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Evaluating Translocation Strategies for Box Turtles in Urbanizing Landscapes

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Evaluating Translocation Strategies for Box Turtles in Urbanizing Landscapes

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of the requirements for Departmental Honors Studies in Biology

By

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Table of Contents

Abstract

Urbanization of landscapes, resulting in habitat degradation, loss, and fragmentation, is a significant contributor to the global decline of reptile biodiversity. Although translocation is a common management strategy for wildlife populations subject to urbanization, the efficacy of reptile translocation studies, including those of box turtles (*Terrapene* spp.), is highly variable. Hard-release translocation of box turtles has often proven ineffective due to homing attempts and rapid post-translocation movements. Some studies have presented soft-release as a possible method for mitigation of the negative effects of hard-release, yet those studies have also produced mixed results. Therefore, I radiotracked 18 translocated *Terrapene carolina triunguis* in an urbanizing area of Northwest Arkansas to determine whether long-term (> 1 year) holding at an off-site location prior to translocation could be an effective alternative to soft- and hard-release translocations. I found that turtles held long-term before a short-distance translocation moved significantly shorter distances each day post-release than hard-released turtles. Turtles held long-term also moved in nondirectional, random orientations, whereas hard-released turtles exhibited consistent directionality in movements back towards their initial capture (home) locations. These results suggest that long-term holding of box turtles prior to translocation could significantly reduce homing responses and wandering, thus increasing the efficacy of translocation efforts.

Introduction

Habitat degradation as a consequence of urbanization can have detrimental effects on wildlife, whether it be from direct effects of development or indirect effects from overall increase in human populations (Theobald et al. 1997, Jackson 2000, Kapfer et al. 2013). Historically, landscape-scale habitat degradation has caused the quality of formerly unaltered habitats to diminish. In North America, European settlers cleared and plowed land for agricultural purposes and rapidly felled forests (Dodd Jr. 2002), resulting in changes of ecological succession processes (Christensen 1989). Additionally, decades of fire suppression have resulted in regeneration of crowded forests with dense canopy cover and little growth of shade-intolerant herbaceous vegetation (Hutchinson et al. 2005, Hanberry 2019). Millions of hectares of degraded natural landscapes that were still suitable for many species are being further altered by the rapid increase in urban and residential development across the United States. Coinciding with urban development, transportation infrastructure now fragments populations across landscapes in small patches of suitable habitat, often resulting in population decline or extirpation (Gibbons et al. 2000, Jackson 2000, Dodd Jr. 2002). Consequently, novel methods are needed to help conserve wildlife populations in urbanizing landscapes.

Globally, reptile species have experienced severe negative effects from habitat loss caused by urbanization (Gibbons et al. 2000, Cox et al. 2022). Approximately 21% of reptile species are currently listed on the International Union for Conservation of Nature (IUCN) Red List as being threatened with extinction (Cox et al. 2022). Among the listed species, urbanization affects 34.8% of forest-dwelling reptiles, in part because 70% of the world’s forests are located within one kilometer of a forest edge (Cox et al. 2022). With 57% of chelonian species listed as threatened, turtles and tortoises are not exempt from the anthropogenic pressures created by urbanized landscapes (Cook 2004, Stanford et al. 2020, Cox et al. 2022). The slow life history traits of chelonians, specifically slow maturation and low reproductive rates, makes them especially vulnerable to impacts of forest urbanization (Budischak et al. 2006, Stanford et al. 2020).

The Eastern Box Turtle *(Terrapene carolina)* is one of 360 turtle species currently listed as threatened with extinction on the IUCN Red List (van Dijk 2011, Greenspan et al. 2015, Stanford et al. 2020). Like many turtles, box turtles exhibit a slow life history, characterized by low recruitment rates, slow maturation, and high adult survivorship. Despite low egg survivorship, undisturbed populations are successful in part due to negligible reproductive senescence (Miller 2001, Dodd Jr. 2002). The slow life history of box turtles renders populations vulnerable to the effects of habitat loss and degradation due to their inability to quickly rebound from declines in adult survivorship (Budischak et al. 2006, Iglay et al. 2007, Stanford et al. 2020), one of the many factors responsible for the current trend of population decline noted by the IUCN (van Dijk 2011, Greenspan et al. 2015).

Mesic forests are the preferred habitat of *T. carolina*, characterized by a sparse understory with a layer of leaf litter, abundant refugia, and a dense canopy allowing dappled sunlight on the forest floor (Dodd Jr. 2002, Kapfer et al. 2013). Box turtles have relatively small average home ranges (estimated 2.04 ha for Ozark/Ouachita-Appalachian forest ecoregion), yet populations subject to forest urbanization have the ability to persist in residential neighborhoods and green spaces within urban areas that maintain critical habitat elements if they survive initial construction activities (Budischak et al. 2006, Fredericksen 2014, Habeck et al. 2019). However, modern construction practices are often unsustainable for box turtle populations because massive mortality of turtles is almost ensured with complete clearing of land and extensive mechanical landscape alteration of their home ranges that accompanies large-scale projects such as multi-home subdivisions. Yet, preservation of these resilient box turtle populations in urbanizing areas could be attainable if met with novel management strategies that attenuate the effects of mortality from construction activities.

