

HOME RANGE AND MOVEMENT PATTERNS OF THE CENTRAL CHIAPAS MUD TURTLE (*KINOSTERNON ABAXILLARE*)

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Abstract.—The Central Chiapas Mud Turtle (*Kinosternon abaxillare*) is one of the least studied turtles in Mexico. The Red List of the International Union for Conservation of Nature categorizes this turtle as Vulnerable (VU), with a steady decrease in its wild populations due to habitat modification to generate agricultural and livestock areas. Currently, an important piece of information (e.g., spatial use) needed for conservation efforts is unknown for this mud turtle. We describe the home range and movement patterns of a population of *K. abaxillare* in Villaflores, Chiapas, Mexico. From September 2020 to April 2021, we tracked nine adult (five males and four females) mud turtles fitted with radio transmitters. We collected data on home range size (ha) and did not find differences in size between males and females using either the Minimum Convex Polygon or the Kernel Density Estimation methods. We also collected data on overall and daily movement distances for turtles of both sexes. Analysis showed no differences between sexes on overall and daily movements. Our analysis showed that *K. abaxillare* moved short distances and used terrestrial habitat to estivate and nest, but otherwise predominantly used aquatic habitats.

Key Words.—daily movements; estivation; Kernel Density Estimate; Kinosternidae; Minimum Convex Polygon; radio-telemetry

INTRODUCTION

Mexico ranks second in turtle diversity among all countries (Turtle Taxonomy Working Group [TTWG] 2021). The southern region of Mexico hosts the highest diversity of turtles in the country; however, many natural areas in this region have been heavily altered by human activity (Ennen et al. 2020; Mayani-Parás et al. 2021). Most turtle species in southern Mexico have not been well-studied, and additional work is needed to clarify essential aspects of turtle ecology to develop informed conservation strategies (Macip-Ríos et al. 2015). An important aspect of conserving or managing threatened or endemic species is to understand their home range size, habitat selection, and movement patterns. Such information will help in designing effective conservation strategies to ensure the long-term survival of these species (Attum et al. 2013; Pérez-Pérez et al. 2017; Alzate-Estrada et al. 2020).

Movement behavior and home range size is known to vary greatly among turtles. Factors such as temperature, water availability, incidence of sunlight, resource distribution, size and location of water bodies, changes in water levels, sex, body size, and mating behavior can

all impact the movement of turtles around the landscape (Doody et al. 2002; Bury and Germano 2003; Pérez-Pérez et al. 2017). For example, larger home ranges in males could be advantageous if it results in an increase of encounters with females and potentially increase their reproductive output (Slavenko et al. 2016), as has been documented for Magdalena River Turtle (*Podocnemis lewyana*; Alzate-Estrada et al. 2020) and Broad-shelled Snake-necked Turtle (*Chelodina expansa*; Bower et al. 2012). Anthropogenic factors can also alter or modify turtle movement patterns due to the modification of the natural landscape for agriculture, roads, water channels, etc., that potentially affect how turtles are able to move and use their habitat (Ryan et al. 2014; Ferronato et al. 2016).

Within the genus *Kinosternon*, it has been shown that some species exhibit high site fidelity, where individuals tend to have small home ranges and make few movements because they eat, court, and nest around the water body they inhabit (Attum et al. 2013; Slavenko et al. 2016; Pérez-Pérez et al. 2017; Aparicio et al. 2018; Enríquez-Mercado et al. 2018). It is also known, however, that some individuals have been observed making long-distance movements to explore other habitats

or possible resources for estivation, hibernation, and/or increasing their reproductive output (Powell 2000). For example, in a radio-telemetry study of the Mexican Mud Turtle (*K. integrum*) in central Mexico, 87.3% of movements in the individuals studied were about 100 m, and the home range sizes did not vary between the sexes (Pérez-Pérez et al. 2017). Some turtles traveled longer distances depending on the season, with shorter movement distances occurring during the dry season and longer ones occurring following the rainy season (Pérez-Pérez et al. 2017). Similar cases have been documented for the Striped Mud Turtle (*K. baurii*; Wygoda 1979), Common Mud Turtle (*K. subrubrum*; Steen et al. 2007), Sonora Mud Turtle (*K. sonoriense*; Ligon and Stone 2003), Rough-footed Mud Turtle (*K. hirtipes*; Enríquez-Mercado et al. 2018), and *K. integrum* (Aparicio et al. 2018).

