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Article

Spatial Ecology and Movement of Ornate Box Turtles in the Escalating Drought Conditions of the Great Plains Ecoregion

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Abstract: Shifts in global climate patterns can alter animal behavior, including movement and space use. The southwestern United States of America is currently undergoing a period of megadrought, which can have profound consequences on small ectothermic organisms like box turtles. We radiotracked eight adult ornate box turtles (*Terrapene ornata*) in eastern New Mexico from September 2019 to July 2022, when the environmental conditions transitioned from a dry season with low cumulative precipitation in 2020 to high cumulative precipitation in 2021, followed by a regression to exceptional drought conditions that culminated with a high-intensity wildfire in early 2022. Turtles exhibited greater mean daily movement and were more active in 2021 in comparison to 2020 and 2022. Turtles were least active in 2022, while mean daily movement was comparative to 2020. All turtles in our study exhibited homing behavior after the wildfire, but individual responses varied. While some turtles initially moved out of the burned area and returned within a month, others remained inactive within a small portion of the burned area. The greatest movement was documented in one female turtle following the wildfire, whose home range expanded to seven times the average maximum annual home range size observed among other turtles. Overall, this is the first documentation of *T. ornata* response to highly altered habitat after high-severity wildfire.

Keywords: *Terrapene*; movement; grassland; climate

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1. Introduction

Understanding animal home range and movement patterns is crucial for determining species habitat requirements and effective conservation planning [1–4]. Local environmental conditions and landscape configuration influence daily activities and movement patterns in animals [5–8]. With the increasing impact of anthropogenic disturbance and climate change, it is vital to understand how animals acclimate and respond to environmental changes, which can be constrained by their morphological characteristics and physiological traits [9–12]. In particular, small terrestrial ectotherms with limited dispersal abilities are disproportionately more vulnerable to rapid environmental changes such as temperature fluctuations, precipitation patterns, and water availability, which can result in direct mortality or a reduction in fitness [13–16].

One ectotherm that exemplifies constrained dispersal and limited mobility compared to most other reptiles is the ornate box turtle (*Terrapene ornata*) [17,18]. Found across the central United States of America (USA) and north–central Mexico, *T. ornata* is adapted to living in semiarid conditions and represents the westernmost species of its genus [19,20]. The recognition of two subspecies, *T. o. ornata* and *T. o. luteola*, whose distributions overlap in New Mexico, USA, has been debated among researchers [21,22]. For simplicity, we refer to ornate box turtles at the species taxonomic level. Due to their slow movement speeds, *T. ornata* is particularly vulnerable to habitat fragmentation, extreme weather conditions, and climate change [17,23–25]. Although *T. ornata* does not need standing water to survive [26], some populations living in the southern, more arid parts of its range may struggle with water retention [20].

While there is a wealth of research on *T. ornata*'s home range, direct comparisons are often complicated by variations in monitoring frequency, sample sizes, and statistical approaches implemented among them [27,28]. Studies have reported home ranges as compact as 0.12 ha [29] and as expansive as 58.1 ha [23], with significant individual variability in home range sizes within single populations [23,29–31]. However, in New Mexico, *T. ornata* home range has not been studied extensively [32,33], despite the species' relatively wide distribution across several ecoregions of the state [26]. In recent years, New Mexico has experienced severe drought conditions, creating urgency in understanding how *T. ornata* responds to rapid environmental changes.

Arid regions are projected to expand globally, with South America and Asia expected to experience the most significant increases [34,35]. The already arid southwestern United States is currently undergoing a period characterized by one of the most extreme megadroughts since 800 CE [36], likely pushing even the most arid-adapted wildlife to the brink of their tolerance limits. Less frequent precipitation events, decreasing water body levels, and a reduction in soil moisture content could alter habitat components and microclimate conditions that affect *T. ornata* movement, home range, and survival [37,38]. Recent studies have attributed low density and high mortality of females, as well as reduced survival of juvenile desert tortoise (*Gopherus agassizii*), to protracted and intensified droughts in the southwestern USA [39,40]. Prolonged drought was also considered a major contributor to the recently reported mass die-off of juvenile *T. ornata* in eastern New Mexico [41].