Negative effects of habitat degradation can, in some cases, be mitigated through translocation, a conservation strategy that consists of moving animals from an area facing immediate threats to a more stable patch of suitable habitat (Cook 2004, Rittenhouse et al. 2007, Germano and Bishop 2009, DeGregorio et al. 2020, Poor et al. 2020). Two common translocation strategies include hard- and soft-release. Hard-release translocation, the most common approach, consists of moving animals immediately from their capture location to their translocation site. However, hard-release translocations can leave animals in a disoriented state that often results in high mortality rates due to long movements or homing attempts. A soft-release translocation is an alternative approach that attempts to avoid erratic movements and homing by providing an acclimation period in an enclosure at the site of translocation before releasing the animals (Tuberville et al. 2005, Germano and Bishop 2009, DeGregorio et al. 2020, Resende et al. 2021).

Although reptiles are historically underrepresented in translocation studies, the global decline of reptile biodiversity necessitates novel translocation strategies to protect populations from the negative impacts of urbanization (Gibbons et al. 2000, Tuberville et al. 2005, Germano and Bishop 2009). Previous studies have produced mixed success in translocation of reptiles. A review assessing the suitability of reptiles for translocation indicated that homing attempts and long movements by released individuals were the primary reasons for translocation failure (Germano and Bishop 2009). In some studies, soft-release has been found to decrease post-translocation movements and homing attempts, thus promoting new home-range establishment (Tuberville et al. 2005, DeGregorio et al. 2020). For example, a study on the soft-release of Texas horned lizards (*Phrynosoma cornutum*) demonstrated that the juvenile lizards responded well to soft-release translocations. However, adult lizards experienced an unsustainably high mortality rate after soft-release translocation (DeGregorio et al. 2020). Another study compared hard-release and soft-release translocation treatments in attempt to reestablish a population of gopher tortoises (*Gopherus polyphemus*), finding that soft-release, as well as duration of time spent in the soft-release enclosure, greatly increased tortoise site fidelity compared to the hard-release group. Soft-release of tortoises also drastically reduced the number of attempted individual dispersal events relative to the hard-released tortoises (Tuberville et al. 2005).

Box turtles (*Terrapene* spp.) are commonly managed with translocation. However, hard-release translocations often fail due to strong home site fidelity of box turtles and their resistance towards new home range establishment (Refsnider et al. 2012, Harris et al. 2020, Poor et al. 2020). For example, an *ad hoc* translocation study monitored 10 *Terrapene carolina carolina* for about three years after a hard-release translocation. Only 4 turtles established new home ranges, while 6 had to be repositioned multiple times to keep them within the translocation site (Poor et al. 2020). Another study comparing movements and home range sizes between resident and hard-released box turtles (*Terrapene carolina triunguis*) found that the hard-released turtles moved farther between relocations with a more directed orientation in movements than resident turtles. Hard-release turtles also had increased home range sizes compared to residents

(Rittenhouse et al. 2007). Variability of success in hard-release translocations led to the overarching consensus across multiple studies that incorporation of strategies such as soft-release, or penning, should be investigated to mitigate the effects of hard-release (Rittenhouse et al. 2007, Hester et al. 2008, Farnsworth and Seigel 2013, Sosa and Perry 2015).

A study involving 53 radiotracked box turtles (*Terrapene carolina carolina*) investigated movements of hard- and soft-released turtles, translocated approximately 70 km from their initial capture sites, for a five-year tracking period. Soft-released turtles were penned for 15 days before release. Individuals in each category were divided between wild-caught turtles (translocated within one week of initial collection) or pets (turtles held in captivity, off-site, for > 30 days). This study did not find a significant difference between homing attempts of wild, hard-released turtles and those that had been penned and/or held off-site (Cook 2004). However, some studies indicate that distance of translocation could impact homing of box turtles, with a distance longer than a few kilometers greatly reducing homing attempts (Dodd Jr. 2002). Since turtles orient their movements primarily based on familiarity with physical landmarks (Dodd Jr. 2002), turtles translocated short distances could exhibit more apparent homing attempts than those translocated 70 km in the Cook 2004 study. Although this study investigated soft-release of turtles held off-site before release, the variability of time in which individuals were held off-site makes it unclear to what effect time spent in captivity really had on movements of translocated turtles. Additionally, it is still unknown how turtles held long-term off-site would respond to a short-distance (about 1 km) translocation from their initial site of capture in comparison to hard-released turtles.

The objective of this study was to evaluate long-term, off-site holding as a variation of soft-release translocation for short-distance translocation of three-toed box turtles (*Terrapene carolina triunguis*). I radiotracked 18 translocated box turtles at Markham Hill, a site undergoing residential development in Fayetteville, Arkansas, USA, to assess movement patterns and behavior. My two treatment groups included hard-release translocation and translocation after long-term holding (> 1 year) at a private off-site holding facility. I hypothesized that hard-released turtles would have a stronger tendency to return to their initial capture locations than turtles held long-term before release, as indicated by distance moved and orientation of movements. Specifically, I predicted that turtles in the hard-release group would average longer daily distances traveled than turtles in the long-term holding group in efforts to return to their initial capture site. Thus, hard-released turtles would need to be repositioned back to the original site of translocation at a higher frequency. I also predicted that the hard-release turtles would exhibit nonrandom orientation in movement directionality back towards their initial capture locations, whereas turtles in the long-term holding group would exhibit random orientation in movement directionality due to having decreased familiarity with their home landscape after being off-site for over one year.

Materials & Methods

Study Site. Markham Hill is a forested area subject to encroaching urbanization in Fayetteville, Arkansas, USA, just west of the University of Arkansas campus (Fig. 1). Planned development along the eastern edge of the property necessitated translocation of resident box turtles to the western side, an area of undeveloped land set aside for conservation. This conservation area is densely wooded, with an overstory composed mostly of ash (*Fraxinus* spp.), cedar (*Cedrus* spp.). elm (*Ulmus* spp.), hickory (*Carya* spp.), and oak (*Quercus* spp.). Invasive Bush Honeysuckle (*Lonicera* spp.) is prevalent in the midstory. Leaf litter, tree limbs, and fallen trees provide refugia for the box turtles. Removal of the invasive honeysuckle is underway on Markham Hill, so many areas in the translocation site contain chopped honeysuckle brush as refugia. The nearby conservation area allowed the turtles to undergo a short-distance translocation, thus remaining in a familiar habitat.

