Brookhaven National Lab solar farm development impacts on eastern box turtle home ranges

Ryan Dougherty, Biology, Lafayette College, Easton, PA 18042

Jennifer Higbie, Environmental Protection, Brookhaven National Lab, Upton, NY 11973

ABSTRACT

From 2011 to 2018, the Environmental Protection Division at BNL has collected data on eastern box turtle (*Terrapene carolina*) movement and occupation of a 200-acre solar array built at BNL from 2010-2011. This solar array is divided into six fenced areas, each containing 30cm X 10cm entrance doors located every 24m around the fenced solar arrays to allow movement of terrestrial fauna. Forty-four box turtles were fitted with radio transmitters and their locations were tracked twice per week from June-August from 2011-2018. Seventeen of the turtles home ranges were calculated to overlap with the solar arrays, 7 were adjacent to the solar field (but never entered it), and 17 turtles home ranges never made contact with the solar arrays. Box turtles are known to shift their home ranges due to human disturbances or environmental degradation, so we hypothesized that the implementation of the solar fields would change the home range size and location of turtle that interact with the solar fields. Using the AdehabitatHR and AdehabitatLT packages in R, the minimum convex polygons, kernel utilization distributions, and Brownian Bridge kernel methods were used to calculate the home ranges of each turtle to explore whether or not home range size differed between the three conditions. Eastern box turtles populations have declined drastically since 1970 with the continued destruction and fragmentation of their habitat. Information on whether or not these turtles are impacted by the solar arrays and can subsist within these solar arrays is important. These results could lead to modifications of the solar farm habitat to increase turtle utilization of the solar array habitat.

I. INTRODUCTION

According to the IPCC Special Report Global Warming of 1.5°C (2018) [1], the world has only eleven years to drastically change its energy infrastructure and reduce global emissions to prevent the impending climate crisis. Solar energy will provide a large portion of the energy infrastructure needed to replace fossil fuels, natural gas, coal and nuclear energy (Edenhofer 2011). With the federal government lagging behind in its obligation to veer away from fossil fuel energy, individual states and cities have taken the responsibility to enact changes to their energy infrastructure. States such as New York have made solar energy a key part of its climate action plan with plans for solar energy to provide 6,000 MW by 2025 [2].

Although implementing renewable energy infrastructure will inevitably aid the world's ecosystems by preventing droughts, catastrophic floods, and ecosystem collapse (Cameron et al, 2012), it is also important to note the environmental harm these solar fields can cause to impacted and surrounding ecosystems. Land cover change due to solar infrastructure construction is garnering more attention over its impacts on local biodiversity (Hernandez et al, 2015, Lovich 2011). Land suitable for solar fields, such as deciduous forests or deserts, is often home to rare species or biota that perform important ecosystem functions. In 2009, one million acres of the Mojave Desert was set aside for solar field construction. This caused major conflicts with conservation groups intending to protect rare species such as the Agassiz's desert tortoise and fringe-toed lizard [3] (Lovich 2011), which are considered vulnerable and endangered respectively [4]. This project was ultimately cast aside in favor of wildlife conservation. However, there were other solar projects in California that were approved including the Ivanpah Solar Electric Generating System, which is located less than 10 miles from the Mojave National Preserve. The environmental impact assessment of the project concluded that there would be significant impacts to the Mojave Desert tortoise population and other vulnerable biota in the area [5].

The construction of the Long Island Solar Farm (LISF) at Brookhaven National Laboratory (BNL), NY, is an example of attempts made to balance the need for wildlife conservation while also providing much needed renewable energy infrastructure to the area. LISF is a 32-megawatt solar photovoltaic power plant that began delivering power to Long Island, NY in November 2011. It is currently the largest solar farm on the east coast (LISF WEBSITE). It is divided into six fenced areas, each containing 30cm X 10cm entrance doors located every 24m around the fenced solar arrays to allow movement of terrestrial fauna. There were approximately 45 acres of grassland and farms and 150 acres of trees, mostly pitch and white pine, displaced by the solar fields. The original plan was for the trees to be removed and understory brush and grasses to remain. Unfortunately, mulch was spread over the understory (ericaceous plants, blueberry bushes), which mostly killed off the remaining biodiversity in the solar fields. Regardless of the preservation measures put in place, the white pine, spruce, pitch pine, oak, and maple forest is a much different environment than the solar fields which replaced it. Although biota-friendly measures were implemented to minimize environmental impacts, biodiversity was reduced from the area, and local biota lost roughly 195 ha of quality habitat. Food availability, plant composition, biodiversity, predator makeup, microclimate shifts due to machinery, and wildlife mortality can be affected by solar arrays [5] (Hernandez, 2014). Given that local and federal regulations and policies have advocated against solar development in the built environment in the United States, it is likely that new solar developments will take place on natural land cover such as scrubland, shrubland and herbaceous environments. (Hernandez 2015). If this is the case, it is more important than ever to assess the potential impacts that renewable energy development will have on flora and fauna.

