions of the western shoreline, and a small peninsula in the southwest are the only natural, non-developed shorelines that remain on the lake.

Data collection.—We used hoop traps baited with sardines and dip nets from motorized watercraft to capture turtles. Incidental captures also occurred if we happened to observe a turtle nesting or otherwise traveling on land. For each captured turtle, we recorded sex, carapace length, and body mass, and inserted a PIT tag (passive integrated transponder; Biomark, Inc., Boise, Idaho, USA).

Radio transmitters equipped with activity loggers (Advanced Telemetry Systems, Isanti, Minnesota, USA) were attached to the carapaces of eight of the Spiny Softshell Turtles and three of the Snapping Turtles that were captured; these individuals were chosen opportunistically during the trapping process. The loggers recorded the date, time to the minute, ambient temperature, and percent activity of the respective turtle every five minutes while the transmitter was in use. Percent activity is measured as the percentage of time that the turtle was active during the five-minute interval. One solitary movement during the five minutes would therefore register as a low percent activity, while continuous movements during swimming or foraging would register as high percent activity. The activity sensor was triggered by any position shift from the horizontal axis greater than approximately 1 mm through a ball switch mechanism, essentially capturing all minor and major turtle activity. The data were obtained by recapturing the turtle and removing the transmitter to download the recorded data.

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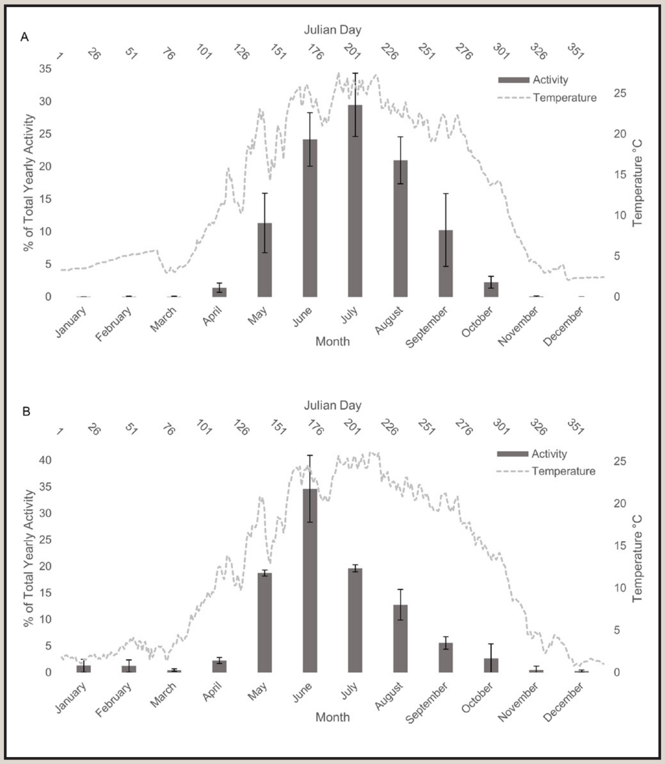

FIG. 1. Average percent of the total yearly activity that takes place in each month for A) *Apalone spinifera* and B) *Chelydra serpentina*. Month is plotted on the primary x-axis and percent of the total yearly activity is plotted on the primary y-axis. Julian day is plotted on the secondary x-axis and temperature in °C is plotted on the secondary y-axis. The error bars represent the standard deviation of the average monthly activity.