The geographic distribution of the Central Chiapas Mud Turtle (*K. abaxillare*) is restricted to the upper Grijalva River basin in the Central Depression of Chiapas, and northwestern Guatemala (TTWG 2021). This turtle is currently listed as Vulnerable (VU A2cd+4cd) on the Red List of the International Union for Conservation of Nature (Reyes-Grajales and Guichard-Romero 2021). *Kinosternon abaxillare* is a small turtle, with a maximum carapace length of 156 mm in males and about 160 mm in females (Reyes-Grajales and Iverson 2020). This species occurs in a variety of water bodies ranging from

permanent to semipermanent and temporary aquatic habitats, and from low to mid elevations across its range (Reyes-Grajales and Iverson 2020). Like many other turtle species, habitat degradation, especially due to agricultural land use, appears to be a significant threat to *K. abaxillare* populations (Klemens 2000; Reyes-Grajales et al. 2021). Despite these threats, the specific movement patterns and habitat requirements of *K. abaxillare* are not currently well documented. The aim of this study was to define the home range size and movement patterns of the *K. abaxillare* in the locality of Villaflores, Chiapas, Mexico, and to identify any differences between males and females in these traits. The information we provide in this study contributes to management and conservation strategies that focus on this turtle due to increased understanding of: (1) how much space a wild population of *K. abaxillare* needs for survival; (2) the potential differences between the sexes in space use; and (3) the habitat components used during estivation.

MATERIALS AND METHODS

Study site.—We studied turtles northeast of the municipality of Villaflores, Chiapas, Mexico from September 2020 to April 2021 (Fig. 1). In the study area, the rainy season occurs from May to October, and dry season from November to April. This area is

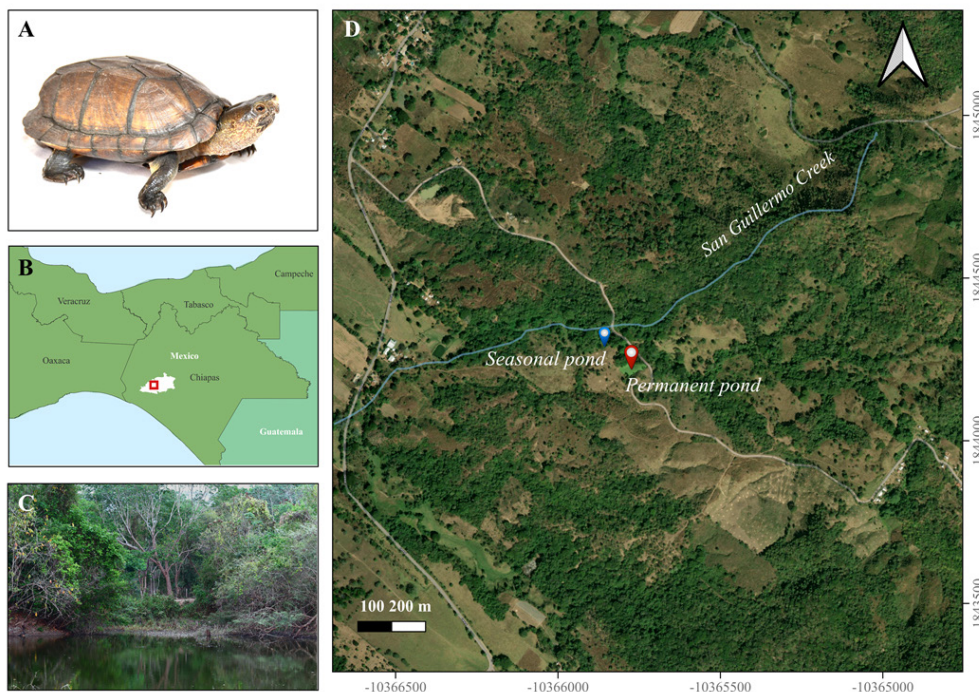


FIGURE 1. (A) Adult male Chiapas Mud Turtle (*Kinosternon abaxillare*; photographed by Eduardo Reyes-Grajales). (B) Location of the municipality of Villaflores (white) and study site (red square) in Chiapas, Mexico. (C) General view of the permanent pond. (D) Satellite image of the study site showing the pond locations in relation to surrounding land cover (taken from Google Earth).