To broadly measure the effects LISF would inflict on biota on BNL property, eastern box turtles (*Terrapene carolina)* native to the area were outfitted with radio transmitters, and their home ranges were monitored from June 2011 to August 2018. Eastern box turtles are a popular species used in radio telemetry studies due to their low mobility, which makes home range area estimation easier and more accurate (Habeck, 2019). Therefore, eastern box turtles are great models for movement ecology. Additionally, the IUCN lists eastern box turtles as vulnerable with a decreasing population trend [4]. Much of this population decline is due to vehicle related mortality, urbanization, habitat fragmentation, ranavirus infection, and illegal pet trading (Allender et al. 2006; Allender et al. 2011; Ferronato 2015, Kornilev 2006). This makes them an important species to monitor in relation to any construction that would negatively impact their native habitat.

Given the grass and forest habitat displaced by the solar fields, our objectives were: (1) to find out if the solar fields affect box turtle movement and home range size, (2) to estimate home range size of each turtle per year of tracking, and (3) determine if home range sizes differ between turtles who live in and around the solar field versus those that have had to interaction with the solar fields.

II. METHODS

A. Fieldwork

This study was conducted at Brookhaven National Laboratory located in Upton, Long Island, New York. TALK ABOUT THE VEGETATION AROUND THE CAMPUS AND IN THE SOLAR FIELDS. From 2011 to 2017, 44 eastern box turtles were outfitted with radio transmitters and given unique notch codes with v-notches filed into the marginal scutes (Cagle, 1939). Radio transmitters were glued to the vertebral scutes of each turtle's carapace with epoxy glue and were replaced every two to three years depending on battery life. Each coded transmitter emits a different frequency with which individuals were identified, and their precise location was tracked. Unless a turtle was found deceased, or the transmitter stopped working, each turtle was tracked twice per week with a handheld Garmin 64s GPS until the end of November 2017. From 2015 to 2017, 8 of the 44 turtles were chosen to be tracked twice per day (Monday to Friday) using the same methods. Transmitter data was recorded in 2018, but was withheld from home range estimation due to small sample size. During each turtle's tracking session the date, time, and GPS location (UTM with accuracy of ± 3m) were recorded.

B. Data analysis

Turtles were divided into three condition groups based on their relation to the solar fields: [1] turtles whose home range intersected the solar fields (SF, n=17), [2] turtles whose home range laid adjacent to any of the solar fields without actually entering them (AD, n=7), and [3] turtles who had no interaction with the solar fields (NOSF, n=17). AD turtles were classified as a separate group because their home ranges laid directly adjacent to one or more LISF fenced areas. On many occasions, the turtles were located within 5 m of the fence. Even though these turtles were not seen to have entered LISF, their movement was clearly impacted by its presence, and so each turtle which did not enter LISF, but was located within 10m of the fence at least once was classified as AD.

Three turtles were omitted from home range analysis due to missing data, the occurrence of extreme outliers, and each turtle only had one years worth of data (Notch ID: 1R2L12R, 4R2L8R, 4R2L9R). Home range analyses were not tested against box turtle sex because a disproportionate number of turtles used in the study were females (39 female, 5 male). According to previous research, home range does not appear to be affected by sex since many studies have presented females to have slightly larger home ranges while other studies showed the opposite (BOOK KD). Straight-line distances were measured between the original location each turtle was found and its final transmitted location to assess the overall shift of home ranges between the three groups.