Establishment of Treatments. Box turtles used in this study were divided into two treatment groups: hard-release translocation and long-term holding prior to translocation. Each treatment had a sample size of 9 box turtles, with as close to a 1:1 sex ratio as possible. The long-term holding treatment initially consisted of 8 (4F, 4M) turtles that had been collected from an area of future residential development at Markham Hill between 16 August and 11 November, 2020, and held at a private off-site holding facility for 18 to 21 months prior to my study. The holding facility consisted of a 2 m x 3 m outdoor pen under partial canopy cover in forest ca. 2 km from Markham Hill. These turtles were housed communally, provided water *ad. libitum*, and fed a mixture of vegetable scraps, greens, and seasonal natural foods (mushrooms, persimmons, mulberries, etc.) several times per week between April and October. For the hard-release treatment, I initially collected 8 (4F, 4M) turtles between 26 and 30 April 2022, directly from the area of future residential development and translocated them immediately after processing (< 2 weeks after capture).

One male turtle from the long-term holding treatment group died from injuries following an apparent predator attack after a tracking period of 31 days. It exhibited normal behavior up until its death, so I included the individual in data analyses. I replaced this turtle with another male from the private off-site holding facility. To maintain a balanced sample size between treatment groups, I added a female turtle to the hard-release group. Both new turtles were translocated on 16 June and tracked for the remaining 45 days of the study. Thus, the final sample size of each treatment group was 9 box turtles (5F, 4M hard-release; 4F, 5M long-term holding).

Box Turtle Processing. Each turtle was weighed and given a unique identification code by filing a set of notches in the marginal scutes (Cagle 1939). I affixed a radio transmitter (Holohil Systems Inc., Model RI-2B) with JB Weld Waterweld Epoxy to the left anterior carapace of each turtle so as not to impede mating (Boarman et al. 1998). The weight of the transmitters was no more than 5% of the total body mass of each turtle. If the antenna stuck out from the shell at an angle, I secured it with epoxy to prevent entanglement. I rubbed the white epoxy on the transmitters with dirt prior to release to make them inconspicuous.

Radiotelemetry and Data Collection. Following release, I used a handheld telemetry receiver to track the translocated box turtles for 83 days (May 9 – July 31, 2022) and record their locations. I tracked the turtles daily (weather permitting) from 9 May to 24 June. Activity of the turtles slowed in mid-summer, so for the remainder of the study (24 June to 31 July), I tracked the turtles every 2-3 days. For each GPS coordinate taken, I noted behavior (resting, eating/drinking, active, mating) and recorded visibility as not visible, barely visible (<50%), half visible (~50%), mostly visible (>50%), and fully visible (~100%). Rocks, sticks, brush piles, fallen trees, tree limbs, vines, burrows, and logs were noted as refugia, and I recorded whether turtles were either actively using a refugium, close (< 0.5 m away) to a refugium, or > 0.5 m from any refugia. I identified dominant vegetation at the location to family/genus and measured percent ground cover using the phone application Canopeo (Patrignani and Ochsner 2015).

The site of initial translocation (Fig. 1) was a densely wooded hillside by an ephemeral stream that was dry throughout the study period. There was no midstory, and ground-level vegetation was sparse. Leaf litter and fallen trees were prevalent and often used by the turtles for refugia. This site was 750 - 1000 m from the initial capture locations of turtles in both treatments and similar to their initial capture site and the long-term holding site in habitat structure.

I delineated a perimeter around the initial translocation site (Fig. 1), inside of which to keep all the translocated box turtles. This perimeter included a private property line to the north, a slight buffer from the highway to the west, and a 500 m radius from the initial translocation site for the rest of the area. Turtles that moved past the perimeter were moved back to the site of their original translocation. Thus, the perimeter prevented movements of the turtles back to the construction zone, into the road, or into private property where they could face other dangers such as mowing. Hereafter I will refer to individual tracking locations of box turtles as ‘relocations’ and the event of moving turtles that crossed the boundary back to the initial translocation point as ‘repositioning.’

Data Analyses. I compared the number of reposition events required for turtles in each treatment group using the Student’s t-test. Despite the addition of one turtle to each group halfway through the study, I did not include time in reposition calculations because the total tracking duration was balanced across treatments. I used the ‘adehabitatLT’ package in R (Calenge 2006, R Core Team 2021) to analyze movement paths and calculate the mean linear distance moved per day for each turtle. Since the sex ratio of the nine turtles in each treatment group was as close to 1:1 as possible, I analyzed differences in distance between the sexes using the Student's t-test. There was no statistically significant difference between the sexes in daily movement distances (see below), so sex was not included as a predictor variable in other statistical analyses.

