BEHAVIORAL ECOLOGY OF THE TABASCO MUD TURTLE (*KINOSTERNON ACUTUM*) IN A SEASONALLY DRY TROPICAL RAINFOREST OF BELIZE

by

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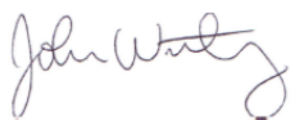

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ABSTRACT

Behavioral Ecology of the Tabasco Mud Turtle (*Kinosternon acutum*) in a Seasonally Dry Tropical Rainforest of Belize

Collin McAvinchey

We studied movement patterns and microhabitat use of Tabasco mud turtles (*Kinosternon acutum*) in a seasonally dry tropical rainforest in the Toledo District of Belize. The Tabasco mud turtle faces conservation threats from local consumption, habitat loss, and changing climate patterns across its limited range in eastern Mexico, Guatemala, and Belize. The natural history of the Tabasco mud turtle remains largely undescribed in the literature and this project is among the first to make a detailed analysis of *K. acutum*'s movement and behavior using radiotelemetry. We made near-daily radiotelemetry relocations and visual observations at the end of the dry season from July 4th to July 20th, 2022. Mean movement observed for male turtles was 34 meters/day and 26 meters/day for females. Maximum male movement observed from Jul 4-20 during a 24h period was 205 meters, and female maximum movement in 24h was 103 meters. Measured rainfall in between observations was checked against movement over the same time period for each individual, yielding a statistically significant relationship between rainfall and distance traveled for one individual out of six with sufficient relocations. Microhabitat was recorded for each observation. Individual observations occurred mostly in leaf litter, at the base of trees, and beneath small woody debris. Notably, this semiaquatic species was rarely observed in water (diurnal observations only). Our findings expand on the understudied natural history of the Tabasco mud turtle and yields insights on microhabitat use, home range, and potentially novel terrestrial habitat utilization.

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Introduction

Freshwater turtles are among the most vulnerable vertebrates on Earth (Rhodin, et al., 2011). There around 330 species inhabiting rivers, lakes, streams, and ponds across all the continents save Antarctica, around 45% of which are considered endangered (Rhodin et al., 2011). Possibly as a result of their somewhat cryptic life histories, freshwater turtles often don't receive the same level of research and conservation attention as some of their more charismatic relatives like sea turtles or large tortoises. Many species have received the "common" moniker, like the common snapping turtle (*Chelydra serpentina*) or the common musk turtle (*Sternotherus odoratus*), although the extents of their distributions and potential ecological threats remain understudied (Munscher et al., 2020).

The mud turtle genus (*Kinosternon*) and its encompassing family, Kinosternidae, is composed primarily of semi- to mostly aquatic animals. They spend a great deal of their lives in water, often in slow-moving streams, lakes, or muddy ponds (Lee, 1996). Mud turtles are considered "opportunistic omnivores" and can be found trundling along stream, pond, and lake bottoms foraging for a diverse array of foods ranging from benthic macroinvertebrates, small fish, amphibians, and the occasional bit of vegetation (Legler & Vogt, 2013; Andresen, 2019). In general, they tend to inhabit waters that undergo significant seasonal variability and are therefore often required to make movements over land to reach more suitable habitat in times of water scarcity (Stone, 2001). Being primarily aquatic animals, mud turtles are particularly sensitive to changes in hydrologic regimes, with the absence or presence of fresh water dictating much of the animals' lives.

This thesis examines aspects of the Tabasco mud turtle's natural history in a seasonally dry tropical rain forest in Belize. The Tabasco mud turtle (*Kinosternon acutum*) is a small, partially aquatic member of the mud turtle family Kinosternidae (Lee, 1996). Originally described by Gray in 1831, the Tabasco mud turtle is found sporadically across Belize, Guatemala, and southeastern Mexico where it inhabits tropical, lowland rainforest environments (Iverson & Vogt, 2011; Legler & Vogt, 2013). Its habitat is characterized by cohune palm (*Attalea cohune*), *Cecropia* spp., *Ficus* spp., and many other tropical, mostly broadleaved, plants. Primarily carnivorous, *K. acutum* seems to dine opportunistically on invertebrates during nighttime forays and rainfall events (Iverson & Vogt, 2011). Like many other species in its family, *K. acutum* appears to be dependent on the presence of fresh water for critical life history processes like foraging and reproduction (Burke et al., 1994; Geller, 2022; Iverson & Vogt, 2011).

The research for this project was undertaken with the assistance and administration of the Turtle Survival Alliance (TSA), a global nonprofit committed to zero future turtle extinctions. The field team leadership was made up of longtime volunteer community researchers with the North American Freshwater Turtle Research Group (NAFTRG). Since 1999, NAFTRG has involved local community members in freshwater turtle conservation by including them in every step of the wildlife research process; from trapping, capturing, and tagging animals to accurately recording biometric data to analyzing population data and presenting results at professional conferences. We attached radio transmitters to 10 adult individuals and tracked 6 of them nearly daily during a field expedition from Jul 4-20, 2022. We observed mean and maximum movement across individuals and noted microhabitat utilization. Our results provide potentially novel insight into the behavioral ecology of the Tabasco mud turtle at the transition from the dry season to the wet season at the eastern and southern extent of their range in Belize.

Literature Review

This literature review discusses environmental and ecological factors impacting the life history and behavioral ecology of the Tabasco mud turtle (*Kinosternon acutum*) relevant to the radiotelemetry study we conducted in the tropical rainforest of Toledo District, Belize, Central America during July of 2022. Necessary to an understanding of *K. acutum*'s dynamics are an examination first of its habitat, both ecological and socioeconomically. Next follows a brief description of *K. acutum*'s phylogeny, closest relatives, and their geographical distributions. We then examine key environmental factors affecting Kinosternon life history processes - precipitation patterns, heat effects and habitat fragmentation. Finally, we discuss potential climate changes that can be expected to impact be turtles overall, the family Kinosternidae, and *K. acutum* itself.

I: Social and Environmental Context

The human geography of the Maya Mountains in south central Belize (Toledo District) is relevant to freshwater turtle conservation and biology. *K. acutum* and other species (notably the critically endangered *Dermatemys mawii*) are hunted and eaten as delicacies by local people (Iverson & Vogt, 2011; Rainwater et al., 2012). Iverson & Vogt (2011) note recent efforts by the Mexican government to quell consumption of Kinosternid turtles by outlawing their sale but that consumption nonetheless continues.

The Maya Mountain foothills region is currently dominated by both conventional and hack-and-slash agriculture. The region produces beef, poultry, fruits, and seafood towards the coast. Much of the population is involved in subsistence farming in small, rural villages (B. Hall, personal communication, July, 2022).

Belize is a diverse melting pot of cultures. Historically and prior to European contact, the region was a part of the Mayan civilization, with many local people still speaking one of several Maya languages (Nations, 2006). Ancient Maya infrastructure can still be found in numerous temples and city sites, as well as more subtle marks left on the landscape itself (J. Marlin, personal communication, July 2021). The research for this project was conducted in and around probable ancient Maya roadworks and house mounds.

European colonization introduced additional cultural elements to Belize. Like much of Central and South America, Belize retains strong aspects of Spanish colonial culture, with many people speaking Spanish as a second language. Uniquely, however, Belize remained a British colony until the 1980s, which has resulted in most of the population learning English as a primary language in the home and in schools (M. Canti, personal communication, July 2022). Belize borders the Caribbean Sea along the East, and a strong Afro-Caribbean cultural presence is also felt. Caribbean influences are particularly notable in cuisine and dialects of local peoples.

The Maya Forest

The research for this project was conducted on the grounds of the Belize Foundation for Research and Environmental Education (BFREE). BFREE borders the Bladen Nature Reserve and a complex of wildlife sanctuaries and protected areas in the Maya Mountains. The area receives around 4 liters of rain annually and fluctuates between a dry season from about November through June and a wet season from around July to November (Bridgewater, 2012). Temperatures remain fairly constant in the range of 26-32 degrees C, with 20 C being considered quite cold by locals. Forsyth and Miyata (2011) describe the tropical rainforest temperature experience as being much more consistent than many temperate climes, with significantly much less temperature variation throughout the year.

The tropical rainforests of the Maya mountains are incredibly biodiverse. There are an estimated 3400 plant species, 40 amphibian species, 16 species of turtle, over 70 snake species, and a host of bats, birds, and other mammals (Bridgewater, 2012). Of Belize's 16 species of turtle, 8 occur within or directly adjacent to the bounds of BFREE and the Bladen Nature Reserve. Five of these are Kinosternid turtles, representing a considerable concentration of the family's diversity at this study site.