The data were analyzed with the program R using the package adehabitatHR (R Core Team 2014, C. Calenge 2006) and ArcGIS. Minimum Convex Polygons (MCP) and kernel utilization distribution ($K_{95\%}$) models at the 95% isopleth were used to compute the area within each turtle's home range. The $K_{95\%}$ uses a bivariate probability density function to give the probability density to relocate the animal at any place according to the coordinates of this place, in this case UTM (ADEHABITATHR, Calenge 2019). MCP was used in addition to $K_{95\%}$ because it is the most commonly used home range estimator for box turtles (Henriquez 2017, Habeck 2019) Only the eight turtles that were tracked twice per day in 2015-2017 were analyzed with the Brownian Bridge kernel ($BB_{95\%}$) method. This was done to standardize the time lapse between turtle relocations. Since the $BB_{95\%}$ method incorporates time dependence, and the path traveled, between successive relocations (ADEHR), it was designed to analyze regular - time lapses are standardized between location tracking - autocorrelated locations (Butterfield 2019). Therefore having large irregular time lapses would render the method less effective. Each of the eight turtles tracking seasons begins in early June and ends in mid November from 2015-2017. The average number of relocations in was: (n=71.71). Data was removed for turtles monitored twice per day if the number of days between monitoring turtle locations exceeded 8 (due to bad weather events, or lag between the end of fall and start of spring the following year), or if locations were repeated in the winter due to overwintering.

In an effort to determine if the solar fields degraded turtle habitat enough for them to relocate their home range, the MCP centroid was calculated for every year a turtle was tracked for each turtle with more than three years worth of tracking data. The centroid is the central coordinate of an MCP. They were calculated using ArcGIS. The distance between centroids of consecutive tracking years was then summed. Given that many turtles were not tracked through 2018, because of death or lost trackers, the calculation was standardized to four consecutive years of distance between centroids. Data was taken from turtles tracked between 2013-2018; 2013 and 2018 data were only used if turtles were not monitored from 2014-2017.

C. Statistical analysis

The question of normality was assessed with the ggformula package, and the Shapiro-Wilkes test from the stats package in R (R Core Team) (R Core Team, 2014). Both MCP and $K_{95\%}$ home range data was not normally distributed. In order adhere to the rule of independence, each turtle's home range area was averaged by the number of years it had been tracked. Since the area of one year's home range data would inform the following years home range data then treating each year as an individual point would break the rule of independence. We tested the null hypothesis that there was no difference between home range sizes among the three conditions with Asymptotic K-Sample Fisher-Pitman Permutation Tests using the coin package (R Core Team 2014). This test was used to compare the three groups MCP and $K_{95\%}$ estimated home ranges. Given the larger sample size of SF and

NOSF, asymptotic K-Sample Fisher-Pitman Permutation Tests were performed solely between the two groups as well.

The final distance in meters between each eastern box turtles first ever location and their final tracked location was measured as a way to compare distance traveled between the three conditions. Final distance was determined to be normally distributed with a qq-plot using the ggformula package in R (R core team 2014). Mean summed-centroid distance between the three conditions was normally distributed and tested with a one-way ANOVA.