To determine if the turtles in each treatment group exhibited directional movement towards their initial capture location (home), I performed the Rayleigh test of uniformity using the 'CircStats' package in R (Landler et al. 2018, Lund and Agostinelli 2018, R Core Team 2021). For each turtle's final location at the end of the study or when it moved outside of the boundary and needed to be repositioned, I calculated the bearing between the initial translocation point and the final point using 'adehabitatLT' (Calenge 2006, R Core Team 2021). I then corrected this bearing by subtracting it from the bearing between the initial translocation point and the turtle's initial (home) capture location, such that movement directly towards a turtle's 'home' location would have a bearing of 0^{o}. The Rayleigh test gave two results for each treatment group to describe the distribution of their respective bearings plotted on a circle: an $\bar{R}$ value and a p value. The $\bar{R}$ value describes the distribution of points around a circle, where $\bar{R} = 0$ represents data that are evenly distributed around a circle, and $\bar{R} = 1$ represents data that are all oriented along the same bearing. For each treatment group, a significant p value ($\alpha < 0.05$) indicated that the data were directionally oriented towards a specific point, whereas a non-significant p value indicated that the data were not different from a random distribution of bearings. I plotted the bearings on a circle plot for each treatment group using the 'circular' package in R (R Core Team 2021, Lund and Agostinelli 2022). For turtles that were repositioned multiple times, I took the mean bearing of their repositions, yielding one mean bearing per turtle.

I compared behavioral differences between the treatment groups by graphing the proportions of observed behaviors relative to the total number of relocations for each respective group. I determined the change in mass experienced by each turtle over the course of the study by calculating the difference in mass (final minus initial mass) and dividing it by the final mass of each turtle, yielding the percent change over the study period. I conducted a Student's t-test to compare mass changes between treatment groups. Means are presented ± 1 standard error and significance was recognized at $\alpha < 0.05$ for all analyses in this study.

Results

Throughout the 83-day tracking period of the study, I made a total of 716 relocations of the 18 turtles: 370 relocations of the hard-release turtles and 346 relocations of the long-term holding turtles. Turtles in the hard-release treatment needed to be repositioned back to the translocation point 62% more frequently (mean = 11.9 ± 3.2 repositions) than turtles in the long-term holding group (mean = 6.2 ± 1.9 repositions) to keep them within the designated area (Figs. 1 & 2); however, this difference was not statistically significant (Student's t-test; $t_{df=8} = 1.270$; $p = 0.240$). The hard-release turtles moved nearly twice as far per day (mean = 178 ± 18 m) as turtles in the long-term holding group (mean = 99 ± 12 m; Fig. 3). This difference in mean linear distance moved per day between groups was statistically significant (Student's t-test; $t_{df=8} = 3.393$; $p = 0.009$). Males (mean = 134 ± 21 m) and females (mean = 143 ± 20 m) did not differ

(Student’s t-test; $t_{df=8} = -0.391$; $p = 0.706$) in mean linear distance moved per day (Fig. 4).

Examination of movement bearings using the Rayleigh test demonstrated marked differences in movement of turtles between the treatment groups (Fig. 5). Turtles in the hard-release treatment group exhibited directional movements towards their initial capture (home) coordinates, with mean bearings of each turtle near 0º ($\bar{R} = 0.903$; $p < 0.001$). The movements of turtles in the long-term holding group were not directional ($\bar{R} = 0.341$; $p = 0.362$) and were widely distributed relative to their initial capture (home) coordinates.

Box turtles in both groups exhibited very similar proportions of behaviors relative to their respective number of relocations (Fig. 6). The most frequently observed behavior was ‘resting’ for both treatment groups, accounting for about 72% of hard-release and 70% of long-term holding relocations. Roughly 30% of observed behavior in the remaining relocations for both groups were all forms of activity, including mating, moving, eating, and drinking. Throughout this study, I observed the box turtles eating berries, fungi, earthworms, and scavenging a mole *(Scalopus aquaticus)* carcass.

Box turtles in the hard-release (mean percent difference per final mass = -1.4 ± 1.1%) and long-term holding groups (mean percent difference per final mass = -2.4 ± 1.0%) both lost mass, however differences between the groups were not significant (Student’s t-test; $t_{df=7} = 0.600$; $p = 0.567$).

Discussion & Conclusions

In this study, long-term holding of *Terrapene carolina triunguis* at an off-site holding facility prior to translocation had a dramatic influence on movements in comparison to hard-released turtles. Though the individuals in both groups experienced a short-distance translocation relative to their initial capture locations, only the hard-release turtles made consistent homing attempts. The nondirectional movements of turtles subjected to long-term holding indicate that holding box turtles off-site prior to translocation mitigates the issue of homing frequently observed in hard-released turtles. Turtles held long-term also had significantly shorter linear mean daily distances moved than hard-release turtles and tended to need to be repositioned less frequently. Thus, box turtles held long-term before translocation could be less resistant to establishment of a new home range than hard-released turtles.

The high site fidelity of hard-release turtles to their original capture locations and resistance toward establishment of new home ranges observed in this study was consistent with previous hard-release translocation studies of box turtles (Rittenhouse et al. 2007, Refsnider et al. 2012, Harris et al. 2020, Poor et al. 2020). Only one turtle in the hard-release group did not repeatedly move back towards its original capture location. Yet, this individual did still exhibit extremely unidirectional, rapid movements and needed to be repositioned more frequently than any other turtle. Other studies have deemed turtles that exhibit consistently unidirectional and rapid movements in a direction other than towards their observed home range as “transients”, and have suggested that these individuals could play an important role in gene flow or metapopulation dynamics (Kiester et al. 1982, Cook 2004). By the end of the study, just one hard-released turtle had stopped attempting to home and consistently remained near the initial site of translocation. Without consistent repositioning, the rest of the hard-released box turtles would have returned to their home areas where they would be at risk from construction activities. Consequently, hard-release translocation of box turtles a short distance from their original site of capture does not seem to be a practical conservation strategy.