Drought conditions can also exacerbate the intensity and severity of wildfires. The timing of fires significantly affects *T. ornata*'s eastern counterpart, the eastern box turtle (*Terrapene carolina*); for instance, summer fires can cause direct mortality or burn injuries, whereas fires occurring during the dormant season generally have less detrimental effects [42–45]. However, the impact of fires on *T. ornata*, a grassland specialist, has not been assessed directly [46]. While North America's grasslands are known for frequent fire regimes in their natural state, to which *T. ornata* should be well adapted to, the combination of anthropogenic fire suppression and climate change has led to less frequent but more intense wildfires. These wildfires, apart from direct mortality, cause significant alterations to the overall landscape and microhabitat conditions that can threaten population persistence of *T. ornata*. The objective of our study was to document the movement, activity, and home range of *T. ornata* in the Great Plains ecoregion of eastern New Mexico and assess the impacts of a drought and a drought-induced high-severity wildfire on spatial ecology of this vulnerable grassland species.

2. Methods

2.1. Study Area

Eastern New Mexico University Natural History Preserve (Preserve) is located in Roosevelt County, New Mexico, approximately 13 km northeast of Eastern New Mexico University (ENMU)'s main campus. The Preserve was officially established in 1970; it is closed to the public and serves as an educational field site for biology classes as well as research. The Preserve has not been grazed since the 1930s, and there have not been any management activities since (e.g., prescribed fires). Vegetational composition is a relatively uniform shortgrass prairie, with yucca plants (e.g., *Yucca campestris*, *Yucca glauca*), cacti (e.g., *Opuntia macrorhiza*, *Escobaria vivipara*), and scattered trees (e.g., *Ulmus pumila*) in the northern portion of the Preserve where most of the project took place. There is no available free-standing water on the property, and box turtles rely entirely on precipitation, dew water, and food to meet their water intake needs. The Preserve borders U.S. Highway 70 to the west, a field cultivated with alfalfa (*Medicago sativa*) and private residence to the north, cattle ranches to the south, and undisturbed land to the east. A small segment of the southern portion of the Preserve also borders New Mexico State Road 202. The Preserve spans roughly 121 hectares, with our radio-telemetry work conducted within an area encompassing approximately 40 hectares.

The United Stated Drought Monitor (USDM) maps the location and intensity of droughts across the USA and represents the collaborative effort between the National Drought Mitigation Center (NDMC), the U.S. Department of Agriculture (USDA), and the National Oceanic and Atmospheric Administration (NOAA). The USDM uses five categories: abnormally dry (a precursor to drought), moderate, severe, extreme, and exceptional drought. In 2020, conditions in our study region ranged from abnormally dry to moderate, severe, and exceptional drought throughout the turtles' active season. More specifically, Roosevelt County was under exceptional drought from the summer of 2020 to May 2021 [47] and received only 110 mL of rain between May and October 2020 [48]. In contrast, numerous rainstorm events temporarily alleviated drought conditions in the summer of 2021. Roosevelt County accumulated 290 mL of rain between May and October 2021, which boosted aboveground biomass. However, this vegetation subsequently dried out by the end of the year as exceptional drought conditions returned [47]. The dried accumulated vegetation became fuel for a wildfire in March of 2022. The fire was contained before spreading to the surrounding private properties, but the Preserve itself, including our study area, was severely burned (Figure 1). The only portion of the Preserve that remained intact was the extreme southern area, which was outside the study site. The fire removed all ground cover while turtles were overwintering underground. The drought conditions continued after the wildfire, ranging from severe, extreme, and exceptional throughout the turtles' active season.

2.2. Radiotracking

Using radio telemetry, we tracked 8 adult turtles (4 males and 4 females) from September 2019 to July 2022. Turtles were originally found by conducting opportunistic visual encounter surveys or while radiotracking other box turtles. We attached radio transmitters to two turtles in 2019 [49], one additional turtle in 2020, and five additional turtles in 2021. Each turtle was tracked for between 294 and 1036 days (mean = 552; SD = 286; Table 1). Turtles were equipped with radio transmitters (RI-2B, Holohil Systems Ltd., Carp, ON, Canada) that weighed approximately 14.5 g and did not exceed 7% of the turtles' mass [50]. Radio transmitters were attached to the anterior portion of the carapace using J-B Weld Steel-Stick TM epoxy [49]. Tracking was conducted using an R4000 Telemetry Receiver and H Antenna (Advanced Telemetry Systems Inc., Isanti, MN, USA).