characterized by a warm sub-humid climate type, with an annual temperature ranging from 22.1° to 27.6° C, and monthly precipitation ranging from 0.70 to 249.9 mm (Thornthwaite 1931; Chanona 2013). The landscape at the study site is characterized by rolling hills, with a main permanent pond that was approximately 0.12 ha in size, and a small seasonal pond with an area of 0.01 ha that filled during the rainy season, usually drying by November (Fig. 1). These two water bodies were about 20 m apart, and each had a muddy substrate about 30 cm deep. The larger pond was circular, and was at an elevation of 527 m, with adjacent bank vegetation dominated by small bushes, vines, and other plants such as the Arrowleaf Elephant Ear (*Xanthosoma sagittifolium*), Guinea Arrowroot (*Calathea allouia*), and Knotweed (*Persicaria segetum*). The small pond was also circular; its size changed rapidly in the rainy season, and it had bank vegetation composed mainly of *X. sagittifolium*. San Guillermo Creek crossed the study site near the main pond, but did not connect with it, even during flooding events in the rainy season. This locality was also one of the few remaining sites with undisturbed habitat; a sub-deciduous low forest (Rocha-Loredo et al. 2010; Miranda 2015). There were forest patches close to the ponds, and other habitats included maize fields (corn), pasture for livestock, and rural, dirt roads (Fig. 1).

Sampling methods.—We captured the turtles using aquatic folding box traps (approximately 70 cm long, 40 cm wide, 30 cm high and a mesh size of 1 cm). We baited traps with fresh dead fish and set them in the shallow water of the ponds. We permanently marked captured turtles using the shell-notch code system from Cagle (1939). The species is sexually dimorphic with males possessing a longer tail and a noticeable concavity to the plastron (Reyes-Grajales et al. 2021). We considered adult turtles lacking these same characters females. We used straight midline carapace length (CL) to delineate life stages; this was measured with a dial caliper (nearest 0.01 mm; Model 01407A; Neiko, Taiwan and China). We classified turtles with carapace lengths > 120 mm as adults (Reyes-Grajales and Iverson 2020).

We equipped nine adult turtles (five males and four females) with a lightweight (< 6 g) radio transmitter (Model SOPR-2190; Wildlife Materials Incorporated, Murphysboro, Illinois, USA). We attached radio transmitters to the turtle with epoxy putty. To minimize the effects of transmitters on turtles, we followed the recommendations of Boarman et al. (1998) and attached the transmitters to the first right costal scute in females to avoid interference in copulation. We also used a minimum amount of epoxy, and we used soil to camouflage the color of the epoxy. We used a 3-element Yagi antenna and a hand-held receiver (Model TRX-48; Wildlife Materials) to record the movements of the turtles. From September 2020 to April 2021, we tracked

each turtle, which yielded a total of 33 sampling events. We recorded each turtle location using the Universal Transverse Mercator (UTM) coordinate system with a handheld GPS unit (Model 66st; Garmin Company, Olathe, Kansas, USA). We considered a turtle to be estivating when we found it on land or in dense vegetation without any activity (completely enclosed within their shell, with no change in carapace direction between relocations). In some cases, we found turtles on land, but they were walking and/or had at least one extremity outside the shell.

Statistical analyses.—We estimated home range using two methods: the Minimum Convex Polygon (MCP) and the Kernel Density Estimator (KDE) at 50% of locations to remove the influence of relocation outliers (Enríquez-Mercado et al. 2018). We estimated a smoothing parameter (h) for KDE estimates using Least Squares Cross-validation (LSCV). We calculated home range overlap by a pairwise comparison using the percentage of overlap of the KDE 50% estimator among all tracked individuals. We calculated home range (MCP and KDE) with the adehabitat package (Calenge 2006) in R (R Development Core Team 2008). We were not able to compare home ranges between the 2 mo rainy season and the 4 mo dry season because our tracking effort was different between seasons. Using coordinates for each UTM relocation, we were able to calculate the distance moved between relocation events, and then estimate daily movements by dividing the total movement between relocations by the number of days between relocations. We calculated total distances moved with the adehabitat package (Calenge 2006).

We conducted statistical analyses with $\alpha = 0.05$ in R (R Development Core Team 2008). To test for the difference between sexes, we used the non-parametric Wilcoxon test because our data did not meet the parametric assumptions for normality (Shapiro-Wilk test) and homoscedasticity (Bartlett test). We also calculated a non-parametric Spearman Correlation value to test for an association between body size (CL) and home range size (using MCP and KDE 50%).