II: The Mud Turtle Family, Kinosternidae

As covered in the Introduction, the family Kinosternidae is composed primarily of semi- to mostly aquatic animals. Most species possess large heads and accompanying muscles adapted for crushing the calcareous shells of invertebrates or even smaller turtles (Lee, 1996; Ernst & Lovich, 2009). The largest Kinosternid species, *Staurotypus triporcatus*, measures in at around 40 centimeters in carapace length. Most species are quite small, with *K. acutum* being considered one of the smallest turtle species in the world at adulthood 80 mm (Iverson & Vogt, 2011; Legler & Vogt, 2013).

The range of Kinosternid turtles stretches across the eastern parts of North America, through Central America, and into South America (Ernst and Lovich, 2009; Lee, 1996). The family's probable original site of evolution is in Mexico, where the greatest amount of species diversity can be found (Ernst & Lovich, 2009). Kinosternidae encompasses four distinct genera: *Sternotherus, Claudius, Staurotypus*, and *Kinosternon* (Ernst & Lovich, 2009; Pempelfort, 2018). A summary of distinctive traits of each genus follows hereafter.

Sternotherus

Sternotherus is widely represented across the eastern United States and Canada and are among the smaller members of Kinosternidae. Commonly known as musk turtles because of the aromatic excretions released from their posteriors (though this trait is not unique to this genus), there are four species of *Sternotherus,* all of whom are endemic to the eastern regions of the United States (Ernst & Lovich, 2009). The most widely distributed species is the stink pot, *Sternotherus odoratus,* which ranges along the eastern coast of the United States as far north as Maine and south along the Gulf Coast into Texas (Fig. 1).

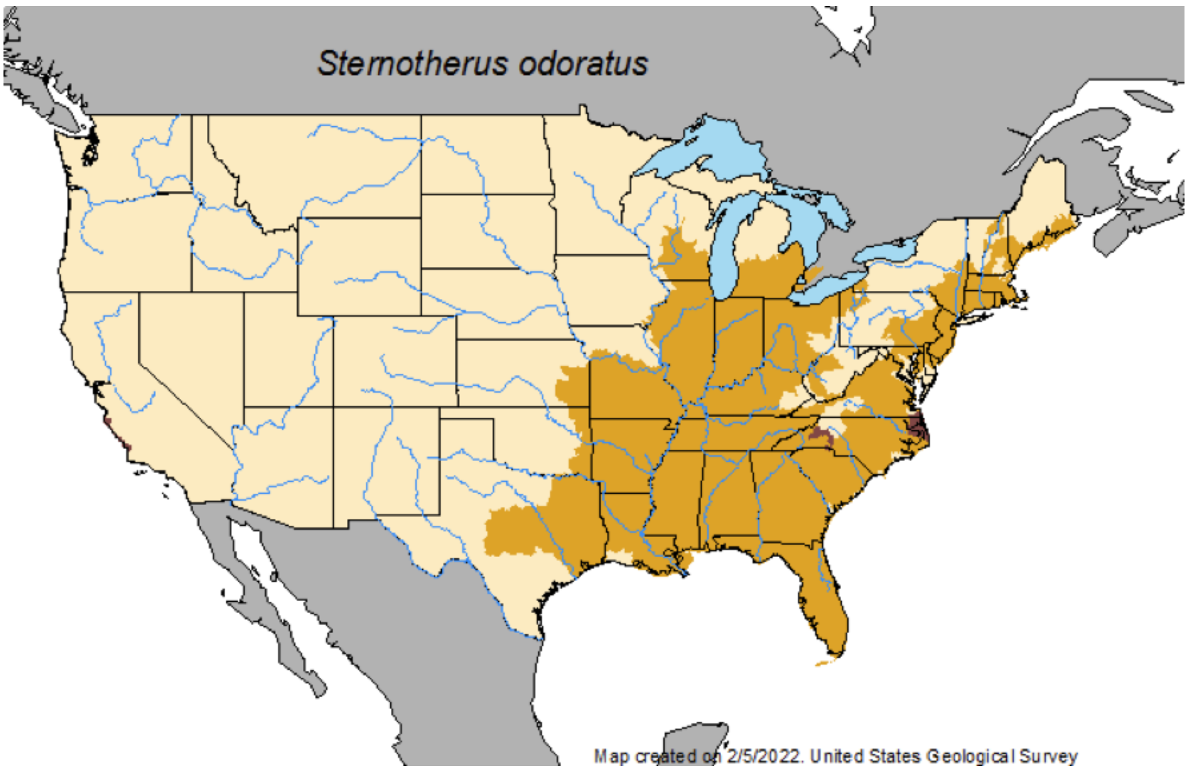


Figure 1: Distribution of the eastern musk turtle, Sternotherus odoratus. Adapted from The United States Geological Survey - Eastern Musk Turtle *(*Sternotherus odoratus*).*

One of the two genera of Kinosternid endemic to Central America, *Claudius* is comprised of only one species, the Narrow-bridged musk turtle *Claudius angustatus*, de Jesús Cervantes-López et al., 2021). *Claudius angustatus* are known for their distinctive cusped jaws that give them a vampiric appearance, earning them the nickname “vampire turtle”. *Claudius* has a particularly restricted range; it occurs only in Belize, Guatemala, and southeast Mexico (Fig. 2). A population of narrow-bridged musk turtles was recently located within a few hundred meters of the BFREE research center, expanding their range considerably both south and east of its previous extent (Munscher et al., 2022).

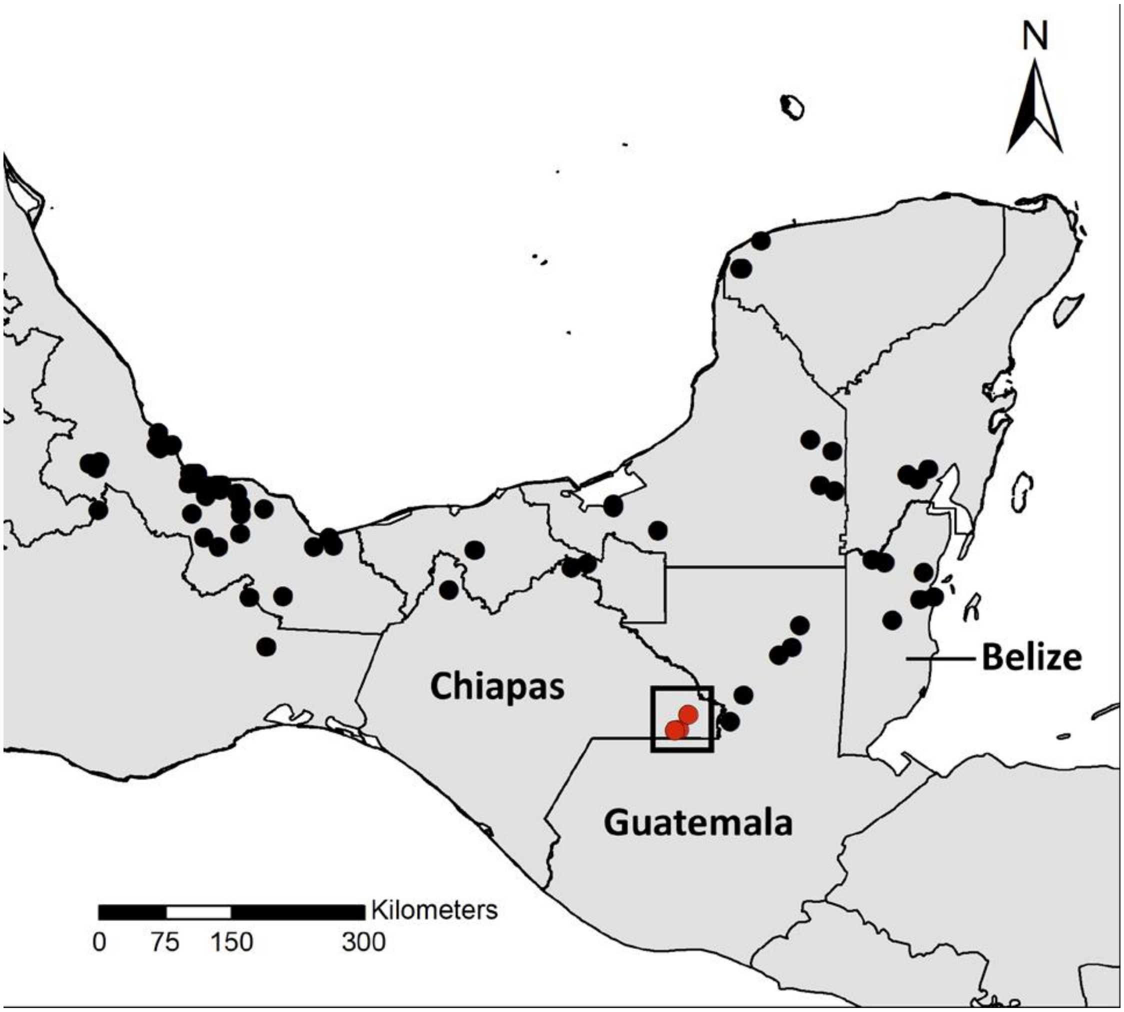


Figure 2: Distribution of known populations of Claudius angustatus in Central America. Adapted from de Jesus Cervantes-Lopez et al., 2021.