Figure 1. Three photographs providing visual context for the ornate box turtle (*Terrapene ornata*) radio-telemetry study in Roosevelt County, New Mexico. The top image is of the study area before the wildfire, showcasing the landscape and vegetation conditions (July 2020). The middle image represents the study site after the March 2022 wildfire, showcasing the post-fire landscape and altered vegetation conditions (April 2022). The bottom image is an ornate box turtle exiting brumation following the March 2022 wildfire, indicated by the arrow (April 2022; bottom).

During the turtles' active season (May to October), we tracked the turtles 3–7 days a week, and during brumation (November to April), tracking occurred 1–13 days per month. Once a turtle was located, we recorded the following: 1. whether the turtle was above or below ground; 2. GPS coordinates using a handheld Garmin GPS (~5 m accuracy); 3. ordinal Julian date; 4. time of day; and 5. weather conditions (see Suriyamongkol et al. 2021 for details). Although tracking times varied based on surveyor availability, efforts were made to monitor the turtles during peak activity hours of early morning or late afternoon [49]. On average, 64% of locations were recorded before 1000 or after 1600 MST (60–66% per turtle).

Table 1. Summary data for 8 ornate box turtles (*Terrapene ornata*) radiotracked between 2019 and 2022 at the Eastern New Mexico University Natural History Preserve in Roosevelt County, New Mexico, including 100% minimum convex polygons (100% MCPs) calculated using all location points throughout the tracking period.

ID	Sex	Start	End	Total Days	Mortality	100% MCPs (ha)
1	Male	5 Sept 2019	7 Sept 2022	1036	No	11.37
2	Female	4 Oct 2019	7 Sept 2022	1007	No	1.78
3	Male	7 July 2020	24 April 2022	656	Yes	2.77
4	Female	1 July 2021	21 April 2022	294	Yes	6.41
5	Female	6 July 2021	11 July 2022	370	No	30.89
6	Female	7 July 2021	7 July 2022	365	No	3.64
7	Male	15 July 2021	7 July 2022	357	No	8.19
8	Male	18 Aug 2021	13 July 2022	328	No	4.53

2.3. Analyses

We estimated annual home range (HR) using the functions 'mcp' and 'kernelUD' in the '*adehabitatHR*' package [51] in R [52]. To ensure a comprehensive analysis, we employed multiple estimation methods: 100% and 95% minimum convex polygons (MCPs) and 95% and 50% kernel density estimation (KDE). When estimating KDE, we used the reference default smoothing parameter (href). KDE typically generated larger area estimates than MCPs, likely due to turtles having multiple points within relatively small areas [53]. Given this, we primarily focused on interpreting 100% MCPs, considering any movement in our study area to be biologically relevant [54]. However, we also reported results from all HR estimation methods to make the data available and facilitate comparisons with previous and future studies (see Supplementary Materials).

To assess whether each turtle exhibits fidelity to particular areas from year to year (i.e., geographic fidelity), we estimated 100% MCP overlap for individuals tracked over multiple years using the following equation: HR overlap = area overlap ij(m^2)/(area year i(m^2) + area year j(m^2) − area overlap ij(m^2)), where years i and j are sequential years [55]. Area overlaps were calculated using the Intersect tool in ArcMap 10.4. In ArcMap, we also calculated the maximum linear distances each turtle covered between two consecutive points. We then divided this distance by the number of days between tracking events to estimate the mean daily movement for each turtle.

To assess turtle activity across different years (i.e., dry 2020, wet 2021, and post-fire 2022), we employed generalized linear mixed-effect models using the 'glmmML' package. The models were fitted with binomial family, where activity was coded as 1 if a turtle was above the ground or 0 if a turtle was below ground. Individual turtles were treated as a random effect. Analyses were conducted on the full dataset and a subset restricted to data collected during the early morning (before 1000) and late afternoon (after 1600), when turtles are more active (Suriyamongkol et al. 2021 [49]). To assess the difference in turtle movements (i.e., mean daily distance covered) across the three years, we used a generalized linear mixed-effect model using the package 'lme4', treating each turtle as a random effect. We used the package 'emmeans' to make pairwise comparisons among the years. Because our data were not normally distributed, we first applied log+1 transformation. When interpreting the results of the model, the estimates were back transformed. We used the same approach to test differences in HR across the years and applied log transformation to meet the assumption of normality. All analyses were conducted in R [52], and statistical inference was set at $\alpha = 0.05$.