This study indicates that collection of box turtles to hold off-site from a developing landscape not only prevents mortality of turtles during construction activities, but also mitigates homing tendencies observed in hard-released turtles when translocated a short distance from their initial capture locations. However, it is still unclear whether these turtles have successfully established new home ranges. Many studies emphasize the necessity of monitoring translocated box turtles for several years to determine if any site fidelity exhibited after translocation is temporary or a true home range establishment. Yet, empirical studies of box turtle home ranges yield extremely variable results due to parameters used for calculations, habitat variation, or individual turtle differences, complicating our ability to classify home range establishment by comparison to the literature (Cook 2004, Rittenhouse et al. 2007, Refsnider et al. 2012, Habeck et al. 2019).

Reduced homing attempts observed by the long-term holding turtles in this study were similarly observed in penned gopher tortoises in Tuberville et al. (2005) and the long-distance (approximately 70 km) translocation study of both hard- and soft-released box turtles (Cook 2004). Box turtles are known to use their familiarity with physical landmarks and sun-compass orientation for navigation and homing (Dodd Jr. 2002). Therefore, it is possible that long-term holding before short-distance translocation, penning (soft-release), and long-distance translocations all similarly influence the tendency of box turtles to home after translocation by affecting their familiarities with the landscape to which they were translocated. Holding box turtles at an off-site location for approximately 1.5 years in this study may have weakened turtles' ability to recognize familiar landmarks from their initial capture locations compared to the hard-released turtles that moved consistently back towards their capture locations. Penning of gopher tortoises in Tuberville et al. (2005) would have increased their landmark familiarity within and around the pens, perhaps a key factor in discouraging the tortoises from homing. The long-distance translocation study of both hard- and soft-released box turtles placed turtles from both treatment groups in a landscape where they had no familiarity with any landmarks, yielding no significant difference in homing attempts between the hard- and soft-released turtles (Cook 2004). Thus, long-term holding prior to short-distance translocation of box turtles in this study provides a different method to produce results similar to those found in Cook (2004) and Tuberville et al. (2005).

In addition to establishment of home ranges and reduced homing attempts, one study emphasized post-translocation reproductive success as a key factor for evaluating the efficacy of box turtle translocation (Cook 2004). In my study, individuals in both treatment groups were observed mating throughout this study, and three females (2 long-term holding, 1 hard-release) lost substantial mass and were suspected of nesting, which indicates signs of post-translocation reproductive success in both treatment groups. Success of translocation can also be evaluated by changes in mass of the box turtles over the course of the study, where a significantly different change in mass between treatment groups could indicate differences in stress levels induced by different translocation methods. Though most turtles experienced minor decrease in body mass by the end of this study, nesting and water loss during drought conditions (~ 2 months with negligible precipitation) were suspected to be the main contributors. Furthermore, mass loss did not differ significantly between the treatment groups, indicating similar levels of stress across treatments.

Long-term holding of box turtles at an off-site location seems to be a promising strategy for mitigating homing attempts of box turtles in short-distance translocations and protecting turtles from constructive or land-restoration activities. It yielded similar results to the long-distance translocation of box turtles in mitigation of homing (Cook 2004) without the disadvantage of having to move the turtles to an unfamiliar habitat a long distance from their capture locations. Additionally, long-term holding of turtles at existing wildlife facilities is inexpensive and less time-intensive than construction and maintenance of a soft-release enclosure. Long-term holding would also be ideal if the designated translocation site is undergoing intense restoration management, preventing immediate soft-release translocation. However, further investigation of long-term holding as a translocation strategy is necessary. Box turtles should be tracked for at least one year after translocation to investigate if site fidelity exhibited by box turtles is temporary, or if the turtles have actually established novel home ranges. Tracking resident box turtles at the site of translocation to determine home range size would provide a useful standard to compare home ranges of the varying treatments of translocated turtles. Long-term holding and soft-release translocation methods should be compared directly through both short- and long-distance translocation studies to elucidate the most effective method of translocation in various contexts.