Staurotypus

Staurotypus are giants among mud turtles, with large adults reaching up to 40 centimeters in length (Lee, 1996). The two extant species, *Staurotypus tricporcatus* and *Staurotypus salvinii* (the giant Mexican musk turtle and the Chiapas giant musk turtle), inhabit a limited range in

Central America (Fig. 3). *Staurotypus* spp. are known both for their size and for their ability to consume other hard-shelled turtles (J. Brian Hauge, personal communication, July 2021).

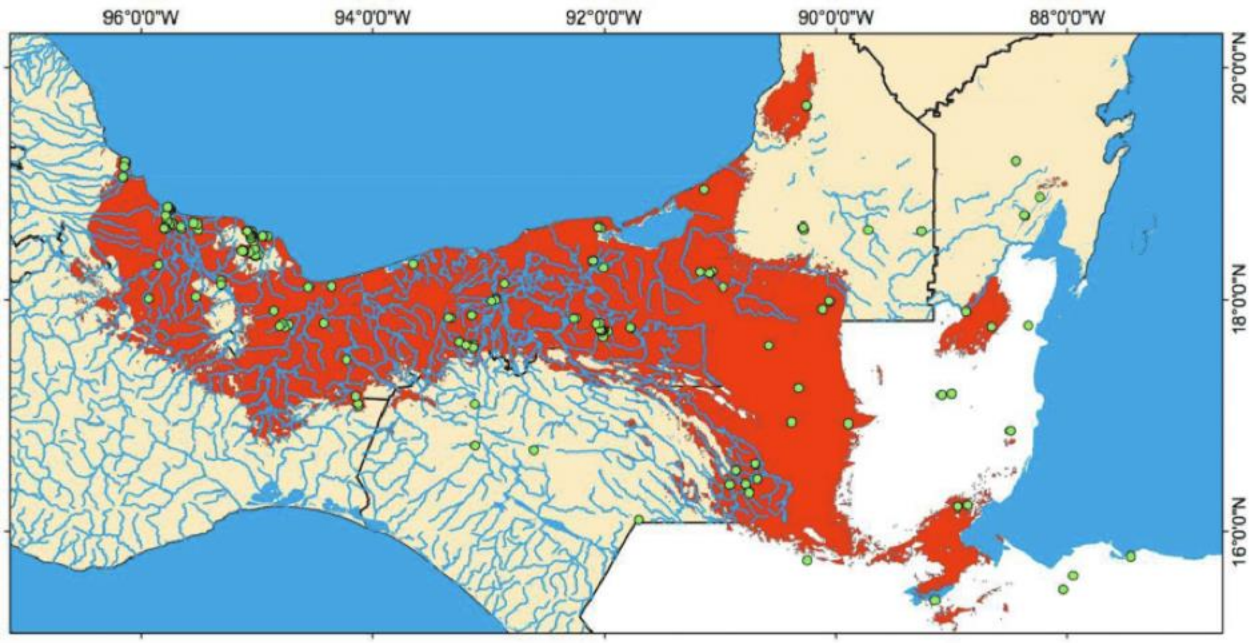


Figure 3: Known distribution of Staurotypus triporcatus, the giant Mexican musk turtle. Adapted from Reynoso et al., 2016.

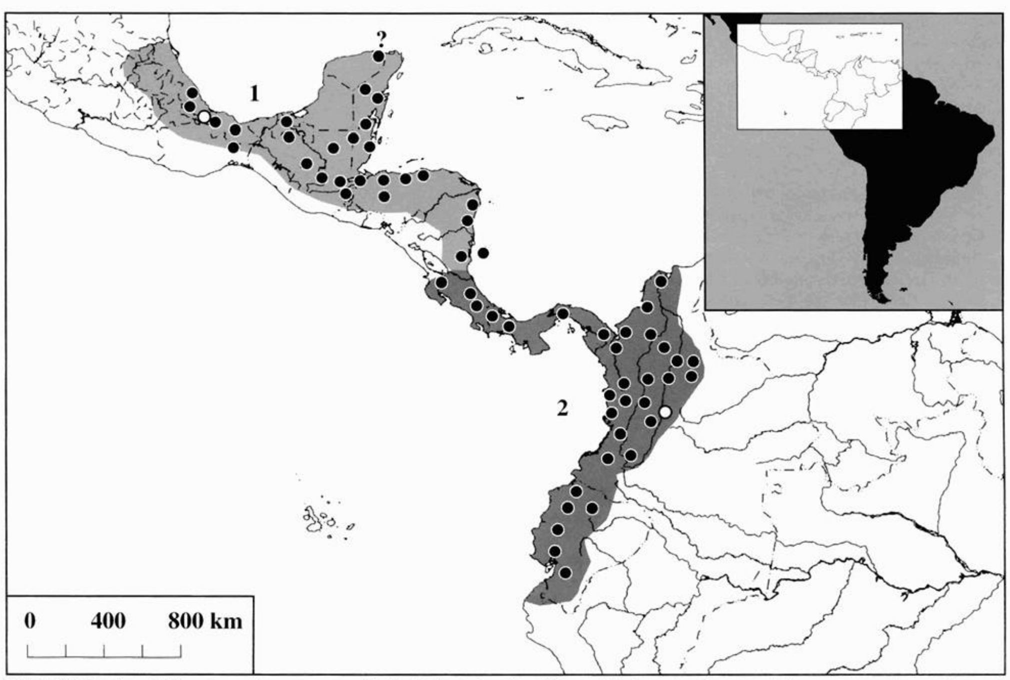
Kinosternon

Genus *Kinosternon* encompasses fifteen species (Lee, 1996). Commonly known as mud turtles, this genus contains most species in Kinosternidae and enjoys the widest distribution across the Americas. Some species occur across Central and South America (Fig. 4), while others are distributed across the southeastern United States (Fig. 5).

Kinosternon acutum

This literature review outlines the basics of *K. acutum*'s life history, though limited in temporal and geographic range. Legler & Vogt (2013) mentions *K. acutum* diets as being primarily composed of various available invertebrates. Vogt observed night-time foraging during the wet season at a site in Veracruz, Mexico; Legler observed the same phenomena at another site in Belize. Legler & Vogt note that *K. acutum* uses local vegetation or woody debris as shelter during the day. They reference a study on *K. acutum* in Veracruz, Mexico conducted by one of the authors (Vogt), and Legler & Vogt (2013) later refer to this work, but it refers to an abstract from a conference.

Given the relatively thin measure of the established literature on *K. acutum* in the wild, comparisons must be made by examining life history habits of other Kinosternid turtles, turtles in general, and other reptiles when applicable. The following are a series of case studies detailing documented turtle and reptilian adaptations to climate phenomena including precipitation, seasonality, heat, and habitat destruction and fragmentation. These examples may illuminate possible related responses evolved by *K. acutum* in lieu of further published research on the species itself.



MAP. Distribution of *Kinosternon leucostomum*. Circles indicate type localities, and dots mark other records (some represent more than one proximate locality).

Figure 4: Range distribution of the white-lipped mud turtle, *Kinosternon leucostomum.* Adapted from Berry and Iverson (2001).