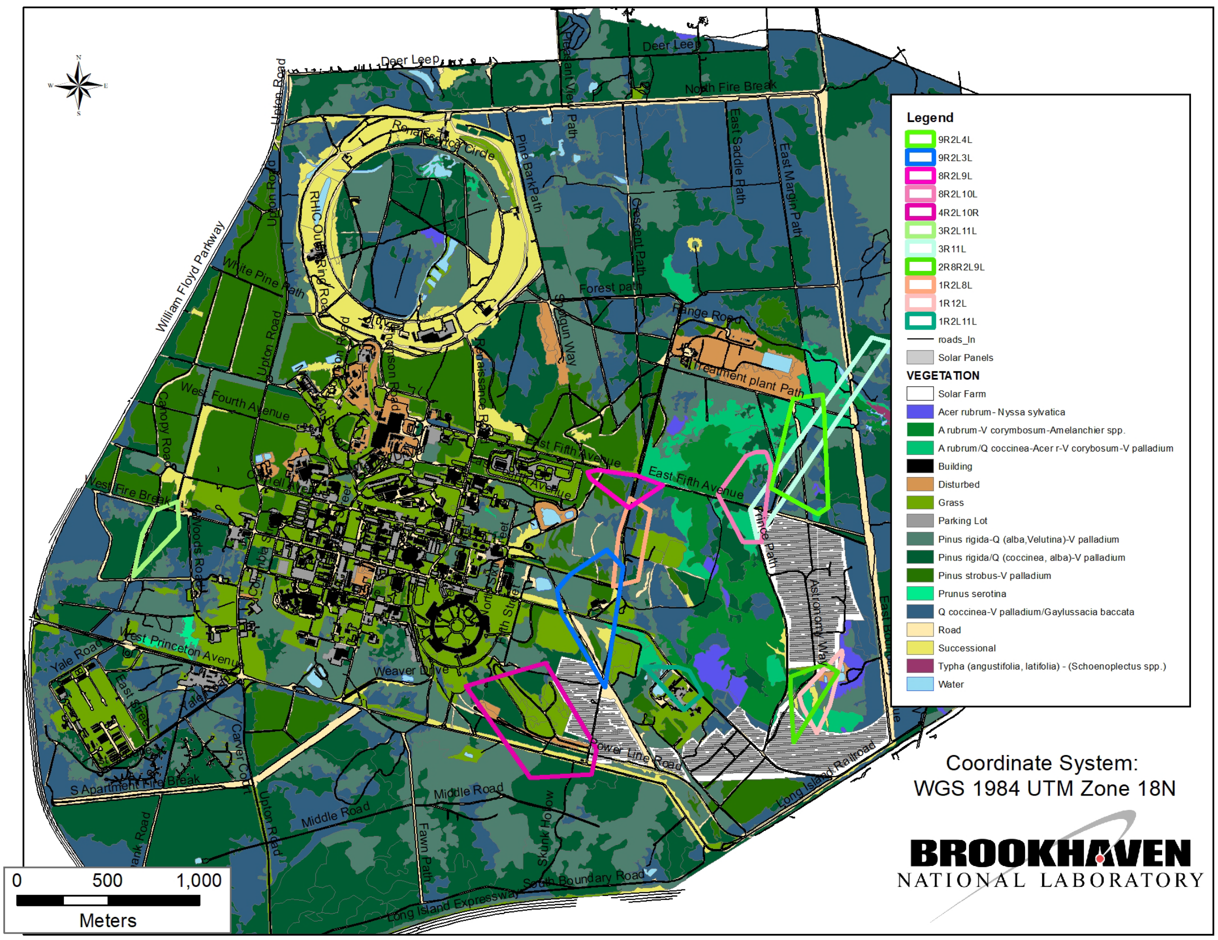

Figure 1. Map of Brookhaven National Laboratory. Colors differentiate vegetation type, and colored outlined polygons are 95% minimum convex polygons for each eastern box turtle monitored in 2012.

III. RESULTS

An alpha level of 0.05 was used for all statistical tests. The Shapiro-Wilkes test for normality provided significant results, thus concluding the home range area data was not normally distributed (MCP: W = 0.82356, p-value = 1.786e-05; $K_{95\%}$: = 0.53042, p-value = 2.887e-10). With the use of the MCP and $K_{95\%}$ estimates, the mean home range area of SF turtles was similar to that of AD and NOSF (MCP: chi-squared = 3.4485, df = 2, p-value =

0.1783; $K_{95\%}$: chi-squared = 2.0383, df = 2, p-value = 0.3609). Additionally, the difference in home range area was not significant between SF and NOSF (MCP: Z = -1.7094, p-value = 0.08737; $K_{95\%}$: Z = -1.3941, p-value = 0.1633). Refer to Table 1 for mean (± SD) home range area of each condition using MCP and $K_{95\%}$ estimators.

TABLE I. Mean (+ standard deviation) home ranges of *Terrapene carolina* for each home range condition calculated using 95% minimum convex polygon (MCP) and 95% kernel utilization distribution ($K_{95\%}$) estimators.

Location	n	MCP (ha)	$K_{95\%}$ (ha)
Solar fields	17	7.41 ± 5.53	7.62 ± 10.90
Adjacent	7	4.70 ± 4.57	6.22 ± 7.78
No solar field interaction	17	4.60 ± 3.54	3.77 ± 2.73

Due to the small sample size (n=8) of turtles whose home range could accurately be measured with the $BB_{95\%}$ estimator, no statistical analysis was conducted on the three groups. However, among the eight turtles located twice per day from 2015-2017, the five SF turtles had an average home range of 5.13 ha, NOSF turtles averaged 4.64 ha, and the AD turtle had a 3.06 ha home range (Table 2). Calenge et al. 2009 describes two classes of trajectory research: type I and type II. Type I does not take time into account while type II does. This study is classified as a type II irregular study which are characterized by a variable time lag between successive relocations. Calenge notes that regular time lapses between successive relocations are easier to analyze, so in the future, it would be beneficial to conduct a regular type II study of eastern box turtles in the solar fields. This way we could more accurately assess the amount of time they spent in the solar fields and perform stronger habitat selection analysis.