3. Results

We obtained a total of 1560 location points among all turtles during their active season, with the number of recorded locations per turtle ranging from 104 to 333 (mean = 182). Generally, turtles entered brumation in the last half of October (October 15 to October 22), except for 2020, when all three turtles went into brumation a month earlier, between September 13 and September 21. Most turtles emerged from brumation between the last week of April and the first week of May, though some became active as early as April 16 (ID 1 in 2020) and as late as May 17 (ID 2 in 2021). Following the 2022 wildfire, two turtles (one male and one female) were found depredated the day they emerged, less than 1 m from their brumation location. Hair samples near the deceased turtles suggested that striped skunks (*Mephitis mephitis*) were the likely predator. The remaining turtles (three males and three females) survived in the post-wildfire environment.

The overall individual home range size (100% MCPs) across all years combined ranged from 1.78 ha to 30.89 ha (Table 1). Annual HR ranged from 0.90 to 6.59 ha for males and 0.32 to 30.88 ha for females (Table 2). The largest HR (i.e., 30.88 ha) was exhibited by ID 5 in 2022, which was seven times the average maximum annual home range size observed among all other turtles (Table 2). For both the full and subset datasets, turtles were more active in 2021 ($p < 0.01$) and less active in 2022 ($p < 0.01$) in comparison to 2020 (Figure 2A). The highest proportion of turtles found above ground occurred in 2021, with 38–62% per turtle. This was followed by 2020, with 26–37% per turtle, and 2022, which had the lowest proportion at 10–19% per turtle. During periods of hot and dry conditions exacerbated by the drought events in 2020 and 2022, turtles were found at the same locations underground for numerous consecutive days (maximum 6–12 days per turtle). The maximum linear distances each turtle covered between two consecutive points (non-standardized data) ranged from 76 to 143 m in 2020, 123 to 311 m in 2021, and 119 to 676 m in 2022. Mean daily movement did not significantly differ between the years 2020 and 2022 ($p > 0.05$). However, in both 2020 and 2022, turtles exhibited significantly lower mean daily movement compared to 2021 ($p < 0.01$ for both comparisons; Figure 2B). On average, turtles in 2020 and 2022 showed a ~57% decrease in daily distances moved in comparison to the wet year of 2021. None of the pairwise comparisons of home range size were statistically significant ($p > 0.05$; Figure 2C). However, home range size in 2020 was approximately 25% smaller compared to 2021 and 2022, while 2022 showed only a 3% reduction compared to 2021. The home range overlap showed a wide range of variation, spanning from 4 to 56% for females (mean = 24%) and 19 to 52% for males (mean = 33%; Figure 3).

Table 2. The minimum, maximum, median, and mean annual home range size (100% MCPs) for each radiotracked ornate box turtle (*Terrapene ornata*) between 2019 and 2022 at the Eastern New Mexico University Natural History Preserve in Roosevelt County, New Mexico.

ID	Sex	Minimum (ha)	Maximum (ha)	Median (ha)	Mean (ha)
1	Male	1.20	6.59	4.0	3.95
3	Male	0.96	2.77	1.87	1.87
7	Male	4.00	6.36	5.18	5.18
8	Male	0.90	4.38	2.64	2.64
2	Female	0.32	1.18	0.94	0.85
4	Female	6.41	6.41	6.41	6.41
5	Female	1.25	30.88	16.07	16.07
6	Female	0.93	3.39	2.17	2.17