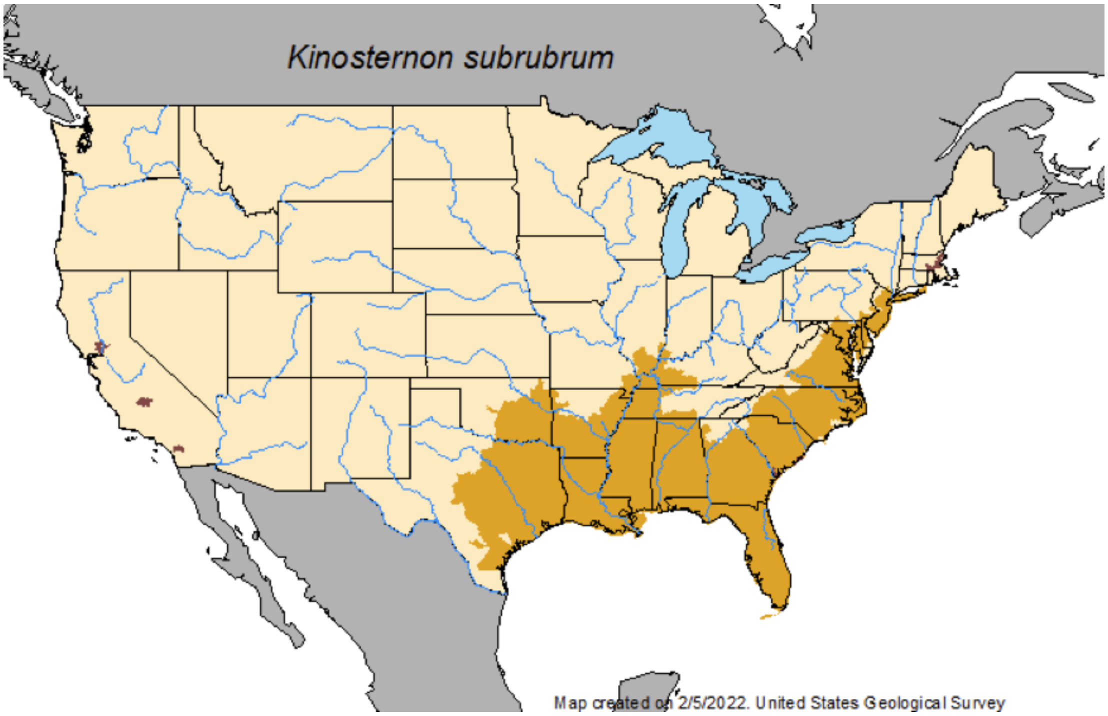


Figure 5: Distribution of the eastern mud turtle, Kinosternon subrumum. Adapted from the United States Geological Survey, (Eastern Mud Turtle (*Kinosternon subrubrum*) - Species Profile, n.d.).

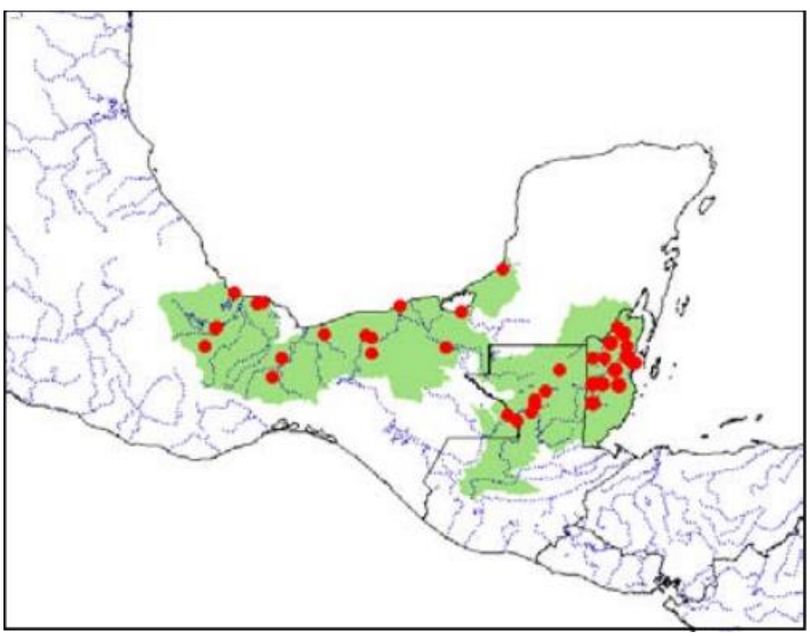


Figure 6: Distribution of the Tabasco mud turtle, *Kinosternon acutum* in Mexico, Guatemala, and Belize. Adapted from Iverson & Vogt (2011).

Figure 7: Adult *Kinosternon acutum.* Photo by Collin McAvinchey.

III: Key Environmental Adaptations

i: Nesting Forays and Precipitation

Precipitation and the presence of fresh water plays a major role in the reproductive and life history habits of Kinosternid turtles. Burke et al. (1994) studied the relationship between eastern mud turtle (*Kinosternon subrumum*) nesting behavior and the onset of rainstorms. Precipitation events appeared to be the primary factor in initiating nesting forays by gravid females. Over the course of nearly a month, these gravid females left the bay in which they spent most of their lives and buried themselves in nearby sediment (Burke et al., 1994). The females then waited until the next rainfall event to construct their nest and deposit their eggs, whereafter they buried themselves in another location and waited for another storm before returning to their original aquatic habitat. The authors remain unsure as to why these turtles used rainfall as an indicator to begin the nesting process, but rain events appeared to be the primary trigger; being unrelated both to overcast cloud conditions and ambient temperature (Burke et al., 1994).

Geller (2022), in a review examining several different studies on the relationship between freshwater turtle behavior and precipitation, corroborates and expands on Burke's (1994) findings. Species besides the eastern mud turtle tie their reproductive efforts to precipitation events, but documentation of this phenomenon is lacking in many species, painting a complicated picture of overall turtle reproductive ecology and its relation to rainfall events. Rainfall does appear to be positively associated with *Kinosternon* nesting, however. Geller posits that turtle embarkation on nesting forays is probably a predation deterrent—that olfactory clues left behind by nesting turtles may be obscured by rainfall and that turtles, whether consciously or not, are using precipitation events as cover from predators.

The response of mud turtles at the species level to changes in amounts and timing of rainfall due to climate change remains unknown. However, major disturbances in precipitation regimes may have significant effects on the life histories of these animals. Changes in timing or amount of rainfall may disrupt vital life history events.

ii: Home Range and Dispersal

Crucial to an examination of the effects of climate change on mud turtles is a discussion of the home range size of a given animal and its ability to escape conditions that might be detrimental to survival, subsistence, or reproduction. Size appears to have a direct relationship on the ability of Kinosternids to physically move themselves around and disperse great distances. In turtles, size appears to be correlated with overall dispersal ability of species (Aparicio et al., 2018**;** Slavenko, 2016). Dispersal can be a dangerous activity for turtles, especially when they inhabit fluctuating bodies of water in highly modified areas. Habitat connectivity becomes key when populations are forced to disperse, as mortality from predation and vehicle strikes can increase when turtles are on the move (Anthonysamy et al., 2013).

Kinosternid turtles display a remarkable ability to disperse themselves on land and in the water. *K. integrum* enjoys a particularly wide range in its native Mexico, where it can be found inhabiting permanent and fluctuating waters from around sea level to over 2000 meters in elevation (Aparicio et al., 2018). This species was found to be highly mobile, relative to their size, with ranges up to about 2.75 hectares (Aparicio et al. 2018).

Other Kinosternids demonstrate similar terrestrial dispersal abilities. The yellow mud turtle (*Kinosternon flavescens*) has been observed moving up to 8 kilometers in search of suitable aquatic habitat (Ernst, 2009). The Sonoran mud turtle (*Kinosternon sonoriense*), the scorpion mud turtle (*Kinosternon scorpioides*), and the white-lipped mud turtle (*K. leucostomum*) have all been observed moving between 0.5 and 1 kilometer over the course of a year (Cordero, 2010; Hall & Steidle, 2007; Stone, 2001).

While Kinosternids may be capable of an unusual amount of terrestrial motion compared to other members of their family, their ability to travel long distances and escape some of the landscape-scale effects of anthropogenic climate change may be greatly limited when compared with more mobile taxa. This relative immobility may be offset by how widespread the family is and by the diversity of the ecosystems they inhabit and the degree to which each species can respond may be highly variable. Family Kinosternidae itself may not be in mortal peril, but the same may not be able to be said for individual species.

iii: Drought

Drought can play a major role in determining turtle movement. The predominant drought-mitigation strategies observed in freshwater turtles are dispersal (Anthonysamy et al., 2013) and estivation (Ultsch, 2006). With limited research on mud turtle response to drought, studies on related turtle taxa or other reptiles must be used as a rough model for Kinosternid response. Anthonysamy et al. (2013) examined responses of a population of Blanding's turtle (*Emys blandingii*) to a particularly dry summer and found a significant amount of movement resulting from decreases in freshwater levels. Subject turtles were observed greatly increasing overland movement while travelling from drying bodies of water, with many individuals found retreating to nearby riparian areas for access to water. Turtles in this study tended to prefer permanent sources of water during drought rather than seasonally fluctuating shallower ponds and wetlands (Anthonysamy, 2013). Turtles were found to begin estivating, with some individuals dramatically decreasing their movement for longer than a month at a time during the height of summer heat and drought.