RESULTS

The mean CL for males was 133.4 ± 6.5 (standard deviation) mm (range from 124.7–139.9 mm), and 130.8 ± 4.8 mm (range from 124.9–135.5 mm) for females. We relocated each turtle from 30 to 33 times (Table 1). Considering all the individuals and their movements, the average (\pm standard deviation) distance moved between relocations was 52.92 ± 177 m, and daily movement was 7.41 m (Table 2). Overall, we did not find a significant difference ($W = 3498$, $P = 0.410$) in movement relocations between males (63.75 ± 197.80 m) and females (39.39 ± 146.53 m), nor in daily movements between males (mean

TABLE 1. Number of relocations and home range areas (ha), calculated by MCP and KDE 50% estimates for male and female Chiapas Mud Turtles (*Kinosternon abaxillare*) from Villaflores, Chiapas, Mexico. Estivation (days) is the sum of days when a turtle was estivating.

ID	Sex	Relocations	MCP	KDE 50%	Estivation
6	Female	33	0.30	0.09	63
12	Male	33	0.41	0.13	56
15	Male	33	5.30	2.38	77
16	Male	32	7.08	5.95	91
17	Female	33	0.25	0.08	63
19	Male	30	8.90	5.13	63
20	Female	33	8.07	3.92	63
21	Female	33	0.75	0.41	63
22	Male	33	4.23	1.23	56

= 8.94 m/d) and females (mean = 5.94 m/d; $W = 3507$, $P = 0.360$; Table 2). It is important to note that we recorded four individuals with movements exceeding 1,000 m in October (one male and one female) and November (two males).

Home range size using MCP analysis averaged 2.34 ± 3.82 ha (range from 0.25–8.07 ha) for females, and 5.18 ± 3.20 ha (range from 0.41–8.90 ha) for males (Table 1). Using the KDE 50% estimator, home range size averaged 1.12 ± 1.86 ha (range from 0.08–3.92 ha) for females and 2.69 ± 2.94 ha (range from 0.13–6.49) for males (Table 1). In both cases, there was no significant difference in home range size between the sexes (MCP; $W = 15$, $P = 0.271$; KDE 50%, $W = 16$, P

= 0.173). Considering both sexes combined, we found home range sizes estimated with both methods were not correlated with body size (MCP, $P = 0.341$; KDE 50%, $P = 0.178$). The home range overlap (estimated by KDE 50%) between all pairs of tracked turtles (males and females combined) ranged from 0.01 to 1.0, with a mean of 0.63 (Table 3). Mean overlap between males averaged 0.56 (range from 0.01–1.0), while the mean overlap between females was 0.61 (range from 0.02–1.0; Table 3).

Movements were most common in the rainy season, especially during September 2020. Estivation started at the end of December and turtles emerged from estivation in early April (Table 2). The tracked turtles estivated for an average of 66.11 ± 11.13 d (range from 56–91 d; Table 1). Males averaged 68.60 ± 15.18 d (range from 56–91 d) of estivation, while all the females estivated for 63 d (Table 1); however, the difference in the total days of estivation between males and females was not significant ($W = 10$, $P = 0.891$). Some turtles (F6, M12, and M22) switched microhabitats during estivation at least once, while another (M15) did it twice. All estivation sites had stinging plants and/or plants with abundant thorns present; some of the main plants identified were the Colombian Timber Bamboo (*Guadua angustifolia*), Velvet Bean (*Mucuna pruriens*), Tree Spinach (*Cnidoscolus aconitifolius*), and Guapilla (*Hechtia ghiesbreghtii*). The average distance from the site where they were estivating to the nearest pond (permanent or seasonal) was 305.71 ± 74.86 m (range from 199–400 m), and an average of 26.9 ± 11.75 m (range from 11–54 m) to the main rural road. We found all individual turtles estivating alone.

TABLE 2. Distance moved by Chiapas Mud Turtles (*Kinosternon abaxillare*) from Villaflores, Chiapas, Mexico, in each relocation and per day (m). Data are presented as average distance moved by month (± 1 standard deviation) and the range of values for all the individuals pooled ($n = 9$), males ($n = 5$), and females ($n = 4$).