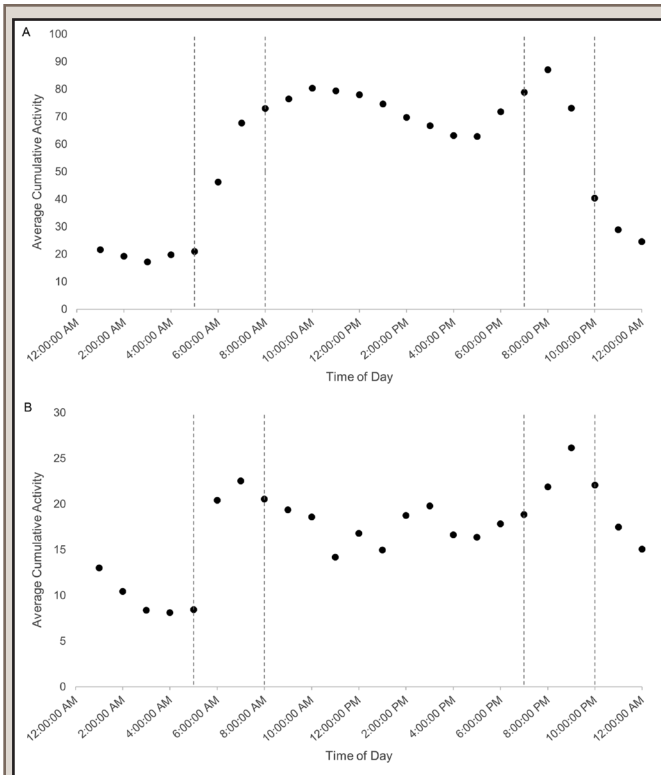

FIG. 2. Cumulative diurnal, nocturnal, and crepuscular (dawn and dusk) activity for A) *Apalone spinifera* and B) *Chelydra serpentina*. Time of day is plotted on the x-axis and the average cumulative activity occurring during each time period is plotted on the y-axis. The four vertical dashed lines represent the times at which nocturnal activity transitions to crepuscular activity (0500 h), crepuscular activity transitions to diurnal activity (0800 h), diurnal activity transitions to crepuscular activity (1900 h), and crepuscular activity transitions to nocturnal activity (2200 h), respectively.

Data analysis.—We used Program R (R Core Team 2017) to quantify the annual activity patterns, diel activity patterns, and basking behavior as described below. We summed the total activity that occurred per month in 2017 for each turtle to determine the average overall activity that occurs monthly for each species. We assessed the daily activity patterns for these species by pooling the total activity that occurred each hour and calculating the percent of the total activity that occurred in each of four daily periods: diurnal, nocturnal, dawn (0500 h to 0800 h), and dusk (1900 h to 2200 h). The periods for dawn and dusk were chosen to account for local sunrise (first appearance above the eastern horizon) and sunset (moment the sun is no longer visible above the western horizon) during the active season of April to October. Activity occurring during both dawn and dusk was considered crepuscular.

We also investigated basking behavior by utilizing the ambient temperature data from the data loggers for one full year for each turtle. We considered that the turtle was likely basking if the activity logger temperature reached 30°C, due to our maximum recorded lake temperature being 29.5°C using YSI multiparameter water quality meters (YSI Incorporated, Yellow Springs, Ohio, USA). This method provided us with the minimum number of aerial basking events that occurred and minimum number of basking days, but our data do not provide information regarding aquatic basking. We calculated the percentage of days in which basking occurred for each turtle during the active season and the average number of basking events per basking day, similar to Plummer et al. (2005).

RESULTS

We were able to recapture and obtain data from six of the seven female Spiny Softshell Turtles (N = 6) and two of the three Snapping Turtles, one male and one female (N = 2). Cumulatively, the data loggers recorded 1,544,918 five-minute time intervals spanning at least one full calendar year of data points for each turtle. We found that specific activity patterns were unique depending on each turtle; however, essentially zero activity occurred when temperatures dropped below 7–8°C in the winter for the Spiny Softshells (Fig. 1A). The Snapping Turtles maintained low, continuous activity levels year-round, although activity levels were reduced substantially when temperatures dropped below 7–8°C (Fig. 1B). We found that Spiny Softshell activity peaked in July and Snapping Turtle activity peaked in June (Fig. 1).

We found that overall, 53 ± 3.4% (mean ± standard deviation) of total Spiny Softshell activity was diurnal, 10 ± 1.7% was nocturnal, and 37 ± 2.1% was crepuscular (16 ± 2.1% occurred at dawn and 21 ± 2.8% occurred at dusk; Fig. 2A). For Snapping Turtles, 43 ± 9.4% of the total activity was diurnal, 18 ± 5.6% was nocturnal, and 39 ± 3.8% was crepuscular (17 ± 4.6% occurred at dawn and 22 ± 0.8% occurred at dusk; Fig. 2B).

We recorded 596 aerial basking events over 216 days from the six Spiny Softshell Turtles (Table 1). The basking events ranged from 5 minutes to 5 hours. Basking occurred between 1000 and 2000 h from April to August, although only two of the six Spiny

Table 1. Basking behavior of six female *Apalone spinifera* in Medicine Lake, Minnesota.

Turtle	Carapace length (cm)	Carapace width (cm)	Body mass (kg)	Percent days basking during active season (April–October)	Number of basking events	Number of basking days	Average basking events / basking days
1	38.5	29.3	4.98	12%	39	26	1.5
2	32.6	25.8	2.98	14%	79	29	2.7
3	36.4	29.6	4.50	17%	75	37	2.0
4	34.2	28.7	3.94	18%	111	38	2.9
5	39.4	29.4	5.40	19%	140	41	3.4
6	39.8	31.9	5.60	21%	152	45	3.4

Softshells were recorded basking during April. From the two Snapping Turtles, only one aerial basking event was recorded for one five-minute interval; this event occurred midday (1300 h) during the month of June.