The second major adaptation employed by Kinosternids is to engage in estivation when faced with extremely hot or dry conditions. Estivation is like hibernation, only it appears to have evolved as a response to arid conditions rather than cold ones (Anthonysamy et al., 2013). Estivating animals sequester themselves in protected areas like crevices in rocks, burrows in mud, or deposited plant material (Anthonysamy et al., 2013; Stone, 2001). Periods of estivation allow turtles to dramatically reduce their body's metabolism and their need for water and food during times of resource scarcity (Aparicio et al., 2018). Estivation periods can last a considerable amount of time; from six months to a year depending on the species and availability of water (Iverson, 1988; Ligon & Stone, 2003)**.** Stone (2001) cites a study by Rose (1980) that claims the yellow mud turtle (*Kinosternon flavescens*) was observed estivating for a two-year period in a laboratory setting.

Stone (2001) studied Sonoran mud turtles (*Kinosternon sonoriense*) in arid southern New Mexico over a period of drought lasting three years and found no significant reduction in resident turtle populations in the area. The surveyed area had remained nearly completely dry throughout that period, yet the turtles' ability to reproduce and maintain a stable population appeared largely unaffected (Stone, 2001). Indeed, the Sonoran mud turtle appears to flourish under such variable conditions. Aparicio's (2018) study on Mexican mud turtles describes estivation periods lasting up to nine months in parts of Mexico, with subject turtles observed utilizing microhabitats like dead trees, old stone walls, and piles of leaf litter as shelter from heat. Mud turtles' ability to estivate may prove one of their most significant advantages as the global climate continues to shift towards more extreme conditions. Compared to those of other aquatic animals (like fish, or even fully aquatic turtles), this adaptation may provide mud turtles with a significant amount of climate resilience. It is possible that estivation among mud turtles may prove an invaluable offset for their relatively limited dispersal ability as the climate changes.

iv: Heat Mortality and Secondary Life History Effects

Mud turtles, and turtles in general, are relatively resistant to extremes of heat (being reptiles and therefore somewhat dependent on it), but only within certain limits. The ability of an animal to tolerate extremes in heat is known as "critical thermal maxima". Hutchinson's (1966) study on critical thermal maxima subjected an array of turtle species to ever-increasing amounts of heat until they lost the ability to right themselves when tipped over (known as the "righting response"), using this as an approximation of temperatures that would cause mortality. The study looked at three species of Kinosternid turtles (though many other turtle species besides): *Sternotherus minor*, *Sternotherus odoratus*, and *Kinosternon bauri palmarum* (Fig. 8). Hutchinson found a loss of righting response between the three species to be around 40 degrees Celsius. In general, land-based turtles were found to have a higher tolerance for thermal extremes, fully aquatic turtles the lowest, with semiaquatic species like Kinosternids about roughly in the middle. Mud turtles will certainly be affected by increases in temperature due to global climate change, but they may be less susceptible to outright mortality than other, more fully aquatic turtles.

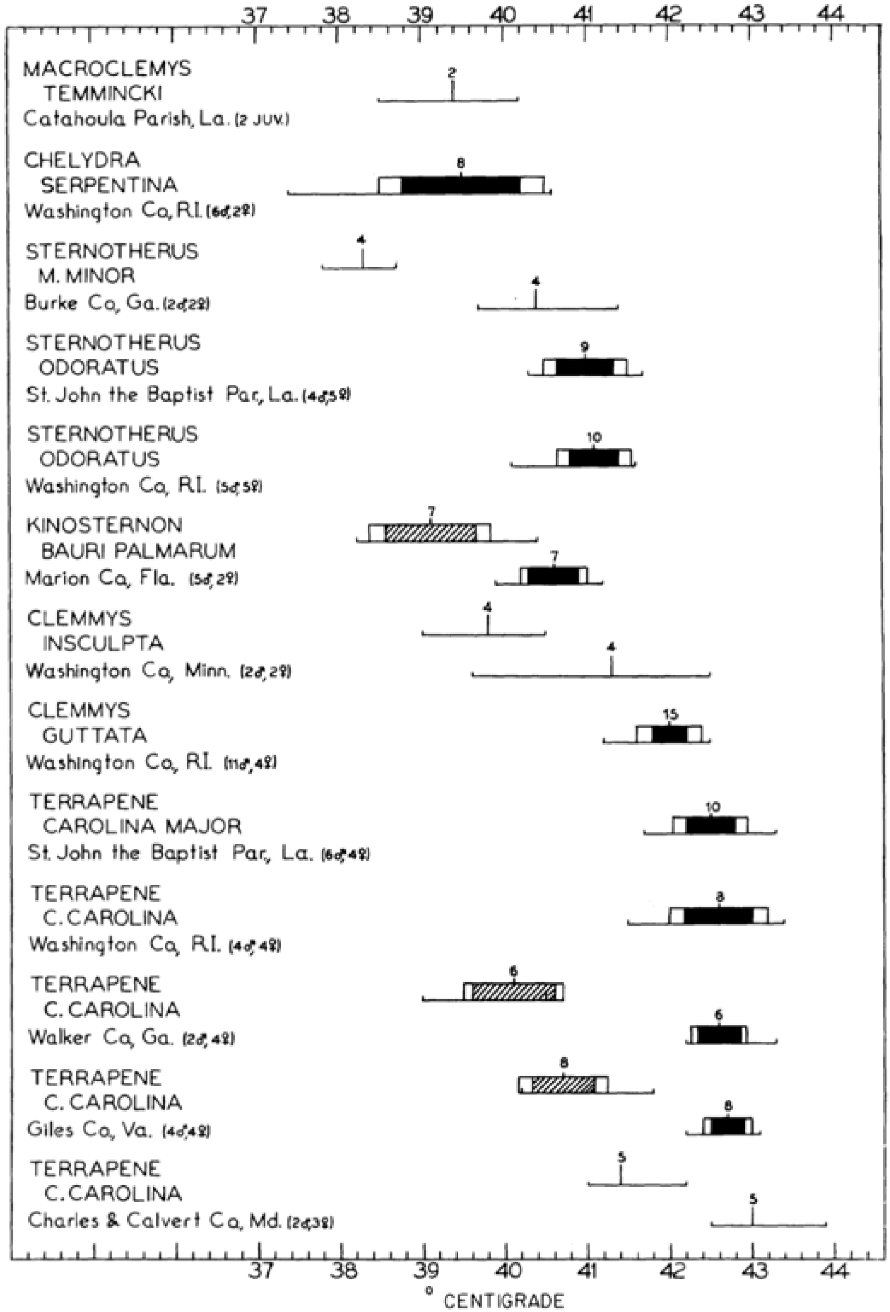


Figure 8: Critical thermal maxima in several turtle species. Adapted from Hutchinson et al., (1966).

The literature is thin on sublethal effects of temperature extremes on turtles, especially among freshwater turtles and even more so for Kinosternids. However, secondary heat effects have been observed in detail on sea turtle populations. Studies on sea turtle nests, like those conducted on olive ridley turtles by Cavallo et al., (2015), have demonstrated significant effects of increasing temperature on egg development. Cavallo et al., (2015) estimate that the sand comprising beaches where sea turtles build nests could see an increase between 2 and 3.4 degrees Celsius over the next six decades. This change has the potential to cause dramatic shifts across several different life history traits. For example, they found that hatchlings exposed to higher temperatures were slower swimmers and generally weaker, but that they had a greater stock of energy fresh out of the egg (Cavallo et al. 2015). On the other hand, increased water temperature (to a point) contributes to overall faster swimming speed for sea turtles. These seeming contradictions illustrate the dynamic and uncertain future of turtles' adaptive capacity in the face of climate change and how changes in climate may affect multiple stages of an animal's life history.

There are additional effects of increasing temperatures on embryonic development of turtles. The sex of gestating infants of many turtle species depends on the ambient temperature the embryos are exposed to while in the egg (Ewert & Nelson, 1991). Two genera in Kinosternidae are temperature-dependent in this way, both *Sternotherus* and *Kinosternon*. Temperature-dependent sex determination is divided into two main classes: Pattern I, in which a threshold of increasing temperature is reached past which all hatchlings develop as males and Pattern II, which presents a more "normal" distribution; after a certain temperature is reached, embryos develop into males while females develop in both the lower and higher extremes of temperature (Ewert & Nelson, 1991). Interestingly, *Staurotypus* was observed to largely be unaffected by temperature in terms of sex determination and is instead dependent on genetic factors to determine male: female sex ratios (Ewert & Nelson, 1991).