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Figures

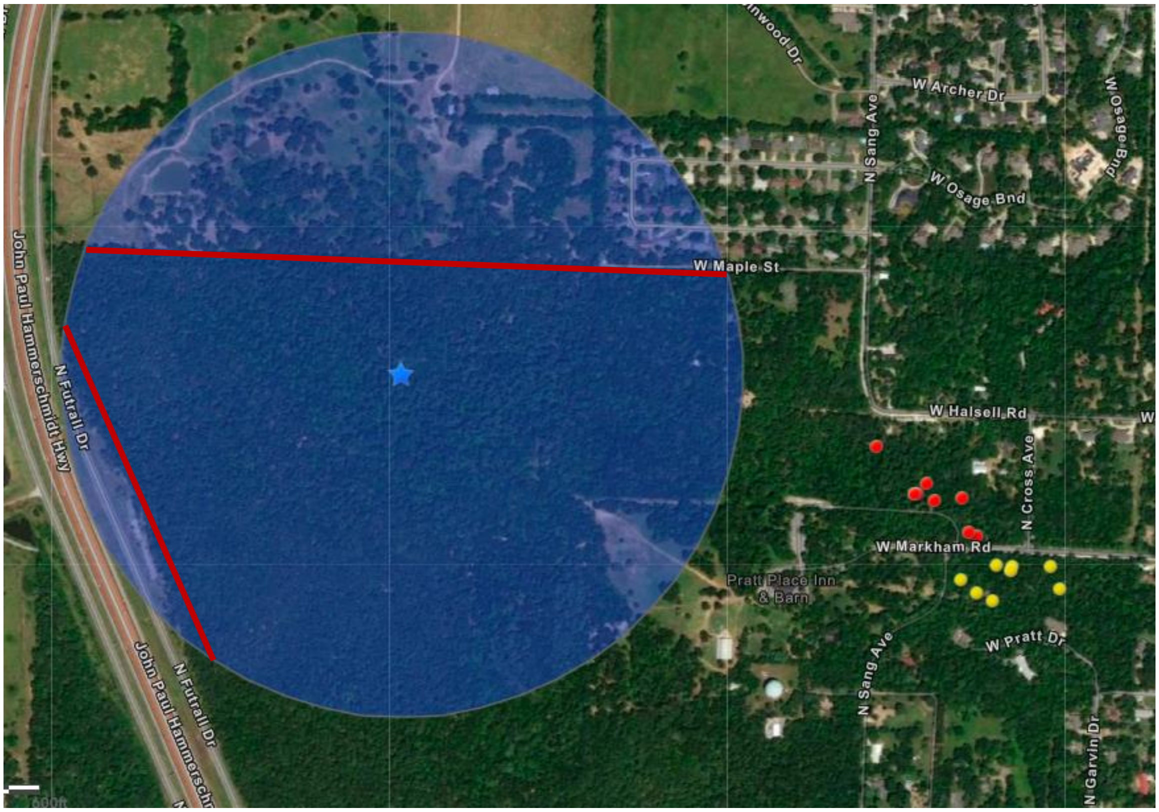

Figure 1. Map of Markham Hill, the study site located in Northwest Arkansas, USA. The red and yellow points on the eastern edge of the property represent the original capture (home) locations of the hard-release and long-term holding three-toed box turtles (*Terrapene carolina triunguis*), respectively. The blue star denotes the site of initial translocation in the conservation area. The perimeter of the translocation area was established by a 500 m radius. Red lines indicate additional boundaries of the perimeter

from a private property line to the north and a highway to the west. Box turtles that moved past the perimeter were repositioned to the site of initial translocation.

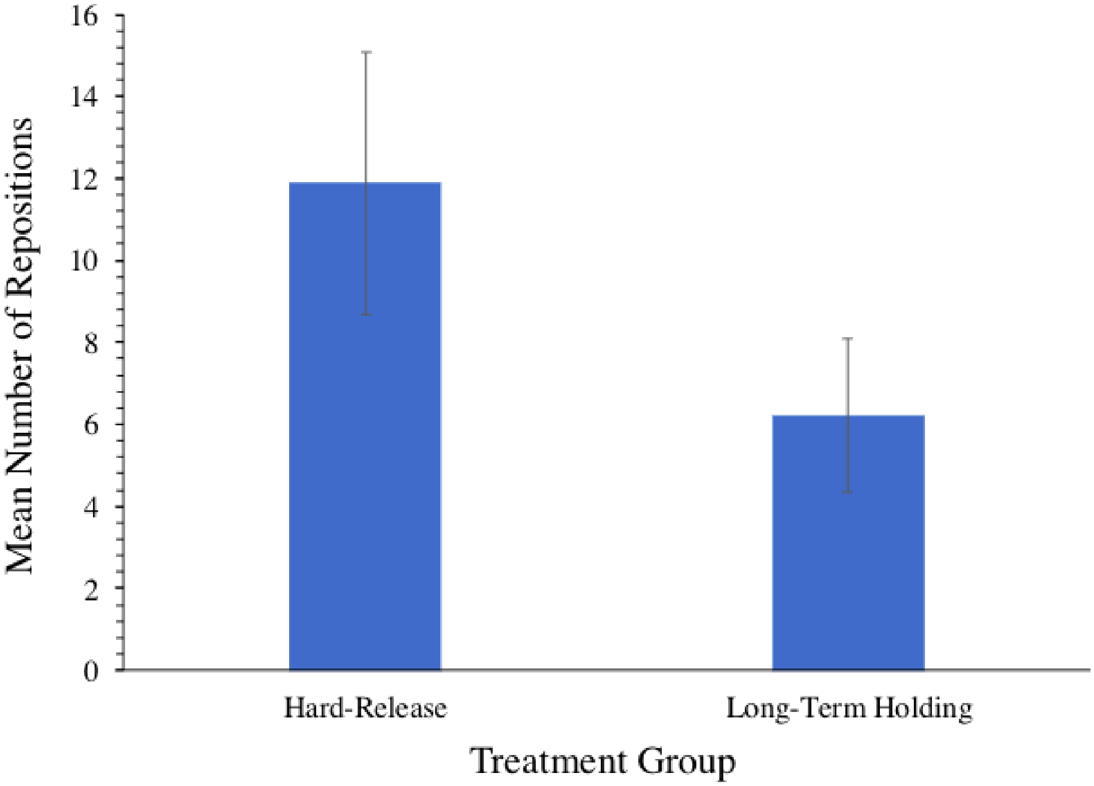

Figure 2. Mean number of repositions required to keep hard-release (Mean = 11.9 ± 3.2 repositions) and long-term holding (Mean = 6.2 ± 1.9 repositions) translocated *Terrapene carolina triunguis* within the designated study site in Fayetteville, Arkansas, USA. Hard-released turtles required a higher frequency of repositions, yet the difference between the groups was statistically insignificant (Student's t-test; $t_{df=8} = 1.270$; $p = 0.240$). Error bars represent ± 1 standard error of the mean.