The results of a one-way ANOVA indicated a significant difference between SF, AD, and NOSF turtle's final distances ($F = 3.391$, $p < 0.05$). SF turtles (n=18) had a mean distance of 567 m, AD (n=7) turtles mean final distance was 283 m, and NOSF (n=19) turtles mean final distance was 267 m. Figure 1 displays a boxplot comparing the median, Q1, Q3, and interquartile ranges between the three home range conditions.

TABLE II. Mean (+ standard deviation) home ranges of *Terrapene carolina* for each home range condition calculated using 95% Brownian bridge ($BB_{95\%}$) estimators.

Location	n	Mean + standard deviation (ha)
Solar fields	5	5.13 ±1.08
Adjacent	1	3.06
No solar field interaction	2	4.64 ±2.88

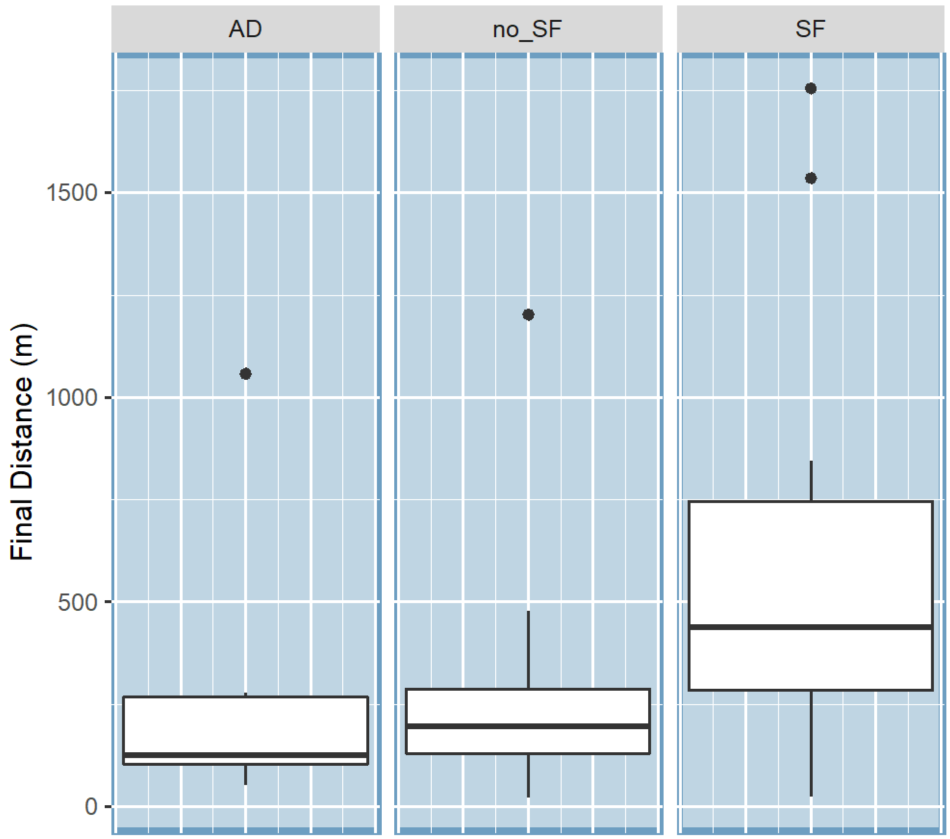

Figure 2. Final distance boxplot between three eastern box turtle groups. Distance measured between first tracking location and final tracking location.

TABLE III. Mean sum of distance between minimum convex polygon centroids. Each group's sum was calculated by adding the distance between centroids for four consecutive years per eastern box turtle.

Location	n	Mean + standard deviation (m)
Solar fields	10	323.88 ± 184.75
Adjacent	3	201.47 ± 91.37
No solar field interaction	9	258.81 ± 157.13

The mean-summed distance was found to be similar between SF, AD and NOSF turtles. There was no significant difference in the summed centroid distances over four years between the three groups ($F(2, 19) = 0.761$, $P= 0.481$).

IV. DISCUSSION

It was hypothesized that the solar farm development would have an impact on the home range area of eastern box turtles due to the displacement of vital habitat by LISF. There were no statistically significant data to back this claim, but given the general trend, which can be seen in Table 2., it would be beneficial to conduct this study again with a larger sample size. Although a p-value of .087, comparing the mean MCPs between SF and

NOSF turtles, is not statistically significant, it points to evidence that home range size was affected by LISF. The average home range area was larger for SF turtles than both AD and NOSF turtles measured with MCP, $K_{95\%}$ and $BB_{95\%}$ estimators. Another indicator that eastern box turtle home range was altered by LISF implementation is the significant final distance results between SF, NOSF and AD turtles. Figure 1 displays the disparity between box turtles with home ranges intersecting LISF, and AD + NOSF box turtles. These data indicate that over the 8 years of monitoring, SF turtles have gradually been shifting their home range.