Month	Distance moved in each relocation			Distance moved per day		
	All	Males	Females	All	Males	Females
September	138.71 (290.05) 5.83–976	124.35 (124.35) 5.83–976	47.51 (47.80) 12.37–147.80	7.09 (5.55) 1.77–23.40	5.14 (1.97) 3.44–9.47	9.54 (7.58) 1.77–23.40
October	89 (228.44) 3.16–1,190	83.29 (211.34) 3.16–1,009	96.13 (253.63) 3.16–1,190	20.15 (41.93) 0.45–169.14	18.81 (38.48) 0.45–139.43	21.82 (46.87) 0.45–169.14
November	135.38 (318.38) 2.19–1,020	227.96 (407.79) 3.16–1,020	19.66 (13.27) 2.19–44.05	19.06 (45.55) 0.30–148.72	31.84 (58.57) 0.45–148.72	3.08 (2.03) 0.30–6.29
December	34.16 (57.33) 0–259.79	47.55 (73.99) 0–259.79	17.42 (14) 0–49.24	3.67 (6.72) 0–37.11	5.15 (8.76) 0–37.11	1.83 (1.30) 0–4.45
January	18.07 (24.52) 0–105.23	16.16 (26.38) 0–105.23	20.47 (22.41) 0–80.62	4.41 (5.67) 0–29.73	4.84 (7.18) 0–29.73	3.88 (2.97) 0–11.52
February	3.11 (9.09) 0–38.60	3.06 (9.55) 0–38.60	3.16 (8.79) 0–34.67	0.35 (1.17) 0–5.51	0.35 (1.23) 0–5.51	0.36 (1.13) 0–4.95
March	0	0	0	0	0	0
April	17.15 (28.02) 0–89.44	18.51 (31.07) 0–89.44	15.46 (24.93) 0–70.01	1.84 (3.61) 0–12.78	1.98 (3.99) 0–12.78	1.66 (3.21) 0–10

TABLE 3. Home range overlap between pairs of individuals of all the Chiapas Mud Turtles (*Kinosternon abaxillare*) tracked in Villaflores, Chiapas, Mexico. Overlap in home range varied from 0 (no percentage of home range Kernel Density Estimator [KDE] area overlap between the individuals) to 1 (100% overlap of the KDE area). Values above the diagonal are the overlap between the individuals in the columns inside the home range of the individuals in the rows, while values below the diagonal are the overlap of the individuals in the rows overlapping the individuals in the columns. Abbreviations are F = female and M = male.

	06F	12M	15M	16M	17F	19M	20F	21F	22M
06F	—	0.92	1	1	0.71	1	1	1	1
12M	0.76	—	1	1	0.59	1	1	0.93	0.93
15M	0.04	0.05	—	0.94	0.04	0.94	0.94	0.18	0.37
16M	0.02	0.02	0.33	—	0.01	0.81	0.55	0.07	0.14
17F	0.85	0.85	1	1	—	1	1	1	1
19M	0.02	0.02	0.37	0.90	0.01	—	0.61	0.08	0.16
20F	0.03	0.03	0.56	0.94	0.02	0.93	—	0.12	0.24
21F	0.22	0.25	0.93	1	0.18	1	0.99	—	0.90
22M	0.10	0.11	0.84	0.93	0.08	0.93	0.93	0.41	—

DISCUSSION

This is the first study to examine movements and home range for *K. abaxillare*. Our results add relevant information on the ecology of home range and movements for turtles (Slavenko et al. 2016; Pérez-Pérez et al. 2017). According to our results, the use of the MCP and KDE 50% method showed a variable, but relatively small home range size for *K. abaxillare* (0.25–8.90 ha and 0.08–5.95 ha, respectively). Similar results were reported for other mud turtles in Mexico (Aparicio et al. 2018; Enríquez-Mercado et al. 2018). In our study, the small home range we report could be related to the sample size (nine turtles), and the turtles we tracked were highly associated with seasonal ponds in a disturbed landscape with very few suitable ponds to move among within the landscape.

Monthly movements were relatively short. It seems that these turtles moved along the edge of the water body (and to land for nesting) during the rainy season, and from aquatic habitats to estivating sites at the beginning of the dry season. During the dry season, turtles barely moved or might switch to another estivation site. In other species of kinosternids, some individuals moved between estivating microhabitats (Aparicio et al. 2018) looking for ephemeral sources of water (Ligon and Stone 2003), or some individuals did not estivate at all (Ligon and Peterson 2002; Enríquez-Mercado et al. 2018).