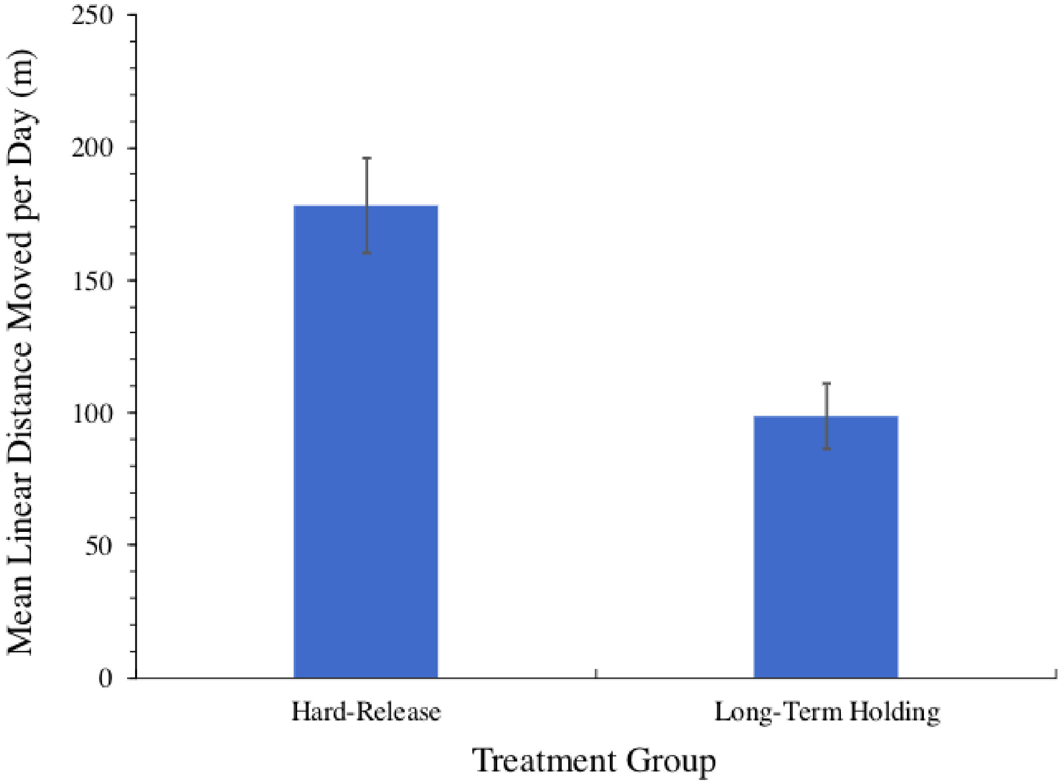

Figure 3. Mean linear distance moved per day (m) by translocated *Terrapene carolina triunguis* in Fayetteville, Arkansas, USA. The difference between hard-release (178 ± 18 m) and long-term holding (99 ± 12 m) treatment groups was statistically significant (Student's t-test; $t_{df=8} = 3.393$; $p = 0.009$). Error bars represent ± 1 standard error of the mean.

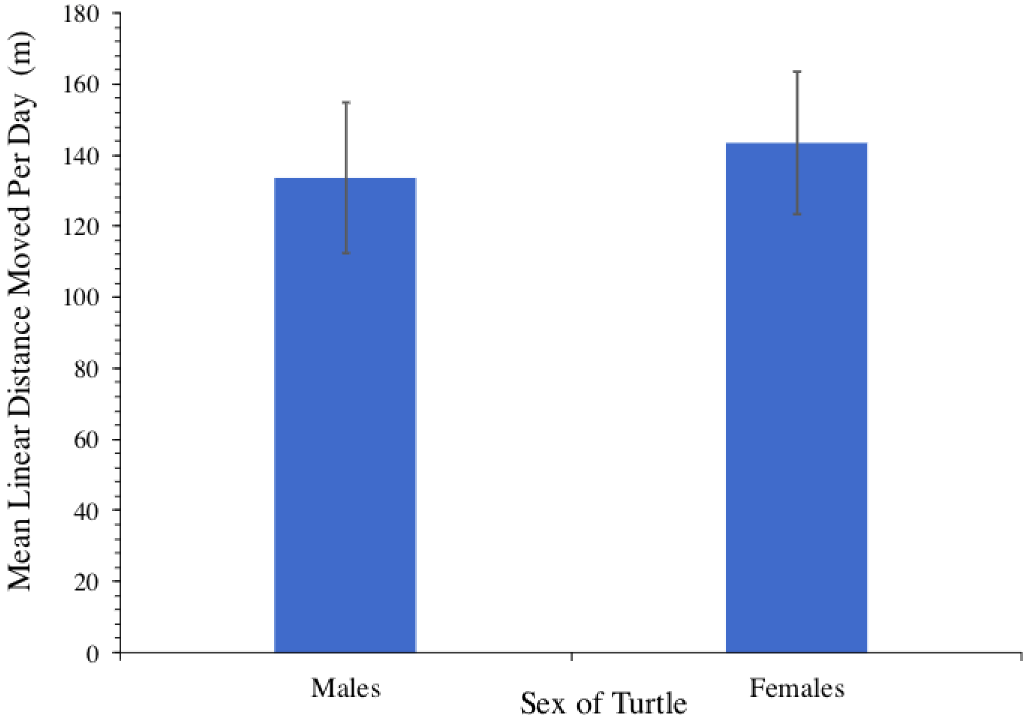

Figure 4. Mean linear distance moved per day (m) by translocated male and female *Terrapene carolina triunguis* in Fayetteville, Arkansas, USA. Males (134 ± 21 m) and females (144 ± 20 m) did not significantly differ (Student's t-test; $t_{df=8} = -0.391$; $p = 0.706$) in mean linear distance moved per day. Error bars represent ± 1 standard error of the mean.