The variability seen across genera in this family further complicate the picture that comprises mud turtle response to climate change. Detailed analyses of expected temperature fluctuations over the ranges of Kinosternid species would illustrate potentially significant changes in sex among and between mud turtle populations.

v: Anthropogenic Habitat Change

In addition to mud turtles having to cope with future perturbations in climate, they have been and will continue to be faced with habitat changes driven by more direct human impacts. Bernstein and Christiansen's 2011 study on the yellow mud turtle (*Kinosternon flavescens*) describes mud turtles enduring just this sort of change. Yellow mud turtle populations observed in this study inhabited a series of wetlands that were formerly connected to a reach of the Mississippi River in Iowa until installation of a levee system and industrial development separated them. The landscape was made up of a patchwork of marsh, forests, and sand prairie, which would have been ideal habitat for mud turtles prior to development (Bernstein & Christiansen, 2011). Disconnecting this habitat complex from much of the riverine input of water from the Mississippi River resulted in lowered water levels that prevented turtles from accessing water to rehydrate themselves following periods of estivation and hibernation. Bernstein and Christiansen found that yellow mud turtles moved into industrial gravel pits where water levels remained high enough to provide suitable habitat. However, these refuges were only a temporary respite; much of the native forests, prairies, and wetlands vital to the survival or yellow mud turtles in the American Midwest is heavily modified and dispersed. The species is in decline, likely due to a lack of habitat connectivity that prevents turtles from reaching refugia during drought or extreme winter temperatures.

vi: Mud Turtle Response to Climate Change

Species in genus *Kinosternon* are expected to struggle as the climate changes over the coming decades and centuries. In a review covering many mud turtle species, Berriozabal-Islas (2020) examines *Kinosternon* ranges and how they might be expected to expand or contract under different climatic regimes. The majority of *Kinosternon* species will be losing considerable amounts of habitat under high emission futures. The authors estimate a 4.5% habitat loss under RCP 8.5 by 2050 for the Tabasco mud turtle, rising to a 14.42% loss in habitat suitability by 2070. Counterintuitively, even species whose ranges are expected to expand may still be imperiled. The white-lipped mud turtle, *K. leucostomum* (believed to be a very close relative and sharing much habitat with *K. acutum*), loses 45% of its habitat under an RCP 2.6 scenario by 2050 but gains 11.84% by 2050 under RCP 8.5 (Berriozabal-Islas, 2020; Iverson and Vogt, 2011).

Butler et al. (2016) suggest further possible futures for other Kinosternid species. The striped mud turtle (*K. baurii*) and the rough-footed mud turtle (*K. hirtipes*) are both expected to see dramatic contractions of their climatic envelope under high emission scenarios. Conversely, the Sonoran mud turtle's (*K. sonoriense*) climate envelope will probably remain somewhat constant and the envelopes of both the yellow mud turtle (*K. flavescens*) and the eastern mud turtle (*K. subrumum*) may see considerable expansions under high-emission climate scenarios in the future (Butler et al., 2016; Berriozabal-Islas, 2020).

Conclusion of Literature Review

Mud turtles' resilience in the face of climate change will be influenced by the key environmental and biological factors examined above – their relatively limited dispersal ability, their dependence on precipitation and freshwater for reproduction and foraging, and their ability to cope with extremes in temperature (Vogt and Flores-Villela, 1992; Cavallo et al., 2015; Berriozabal-Islas et al., 2020). Their ecological success will also depend on the availability of suitable habitat, much of which may face fragmentation by increasing human development (Bernstein & Christiansen, 2011).

The goal of this thesis is to provide novel insights into the behavioral ecology of the Tabasco mud turtle. Research efforts like this that focus on fine-scale zoological phenomena are vital to preparing and informing conservation efforts that protect lesser-known species like *Kinosternon acutum* in this ongoing period of environmental upheaval.

Methods

Study Area

The field research portion of this study was undertaken from Jun 30, 2022 - Jul 22, 2022 on the grounds of the wildlife preserve at the Belize Foundation for Research and Environmental Education (BFREE, Fig. 9). BFREE is a 1,153 acre privately held nature preserve bordering the Maya Mountains rainforest complex in the Toledo district of Belize. The preserve is dominated by native tropical broadleaf forest and interspersed with ephemeral wetlands and incursions by the nearby Bladen River. The majority of *K. acutum* captures were made along an ATV and foot track that follows the boundaries of the preserve.

Figure 9: Map showing extent of Belize Foundation for Research and Environmental Education in southern Belize.

Capture and Tagging

In total, 10 individual *K. acutum* were captured opportunistically during surveys along the northern and eastern boundaries of BFREE from Jul 4-20, 2023. Captures all occurred during daylight hours in standing pools, usually during or immediately following rainfall. Iverson and Vogt (2011) claim *K. acutum* is primarily nocturnal in habit, but extensive nighttime capture efforts were not undertaken for safety reasons.

All *K. acutum* captures were achieved by hand. Animals were placed in a breathable mesh bag and either carried by hand or stowed safely in a backpack. The location of each capture was noted using a Garmin GPS Map 64s unit. Flagging was affixed to each mesh capture bag and labeled appropriately to ensure each animal was returned to its original capture point.

Animals were carried back, between 1-3 km, to a processing station on the Boundary Road where biometric data was recorded, numerical shell marking identification number etched (a modified version of Cagle, 1939) and a PIT tag was implanted if the animal was large enough (carapace length greater than 70 mm, as outlined in Munscher et al., 2020). Biometric data collected included carapace length, carapace width, shell height, plastron width, plastron length, and mass.

Holohil PD-2 transmitter units weighing 3.8 grams each were attached to each captured turtle. A combined mass of the transmitter unit and epoxy of no more than 8% of total body mass was considered ideal. The transmitters were calibrated and tested prior to use and affixation to animals. The frequency of each unit was confirmed to be functioning and readable by handheld radio units with Yagi antennae attachments. Care was taken to apply as little epoxy as possible to securely affix each transmitter without adding unnecessary mass to each animal. This consideration further limited suitable Tabasco mud turtles, as individuals had to be above about

90 grams in mass to be large enough to tolerate transmitter affixation**.** Epoxy was activated while mixing by hand and then used to encase transmitter units which were then attached to the rear-top-center of the carapace (Fig. 10). Turtles were then placed in containment bins while epoxy cured. Each animal was placed on its side after transmitter affixation to ensure that their righting response remained available despite the added weight of the transmitter. Animals were released at their original capture location after epoxy was deemed to have cured sufficiently. The decision was made not to mix local mud into the epoxy (i.e., for camouflage) because of the remoteness of the site and our inability to obtain more epoxy if we incorrectly calculated the amount of mud to be mixed in and rendered the epoxy useless. Fortunately, the animals were observed to have managed to camouflage themselves while moving about (Fig. 11).

Figure 10: Adult *K. acutum* in a shallow ephemeral pool after release with transmitter attached. Photo by Collin McAvinchey.

Figure 11: Mud obscuring white color of adhesive epoxy on adult *K. acutum*.
Photo by Collin McAvinchey.

Relocation Data

Radiotelemetry observations began the day following each animal's release. Surveys were conducted in teams of two researchers—one to operate radiotelemetry equipment and the other to record notes and act as a spotter and mitigator against potential hazards. The research team daily (usually starting in the mornings before afternoon rains began) set out on foot from the BFREE basecamp. We followed the Boundary Road to the most distant turtle capture point, about 3.2 km away. We started with the turtle farthest away and worked backwards along the transect of the Boundary Road.

The radio receiver unit was activated upon arrival at the last known location of each turtle and tuned to the frequency broadcast by each transmitter. Each animal was then located to within 1 meter using radio and antennae. A flashlight was used for visual verification of each animal if they were present on the surface or visible in substrate, but substrate was not disturbed if animals were not visible.

The GPS unit was held motionless during a triangulation process to gain the most accurate position. Upon calibration, coordinates were saved to the unit's memory and written in a notebook along with date, time, turtle ID number, and notes about microhabitat utilization. Relocations were collected every day from Jul 4 - 20, 2023 except for (Jul 5 and 18) when staffing or safety issues (lightning storms and illness) prevented data collection.