Other species such as *K. integrum* (Aparicio et al. 2018) and *K. hirtipes* (Enríquez-Mercado et al. 2018), have been shown to move longer distances on a regular basis compared to *K. abaxillare*. In contrast, in Palo Verde National Park, Costa Rica, the Scorpion Mud Turtle (*K. scorpioides*, a species closely related to *K.*

abaxillare) moved shorter distances from water to estivation sites (average of 156 m; Mora and Castañeda 2022). Extreme or very long movements in *K. abaxillare* and other species could be related to landscape change and habitat degradation (Gibbons 1986; Munscher et al. 2021). Because the study site was embedded in a landscape with high levels of crop production, livestock pastures, small patches of native vegetation, and seasonal ponds, turtles probably have to adjust their movements to find adequate estivation microhabitats.

Compared with the home range and distance moved by other kinosternids (see Pérez-Pérez et al. 2017; Tables 3 and 4), the home ranges of tracked individuals of *K. abaxillare* were on the smaller end for mud turtle species. The home range of *K. abaxillare* was similar to that of other small to medium-sized mud turtles such as *K. acutum* (Legler and Vogt 2013) and *K. integrum* (Pérez-Pérez et al. 2017). In some cases, however, larger aquatic species (such as the Pacific Coast Musk Turtle, *Staurotypus salvinii*) may also have relatively small home ranges (Legler and Vogt 2013). The tracked individuals exhibited shorter movement distances compared with other mud turtles; however, the distance moved between the measured sampling events was like that of smaller species from temperate environments such Stinkpot Turtles (*Sternotherus odoratus*; Rowe et al. 2009), *K. sonoriense* (Ligon and Stone 2003), *K. baurii* (Wygoda 1979), and other closely related species (Pérez-Pérez et al. 2017).

Home range overlap among the tracked turtles was relatively high overall, although there was much variability in that some comparisons showed 100% overlap, while in other pairs of individuals, their home ranges showed little or no overlap. Because these turtles seem to mostly remain near their ponds, they may only move a few meters away from the source of water to nest and to estivate. Other studies, such as Pérez-Pérez et al. (2017) and Aparicio et al. (2018) also reported similar overlaps in home ranges; however, in those cases the overlap could be driven by individuals with larger or extreme home ranges. We did not find a correlation between home range size and body size in *K. abaxillare* at our study site, but Slavenko et al. (2016) proposed that home range size should be positively correlated with body mass in turtles. Our results are based on a limited sample size, and this could be one reason why the tracked turtles did not follow an expected pattern.

During the dry season, when the tracked individuals of *K. abaxillare* showed less movement, they were in vegetation mainly composed of *G. angustifolia*, *Mucuna pruriens*, *C. aconitifolius*, and *H. ghiesbreghtii*. These plants have the potential to offer refuge and protection during the dry season, and the turtles must wait until the rainy season to return to their main aquatic habitats. Our results corroborate results from Aparicio et al. (2018),

which showed that during the dry season, turtles tended to select microhabitats that enhance protection rather than provide humidity, and later go back to the ponds during the rainy season to feed and reproduce.

Estivation of our turtles occurred in terrestrial microhabitats that were close to the ponds. Turtles mainly used covered microhabitats under leaf litter, which could also be related to remaining cryptic, as found in other species of turtles (Acuña-Mesén 1990; Butterfield et al. 2018). Turtles also used other protected microhabitats such as underneath logs or between rocks. This indicates that *K. abaxillare* sought protected microhabitats similar to those used by the Yellow Mud Turtle (*K. flavescens*; Seidel 1978), *K. scorpioides* (Acuña-Mesén 1990), *K. sonoriense* (Ligon and Stone 2003), and *K. integrum* (Aparicio et al. 2018). Some species of turtles tend to migrate from permanent or large seasonal bodies of water to other ephemeral water habitats to increase survivorship during the dry season (Roe et al. 2008). In our study, *K. abaxillare* seemed only to use terrestrial microhabitats for estivation, but it seems that most individuals tried to maximize the time they spent in water because turtles started estivation in late December and ended it by early April when the rainy season began.

Some of our turtles moved longer than average distances and these outlier movement distances finally concluded with the turtle estivating, as reported in other studies (Pérez-Pérez et al. 2017; Aparicio et al. 2018; Butterfield et al. 2018; Enríquez-Mercado et al. 2018). This observation indicates that the range of movement to search for estivation sites could be larger than expected, and this in turn could be related to their fidelity for estivation sites or to the transformation of their original habitat. We documented that *K. abaxillare* moved around the ponds they inhabit, estivated up to 91 d on land, and then returned to their aquatic habitat. Our results are useful to understand what type of habitat is needed to conserve for the Central Chiapas Mud Turtle, which seems to be a relatively small amount of land with at least seasonal water bodies and some terrestrial habitat where they can estivate.

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