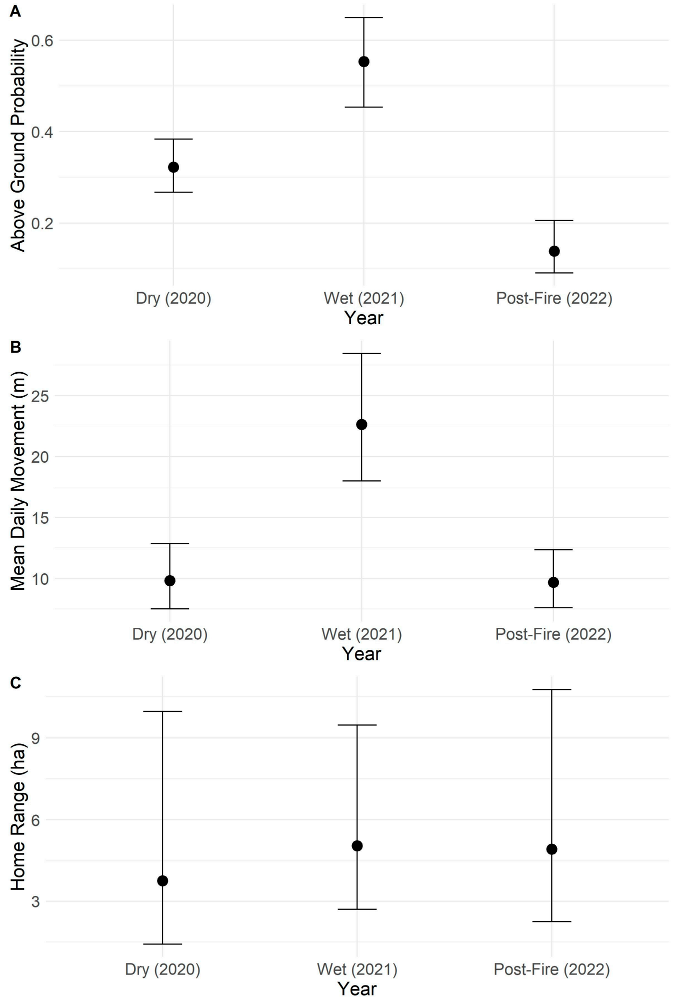

Figure 2. Mean estimates and 95% confidence intervals derived from linear mixed-effect models evaluating differences in the probability of turtles being above ground for the full dataset (**A**), mean daily movement (**B**), and home range size (**C**) for ornate box turtles (*Terrapene ornata*) across three consecutive years in Roosevelt County, New Mexico.

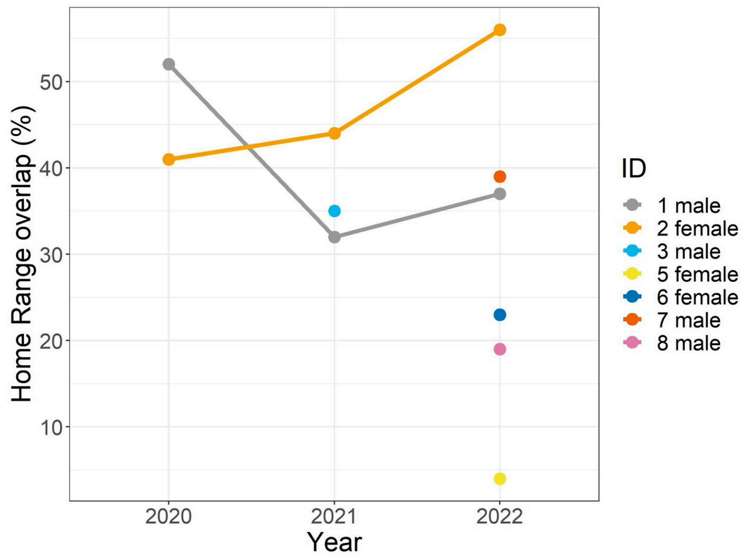

Figure 3. Home range overlap (%) for individual ornate box turtles (*Terrapene ornata*) radiotracked over multiple years (2019–2022) in Roosevelt County, New Mexico. Home range overlap (%) was calculated for each turtle as the proportion of space shared between sequential years relative to their total home range area.

4. Discussion

This study is the first to examine the home range of *T. ornata* in eastern New Mexico, a region where ecological understanding of this species remains limited [49]. Although the original intent was not to study *T. ornata* responses to drought and fire, a unique set of circumstances provided valuable insights on how precipitation and wildfire affect species daily activities. The two caveats of our study were the small sample size and our inability to track all turtles simultaneously due to limited funding. However, the limited sample size afforded us the opportunity to track all turtles more frequently, yielding higher-resolution data.