Weather Data

Ambient weather data (precipitation, temperature, relative humidity, atmospheric pressure, and wind speed and direction) was collected by passive two H0B0 units present within the wildlife reserve; one directly adjacent to the processing station and another within two kilometers of most capture locations. A reading was collected every five minutes over the duration of the study period. Two variants of precipitation were calculated to be measured against turtle straightline movement. Rain coincident, which was a sum of measured rainfall in between observations from one day to the next; and accumulated rain, which was a measure of the total amount of precipitation that had fallen since the start of the study period on Jul 4.

Data Analysis Methods

The relationship between movement and precipitation was analyzed in JMP to obtain correlation values (both Pearson's and Spearman's). Precipitation data was examined in two analyses: 1) distance between consecutive relocations, and cumulative rainfall during the same time period (for each individual), and 2) distance between relocations correlated with total accumulated rainfall over the study period.

We performed a χ^2 test in JMP in order to test the null hypothesis of no difference in proportion between individual microhabitat utilization occurrences. Microhabitat classes were designated to capture the full extent of utilized structure variation and are defined as such:

Wood: animal was observed in and/or under small woody debris like sticks and logs

Water: animal was observed at least partially submerged in a body of water like a stream or puddle

Tree: animal was observed at the base of a tree

Leaves: animal was observed in and/or under fallen leaf litter

Cohune: animal was observed in association with a cohune palm.

Cohune palm seeds look strikingly like *K. acutum* carapaces when submerged in shallow water and many were mistakenly captured (Figs. 12 & 13). Their resemblance to adult Tabasco mud turtles led to the cohune's inclusion for analysis as a potential microhabitat factor.

Figure 12: Cohune seeds in ephemeral pools bearing a striking resemblance to adult *K. acutum.* Photo by Collin McAvinchey.

Figure 13: Adult *K. acutum* in ephemeral pool bearing a striking resemblace to Cohune palm seeds. Photo by Collin McAvinchey.

Results

Mean movement between near-daily observations for male turtles was 34 m and 26 m for females (Table 1). Maximum straight-line movement observed between individual consecutive observations was 205 meters for males and 103 meters for females. The maximum straight-line distance across all relocations of individual turtles (Total max in Table 1) across the entire study period was 196 meters for females and 275 for males. Distribution of all individual observations is shown below (Fig 14).

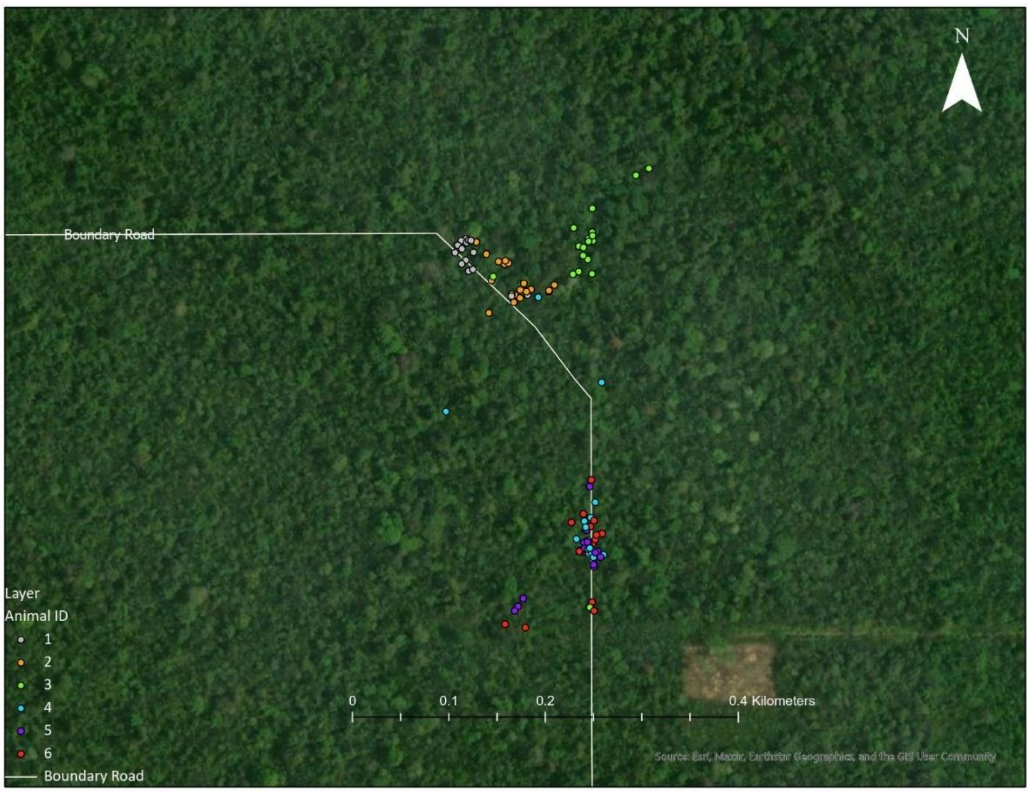


Figure 14: GPS points of relocated *K. acutum* in the northeast corner of the BFREE preserve.

Table 1: Mean and maximum movement by sex. Mean is average of total observed straight-line movements. Max straight-line is the maximum distance observed between two adjacent movement observations. Total max is maximum distance traveled between any two observations, whether subsequent or not.

ID #	Sex	Mean (m)	SD	Max straight-line (m)	Total max (m)
1	F	14	7	71	105
2	M	16	11	67	92
3	F	29	29	29	196
4	M	52	13	205	275
5	F	18	6	103	151
6	F	28	22	93	174

Individual turtles were observed in microhabitat types in similar proportions ($\chi^2_{20} = 21.4$, $p > 0.37$). Microhabitat feature classes were not mutually exclusive, for example it was possible for an individual to have utilized both woody debris and leaf litter at a single relocation. Individuals were found to utilize each microhabitat type except for water, with only half of individuals observed in standing or moving water over the near-daily study period. Leaves were observed as the dominant microhabitat utilization type, followed by an association with the base of trees and then by cohune palm and small woody debris (Figs 15, 16, 17).

Figure 15: K. acutum utilizing small woody debris and leaves, presumably for cover from heat and predators.Photo by Collin McAvinchey.

Figure 16: Cohune palm frond and leaf litter creating microhabitat for *K. acutum*, turtle was buried beneath this debris and is not shown. Photo by Rebecca Cozad.

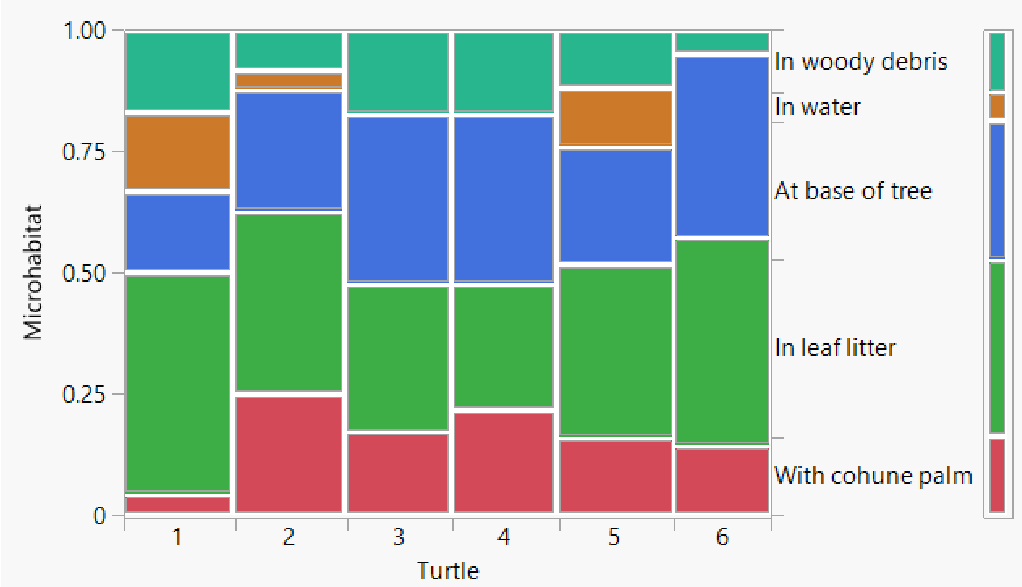


Figure 17: Relative frequency of microhabitat use across turtles.

Most individuals had no significant correlations between movement distances and either coincident or accumulated precipitation (Table 2). Movement vs. rain coincident refers to the amount of movement observed and rain measured in between near-daily observations, while movement vs. accumulated rain refers to the correlation coefficients of near-daily observed movement and cumulative rainfall over the study period. H0B0 loggers in and adjacent to the study site recorded 91 millimeters of rain over the course of the study period from Jul 4 – 20. One individual (turtle #6, Table 2) had a significant positive correlation of movement with coincident rain (Pearson's $r = 0.77$, Spearman's $rho = 0.80$, both p-values < 0.001). The strength of these coefficients, along with the low p-value, allow us to reject the null hypothesis of no relationship between rainfall and movement of *K. acutum* #6.