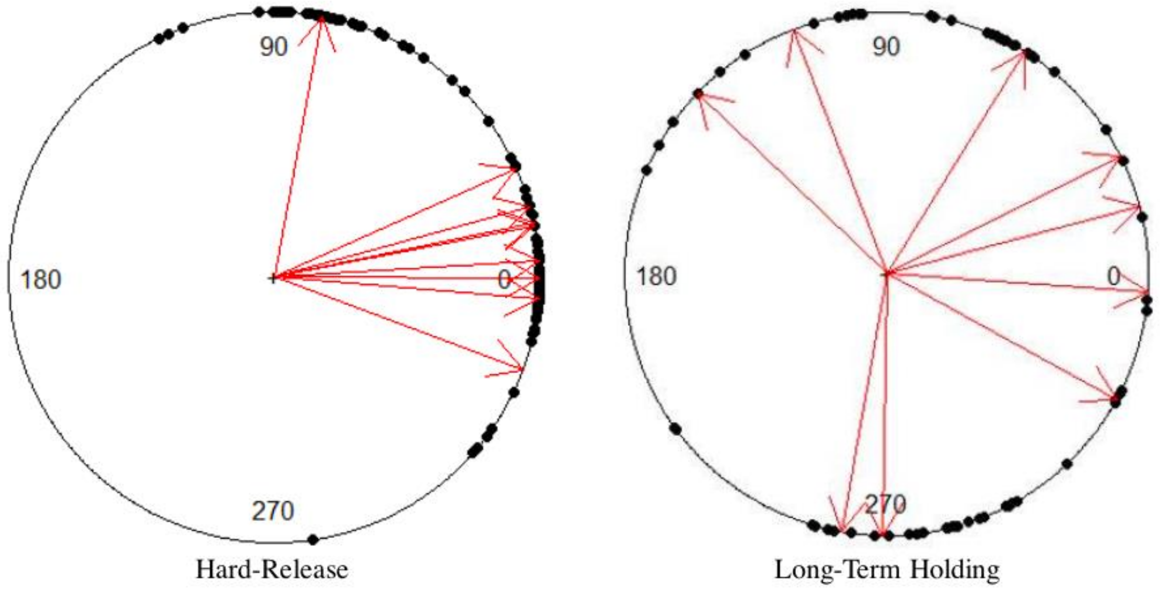

Figure 5. Movement bearings of translocated *Terrapene carolina triunguis* subjected to hard-release and long-term holding, within the study site (Fig. 1) in Fayetteville, Arkansas, USA. Black points indicate the individual repositioning events for all turtles in both groups. Red arrows represent the mean bearing of repositioning for each individual box turtle in each group. The bearings were corrected for each turtle such that their initial capture (home) location would have a bearing of 0º. The hard-release group exhibited extremely directional movements towards their home locations (Rayleigh Test: $\bar{R}$ = 0.903; $p < 0.001$), as indicated by the concentration of points and red arrows near 0º. Movement bearings of turtles in the long-term holding group did not differ significantly from random (Rayleigh Test: $\bar{R}$ = 0.341; $p = 0.362$), as indicted by the even distribution of points and arrows around the plot.

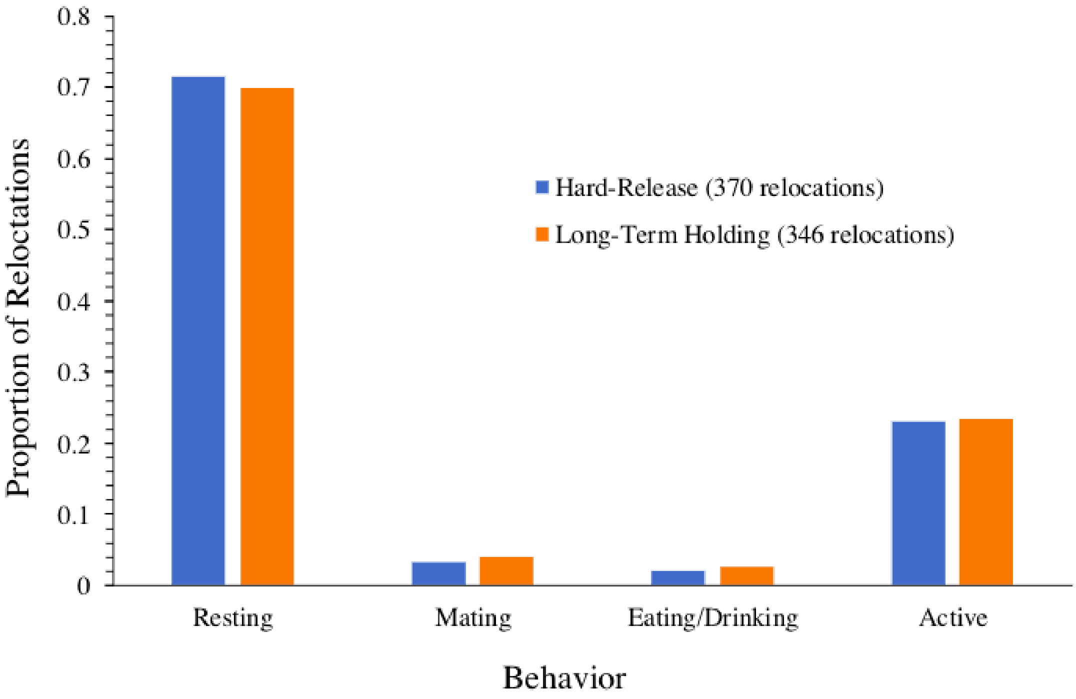

Figure 6. Behavior exhibited by hard-released and long-term holding *Terrapene carolina triunguis* translocated in Fayetteville, Arkansas, USA, relative to their respective number of relocations.