Discussion

Our findings agree with the literature that these turtle species are most active from the beginning of April through the end of October (Brown and Brooks 1994; Galois et al. 2002; Tornabene et al. 2017, 2018). The decline in activity levels in response to a decrease in temperature is not surprising as turtles are ectothermic, with their body temperature and metabolism dependent on the temperature of their environment. Spiny Softshell Turtle activity dropped to zero in the winter months which is in contrast to Snapping Turtles who still maintained low levels of activity. Spiny Softshell Turtles can withstand prolonged cold temperatures but are the least tolerant of anoxia of all freshwater turtle species studied to date (Reese et al. 2003; Ultsch 2006). Spiny Softshells are therefore likely restricted to hibernacula with sufficient dissolved oxygen and may not move because further movement would necessitate oxygen consumption. Snapping Turtles can tolerate prolonged cold temperatures and are anoxia-tolerant (Reese et al. 2002; Ultsch 2006) and may therefore maintain low levels of activity throughout winter.

We recorded nocturnal activity for both species, resulting in the first record of directly measured nocturnal activity for both Snapping Turtles and Spiny Softshell Turtles. Spiny Softshell Turtle activity was mostly diurnal, with a spike in activity levels at dusk, and minimal activity throughout the night (Fig. 2A). The activity signature for Snapping Turtles showed spikes in activity levels at dawn and at dusk, supporting the claim that this species may be crepuscular (Fig. 2B).

The six Spiny Softshell Turtles basked frequently during the months of May through August with isolated basking events in April for two of the six individuals. Basking occurred only after 1000 h which is consistent with the literature for this species (Lindeman 1993). Our methods likely underestimate frequency and amount of time spent basking as any aquatic basking below 30°C is not included in our estimates; however, the basking behavior we recorded is comparable to behavior documented by Plummer et al. (2005) for female Spiny Softshells using surgically implanted temperature sensors, indicating that ambient temperature from externally attached data loggers may be a reliable and less invasive way of measuring minimum levels of basking activity. According to our data, Snapping Turtles apparently rarely bask aerially; however, it is probable that they are basking aquatically to regulate their body temperatures (Brown et al. 1990). Overall, our basking data support the literature on Spiny Softshell (Lindeman 1993, 2001; Plummer et al. 2005) and Snapping Turtle (Brown et al. 1990) basking behavior.

We studied a wild population of turtles, and therefore we were unable to distinguish different types of active behavior, such as foraging versus swimming, based on distinct patterns in the data. Additionally, due to the sensitivity of the activity loggers, the measure of activity consists of a wide range of activity levels, from simple adjustments of body orientation to larger scale movements. Thus, further studies are required to link specific types of active behavior to the time of day. This could be done by observing the behavior of captive individuals equipped with activity loggers and parsing the data for distinct activity patterns that correspond with specific behaviors using methods similar to Lagarde et al. (2008) and Whitney et al. (2007). We recognize that the small number of individuals from which we obtained data may not be representative of the larger population; however, we have no indication that they differ substantially from other individuals. We believe this information will be informative for wildlife managers, conservationists, and future researchers. We also hope that for future radio-telemetry studies researchers will consider utilizing radio transmitters equipped with activity loggers to better investigate both the spatial and temporal aspects of animal movements and activity at a finer scale.

Acknowledgments.—This project was funded through the Environment and Natural Resources Trust Fund (ENRTF) as recommended by the Legislative-Citizen Commission on Minnesota Natural Resources (LCCMR). We thank Jeff Lang for the use of field equipment and traps. We thank the University of St. Thomas and Three Rivers Park District for logistical support. We also thank 18 Students of Team Turtle for many hours in the field.

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Herpetological Review, 2019, 50(4), 712–717.

Clutch Size in *Plestiodon fasciatus* Near its Northern Range Boundary and Variation Across the Species Range

Reproductive effort of animals is a topic of fundamental importance that continues to attract much interest from both ecological and evolutionary perspectives. Clutch size differs greatly among lizards reflecting adaptation and evolution of life history strategies to spatial and temporal environmental variation (Pianka and Vitt 2003). Average clutch size among species of oviparous lizards ranges from 1 to over 50 eggs (Fitch 1970). Species with higher fecundities generally have lower survivorship and clutch size is often positively related to female body size both among and within species (Fitch 1970; Tinkle et al. 1970). In highly seasonal areas, lizards tend to have only one clutch annually and the number of eggs produced can be related to resources and fluctuations in local conditions (Tinkle 1969; Pianka and Vitt 2003). Latitudinal clines in clutch size within some species have also been noted (Fitch 1980, 1985).

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The Common Five-lined Skink (*Plestiodon fasciatus*) is the most widely distributed lizard in Eastern North America; however, there are relatively few detailed studies of its reproductive biology (e.g. Vitt and Cooper 1986; Hecnar 1994). Being small (12.5–22.2 cm total length, 8.6 maximum snout–vent length (SVL); Powell et al. 2016), secretive, semi-fossorial lizards that spend most of their time under or within cover (Fitch 1954; Seburn 1993; Hecnar 1994) likely accounts for why gaps exist in knowledge of its biology and ecology. Various aspects of