Table 2: Correlation coefficients between precipitation and observed movement (m). Rain coincident refers to accumulated rainfall in between observations; accumulated rain is the relationship between observed movement and total rainfall over the July 2022 study period.

Turtle #	**Movement vs. rain coincident**			**Movement vs. accumulated rain**		
	Pearson's r	*P-value*	*Spearman's rho*	*Pearson's r*	*P-value*	*Spearman's rho*
1	0.22	0.73	-0.10	-0.10	0.35	-0.27
2	0.36	0.33	0.28	-0.29	0.31	-0.29
3	-0.21	0.55	-0.17	-0.43	0.90	-0.04
4	0.37	0.20	0.36	-0.12	0.77	-0.08
5	-0.14	0.77	0.09	0.15	0.50	0.19
6	**0.77**	**<0.001**	**0.80**	0.31	0.93	-0.03

Discussion

i: Precipitation, Movement, and Terrestrial Microhabitat Use

Our results demonstrate a positive relationship between rainfall and movement in one individual *K. acutum*. Given that only one animal examined produced statistically significant results and that n=6 for all individuals, caution should be taken when attempting to draw conclusions about patterns of behavioral ecology for *K. acutum* as a whole. However, this is the first documented evidence of a correlation between *K. acutum* movement and precipitation in their environment; a relationship that has been anecdotally taken for granted.

The statistically significant relationship found between precipitation and turtle #6's movement may support the notion that the Tabasco mud turtle's forays are driven, at least in part, by rainfall events. Burke et al., (1994) document *Kinosternon subrumum* in the southeast United States remaining stationary in burrows until the advent of rainfall events that trigger nesting behavior. The authors hypothesize that rainfall may be acting as camouflage from predators; eliminating odors and tracks left by the nesting turtles. We did not observe any nesting behavior but suggest that #6's spikes in movement after rainfall may serve a similar function in foraging or reproduction.

Our findings of statistically significant relationships between precipitation and movement extended to only one animal out of the six examined in this study. The remaining five animals' movement does not appear to be correlated with rainfall as we might have expected. We have identified three potential explanations for this occurrence: 1) that the Tabasco mud turtle is not as reliant on the presence of fresh water as previously thought (Iverson & Vogt, 2011); 2) that conducting surveys during daylight hours may have missed nocturnal aquatic foraging behavior by these animals and; 3) that our survey took place during an abnormally dry beginning on the wet season in this region of Belize.

Our analysis of *K. acutum*'s microhabitat use may support the notion that the Tabasco mud turtle is not as dependent on dry land as previous researchers have identified (Legler & Vogt, 2013; Iverson & Vogt, 2011). *K. acutum* is considered a semi-aquatic animal and this study focused on observing its behavior at the transition from dry- to wet-season in this region of Belize. The vast majority (92%) of observations were made on dry land, despite the presence of ephemeral pools, wetlands, and streams nearby. The question of why these *K. acutum* were not utilizing available aquatic habitat remains open. Consulting freshwater turtle and tortoise experts were surprised to hear our preliminary results indicating much greater use of land-based microhabitats than aquatic (Fig. 17) by the animals in this study, and made the claim that these *Kinosternon* were behaving much more like wood turtles of the genus *Glyptemys* than their other congenerics (Eric Munscher, personal communication). Perhaps the amount of precipitation during the study period was not sufficient to stimulate an adapted rainy-season response. We measured 91 mm of rain during the first weeks of July, which was below average for this time of year in southern Belize (Bridgewater, 2012; Heyman, 1999).

Stone (2001) notes that the Sonoran mud turtle (*Kinosternon sonoriense*) is forced to make use of terrestrial habitat for aestivation during periods of drought and heat but that their populations don't necessarily suffer negatively during extended periods of adverse conditions. The subject animals for this project were located during daytime hours when ambient temperatures were at their highest; perhaps these turtles were engaging in aestivation behavior, as documented by Iverson & Vogt (2011). Their high use rate of leaf litter and tree cover (leaf litter and tree cover made up over 2/3 of our microhabitat use observations) may support this assertion. Aparicio et al. (2018) note the use of heat-sheltering microhabitat among Mexican mud turtles during their aestivation periods lasting up to six months. Perhaps the Tabasco mud turtles in this study were engaging in similar behavior.

Our movement results contrast sharply with movement described by other authors like Aparicio et al. (2018). They found the Mexican mud turtle's movement range to up to 27,000 meters, while our maximum straight-line movement observed was only 275 meters, though we did not perform a home range analysis. The limited distance our turtles traveled over the course of this study may also contribute to a corroboration of findings by Slavenko et al. (2016), which state that a turtle's range size is closely linked with the size of its body.

Iverson and Vogt (2011) report that *K. acutum* is largely nocturnal but do not present this data so it remains anecdotal. Primarily nocturnal foraging behavior may account for the lack of observations made in water bodies; surveys were conducted exclusively during the day, and it is certainly possible that the animals were utilizing aquatic habitat at nighttime and returning to a day-time resting location. Animals were also rarely located in motion; most observations were of stationary animals hiding in vegetative material. It is possible that the turtles were aware of the research team's presence and deliberately concealed themselves before the team was close enough for visual observation.

Regardless, our findings highlight literature gaps in *K. acutum*'s natural history and behavioral ecology. Future research is needed to establish the extent to which *K. acutum*'s movement and behavior is influenced by local precipitation patterns, the extent to which it may or may not be nocturnal, and its use of terrestrial habitat.

ii: Animal Size

We had trouble locating enough individuals of sufficient size to affix transmitters to. We decided not to attach more than 8% by body weight of transmitter and epoxy to each animal and this proved a significant deterrent to our eventual sample size. Our original goal was to have 20 animals tracked over the course of the study period. After 5 days of searching yielded only 6 animals massive enough to bear the weight of the transmitters, we decided to use half of the transmitters on another species present at the site, *Claudius angustatus*, which is also greatly underrepresented in the literature (those results will be presented elsewhere).

We located numerous juveniles and subadults while searching for adult *K. acutum* and have speculated on the reason for a dearth in adequately sized adults. We surveyed the site during the summer of 2021 and located numerous adequately sized adults (Munscher et al., 2023, in press). We suspect the difference between the initial survey in 2021 and the 2022 period may have been amount of precipitation. 2021 saw a much wetter beginning to the dry season than did 2022 and this may account for continued torpor in the local Tabasco mud turtles and thus our less successful capture rates.

It's also possible that *K. acutum* is in competition with the white-lipped mud turtle (*Kinosternon leucostomum*) at this site in Belize. Numerous *K. leucostomum* were captured using baited hoop and net traps while only a few *K. acutum* were netted in this manner. *K. leucostomum* inhabits a similar ecological niche as *K. acutum* and may be preventing Tabasco mud turtles from utilizing, through competitive exclusion, the same aquatic habitats the white-lipped mud turtles are enjoying. This would account for the small amount of *K. acutum* captured in aquatic traps despite their being considered a semi-aquatic species.

iii: Cohune Palm

Finally, we included the cohune palm (*Attalea cohune*) in microhabitat use analysis due to its ubiquity across the study site and its seeds' similarity in appearance to the carapace of an adult *K. acutum* when partially submerged in water. They appear so similar at a glance that many *Attalea cohune* seeds were ‘captured’ in lieu of Tabasco mud turtles. The turtles could have been subject to natural selection favoring a resemblance to cohune seeds to act as camouflage from predators (Duarte, 2018). This is of course speculative, but the similarity is so striking it seems worth further investigation.

Conclusion

In conclusion, we present this expansion of the Tabasco mud turtle's known natural history. This thesis has examined relationships between precipitation and movement in a population of *Kinosternon acutum* in a seasonally-dry tropical rainforest of southern Belize. Our results, while limited in temporal and geographic scope, are at least suggestive of a potentially contradictory duality in the Tabasco mud turtle's behavioral ecology. We uncovered a statistically significant relationship between movement and rainfall for one individual while failing to achieve the same results for the remaining animals studied. Far from being disappointing, this seeming contradiction opens the door for further research and speculation on the Tabasco mud turtle's life history by potentially undermining assumptions about its use of terrestrial habitat. We hope that this project will pave the way for future studies of *K. acutum* and provide further illumination of this animal's unique life history.

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