Our overall findings suggest that time spent above ground and mean daily movement were influenced by the prevailing drought conditions throughout the study period. These spatial metrics were greater in the wet year of 2021 in comparison to the dry 2020. Conversely, the removal of ground cover by the wildfire and the continuing drought in 2022 caused turtles to be considerably less active. Frequent fire regimes are vital to the maintenance of the shortgrass prairie ecosystems [56]. The Preserve, however, had not experienced a burn since at least 2015. At the time of the high-intensity March 2022 wildfire, the turtles were still in brumation, and the fire did not cause any direct mortality or scarring of turtle shells. Consistent with our findings, other studies recommend that prescribed burns occur in early spring when turtles are in brumation, minimizing the risk of mortality events [46,57]. While prescribed burns can be meticulously planned to mitigate adverse effects on turtle populations, the threat of drought-induced wildfires during the active season of *T. ornata* remains a concern. Beyond serving as a direct food source and habitat for invertebrate prey, *T. ornata* explicitly depends on vegetative cover for concealment from potential predators [25]. The only mortality events in our study occurred immediately after emergence in 2022. Throughout the study, we encountered many other box turtles we did not radiotrack, and we observed no mortality events that resemble those in 2022. Therefore, our study revealed that high-intensity wildfires, even when occurring in late winter or early spring, can be detrimental to box turtles by leaving them exposed to predators as they emerge from brumation without sufficient ground cover [25,58].

Although the home range sizes of *T. ornata* were not significantly different across years, we observed a diverse array of turtles' responses to the wildfire. Some of the smallest and the largest home range sizes were documented post-wildfire. Both contrasting phenomena contributed to minimal home range overlap between 2021 and 2022. One female and two males moved to the unburned areas immediately after emergence, making movement of up to 300 m over two days, and eventually returned to the original area they came from. While the males' path of return was straightforward, the female moved approximately 815 m over two days away from the 2021 home range area, and after several more movements, returned to the general area it originally occupied (i.e., in 2021) by mid-June. Excluding the bursts of relatively long-distance movements, the mean daily distance moved for this turtle in 2022 was 9 m. In contrast, the other three turtles remained in the core area of the home range they occupied before the fire. Therefore, all turtles exhibited strong homing in 2022 either by (1) making initial short-term explosive movements away from the burned area in search of cover before eventually returning to the same area they occupied the previous year or (2) remaining mostly inactive within a small core area, likely to avoid exposure to predation [53,59].

Successive days devoid of activity have been reported in *T. ornata* populations [60,61]. We observed an even greater amount of time spent underground during the hot and dry summer months of 2020 and 2022 as drought conditions in the southwestern USA escalated. Although aestivation serves as a strategy to alleviate challenges related to harsh environmental conditions and water loss, extended periods of inactivity can reduce time available for foraging and finding mates, which can negatively affect individual fitness and population viability [32,62]. Moreover, in response to elevated ambient temperatures, *T. ornata* may undergo a substantial decrease in body mass due to water loss through evaporative cooling, and body temperatures above 40 °C can be lethal [63,64]. In Arizona, *T. ornata* were notably dehydrated when they emerged at the onset of summer monsoons [65]. Within our study area, the wildfire consumed *Opuntia* cactus, a recognized water source for *T. ornata* in regions devoid of standing water [66]. Thus, we hypothesize that the lack of dietary water could have broader implications for their body conditions and aboveground activity patterns.

5. Conclusions

This study provides valuable information that natural resource agencies should take into consideration when managing *T. ornata* habitats in New Mexico grasslands. The home range sizes reported here can be used as a general guideline on the minimum size requirements of intact habitat for the species. Additionally, mean daily movement and time spent above ground appeared to be impacted by drought conditions. We emphasize that turtles in our study exhibited strong homing behavior after the severe wildfire even when initially moving outside of the burned zone. Mortality also increased post-fire due to predation, posing a significant threat to the persistence of *T. ornata* [58]. However, the long-term consequences of reduced activity and diminished resource availability due to drought and fire need to be further investigated. Systematic monitoring and adaptive conservation plans over multiple years can substantially increase our level of understanding of this grassland specialist, especially in the light of climate change [67].

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/fire8010024/s1, Table S1: A summary table of home range size estimates based on: 95% Minimum Convex Polygons (95% MCP), 95% Kernel Density (95% KDE), and 50% Kernel Density Estimation (50% KDE) of ornate box turtles (Terrapene ornata) at Eastern New Mexico University Natural History Preserve, Roosevelt County, New Mexico.

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