Since the AD group consisted of only 7 turtles overall conclusions will not be made about these results. However, It would be interesting to conduct a study on turtles in and around LISF to see which gates they use to traverse the fence. The 24m gaps between gates may not be adequate entrance space for the turtles. AD turtles potentially never walked along the fence far enough to find a gate, and if they can't find a gate, their home range may be restricted by the fence, thus decreasing home range area.

Given the lack of solar farm facilities in the northeast, this is one of the first studies measuring the wildlife impacts on native species. As of today, due to its status as a keystone species, the Agassiz's desert tortoise has been studied the most in regards to solar farm impacts on the species and its habitat (Lovich 2011). Current research indicates that the largest impacts of utility scale solar developments on desert tortoises are habitat fragmentation by roads, habitat loss and direct mortality, all of which are linked to population declines (Lovich 2011). There are many factors that have been documented to affect home range size in turtles including protection from the elements, food access, certain precipitation levels, available nesting sites, and proximity to other individuals (Donaldson and Echternacht 2005, Kenneth Dodd book). When eastern box turtles habitat is lacking some of these factors, or is disturbed, they are known to expand their home range area and travel further than individuals with a stable environment (Hestor 2019, Farnsworth, 2013, Habeck 2019). This behavior has also been seen in other turtle species (Tuberville 2005). Hestor et al. (2019) found a link between home range size and mortality in translocated eastern box turtles. This could potentially be due to an inability to find food resources in a new environment, stress, and augmented energy exertion.

Direct mortality is a huge problem for utility scale solar developments. Unless they are relocated, tortoises and turtles can be crushed when areas are graded (Wildlife defenders). In a study analyzing the effects of eastern box turtle relocation from an active construction site, two turtles were killed by machinery, one was buried by road construction, and one was hit by a vehicle (Farnsworth, 2013). In fact, within this study, two turtles were lost due to BNL maintenance work not associated with LISF. Their transmitter signal was near a construction site, and it was assumed that the turtles were crushed or buried by earth moving equipment. Unfortunately, research has indicated that turtle relocation is not a completely viable solution to the construction problem. Relocating turtles has been shown to increase turtle home range size, average distance traveled, and mortality rate (Hester 2019, Farnsworth, 2013).

As solar power becomes more popular on the east coast, it is imperative that developers make decisions with wildlife conservation as a main concern. Large swaths of deciduous forest should be a last resort for new development not only because forests provide vital habitat for vulnerable populations like amphibians and reptiles, but also because of the immediate carbon sequestration and biomass loss caused by deforestation. (Schulp, 2008). There are less ecologically deleterious options such as manipulating the built environment. For example, as of 2005, there were 15 million square meters of solar water heater panels in households in western China (Yao 2005). Additionally, the photovoltaic electricity production potential is massive within city and suburban rooftops, and only a fraction of potential city wide photovoltaic capacity has been reached in most cities (Kouhestani, 2019). Taking advantage of unused space in the built environment for solar development will protect vulnerable species like the eastern box turtle and Agassiz's desert tortoise form further harm. Given that solar power is meant to be a sustainable alternative to protect the planet from long-term ecological destruction, the short-term impacts of its implementation should also be considered.

Their home range may or may not contain their nesting site or overwintering sites (Kenneth Dodd book).

Since turtles are known to wonder outside of their home range for reasons relating to overwintering, mating, nesting, and relocation due to habitat degradation, it is not surprising that our data was not normally distributed. talk about autocorrelation if it applies.

In the future, we will go out and measure the biodiversity and food availability in each fenced area in the solar farm to determine food resource availability for the turtles.

MCP and Kernels: Neither the MCP nor K95% home range areas were significantly different between the AD, SF, and NOSF box turtles. However, given that the SF turtles were significantly further from their original location than both AD and NOSF turtles, there is a trend which points to the fact that the solar fields were not adequate habitat for the box turtles.

In between tracking seasons, turtle 9R2L4L traveled more than 1000m from her last recorded location from December 2017 and June 2018. Given that female eastern box turtles often travel outside their home range in search of adequate nesting sites, it is likely that this excursion is not part of her normal home range. Females have been documented to nest up to 774m away from their typical home range (Stickel, 1950, FROM KD). Therefore, data from 2018 was removed.

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