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Modeling Home Ranges of Turks Island Boas (*Chilabothrus chrysogaster*) on Big Ambergris Cay, Turks and Caicos Islands Using Three Mathematical Models

Keeley Peek
Biology Department
The University of North Carolina Asheville
One University Heights
Asheville, North Carolina 28804 USA

Faculty Advisor: Dr. R. Graham Reynolds

Abstract

Radio telemetry has been used in many species of snakes to estimate and describe spatial ecology, resource use, and behavioral patterns. These data are especially useful in the study of endangered species such as the Turks Island Boa (*Chilabothrus chrysogaster*). The Turks Island Boa is found throughout the Turks and Caicos Islands (TCI), but in exceptional densities on Big Ambergris Cay, TCI. This island is undergoing increasing amounts of development that is causing concern for several endangered terrestrial reptile species whose last refuge was this island prior to development. Very little is known about habitat use in most members of the genus *Chilabothrus*, and hence designing conservation strategies in the face of development can be challenging if simple natural history information, such as home range sizes (the use of space by an animal during normal annual activity), are not known. To help increase the effectiveness of ongoing conservation efforts, two cohorts of boas were implanted with radio-emitting tags and tracked intermittently over the course of two years. Space use and home ranges were calculated from GPS locations obtained during tracking sessions using Kernel Density Estimation, Multi Convex Polygons, and Brownian Bridge Movement Models. Each of these models has differing assumptions, and recent papers have called out researchers for not being explicit about why specific models were chosen, or for excluding relevant details about the models that would increase repeatability of the projects. All three models were evaluated, and compared to see whether similar estimates for spatially-relevant data, such as home ranges, can be inferred from all models. Multi Convex Polygons produced the lowest home range estimates compared to Kernel Densities and Brownian Bridge models. The majority of Brownian Bridge home range and space use estimates were slightly larger than Kernel Density estimates. Averages of all estimated models for home ranges and space use were higher in Cohort A than in Cohort B. By using all three models, a more comprehensive and accurate representation of home ranges and space use can be created, as it is apparent that each model produces different estimates of these measures.

1. Introduction

The use of spatial ecology in conservation research not only allows characterization of spatial habitat use, but can also provide descriptive measurements of species' population size, population health, conservation status, and/or demographic dynamics[1]. For example changes in habitat can produce negative impacts on the fitness and survival rates of species that depend on specific aspects of their environment[2]. Negative factors such as development and associated habitat loss, as well as damaging non-native species introductions, are causing native herpetofauna in the West Indies to face increasingly concerning threats[3]. Nevertheless, the opportunity exists to mitigate threats such that they would have a lesser effect owing to conservation intervention.

A study observing the endangered Eastern Indigo snake (*Drymarchon couperi*) used radio tracking as a vital tool to determine the result of habitat fragmentation on survival[4]. Found in Florida, this species faces an increase in habitat loss due to human interaction and development which has led to the species decline. With a sample size of 103 snakes, this study implanted each snake with an SB-2 tracker and obtained location fixes for each snake on a weekly basis for periods longer than one year. The habitat types were classified based on the amount of roads and houses were present. Snakes that were found to be underground for an extended period of time and close to roads or houses were considered to be dead or excluded from the study. Multistage analysis was performed which included variables such as health state, seasonality, and observational data to determine survival probability. Candidate models were made to compare the interactions between sex, landscape and season. It was found that the probability of survival was highest in the areas with fewer roads and less human interference and decreased with increasing habitat fragmentation. It was also found that a large portion of snake mortalities were caused by roadstrikes. This study shows that habitat fragmentation decreases the survival rate of these snakes, largely due to human interaction. This cause and effect relationship supports the need for protected areas and low impact zones of habitat, especially for endangered species. The size of each home range can also be influenced by sex; males were found to have a larger home range, and body size, larger size leading to larger ranges[5].

An arboreal snake in Australia, Stephen's White Banded Snake (*Hoplocephalus stephensii*), shows behavior that elevated their need for a specific habitat type[6]. As a threatened species, obtaining spatial ecology data was important for further conservation methods. This study consisted of 16 individuals that were implanted with small transmitters due to the small size of the species and recorded for 25 months. Visibility was difficult during tracking so triangulation was used to obtain fixes. Home ranges were calculated based on the number of observations during the active season of each individual which varied between subjects. It was found that this species sheltered in tree hollows and avoided sheltering in the same tree with a conspecific despite the overlap in travel ranges. Spring, summer and fall made up the active seasons in which the snakes were tracked. While some snakes were observed in terrestrial habitats, they were more often in the arboreal forest and moved less often when they were in trees. Multi Convex Polygons were used to determine home range size in the 95% confidence range. It was found that the home range was a mean of 11 hectares while males had a significantly larger home range than females. There was overlap between individual home ranges but snakes in overlapping ranges stayed far away from each other. This study shows that this species relies on forested areas with tree hollows and arboreal habitat, but has overlapping home ranges with conspecific avoidance. While these snakes avoid each other, there is not enough room for them to spread far enough apart to not have overlapping home ranges. This suggests that habitat loss is forcing this species to cohabitate an area that is smaller than their natural range.

GPS technology has proven to be a useful tool in determining behavioral and spatial details of many species[7]. The spread of large Burmese pythons (*Python bivittatus*) throughout Florida has spurred management efforts to understand and control the growth of this invasive species. In this study, GPS technology was used instead of VHF telemetry which had limited data fix information and time constraints. The GPS tags could give pings every 90 minutes and did not require visualizations, which are difficult due to effective camouflage of the pythons. The size and invasive nature of this species made them an ideal candidate to test GPS data effectiveness. Each snake was also fitted with a VHF tag as well as the GPS tag for monitoring purposes. Subjects were tracked in the wet and dry seasons with the data being stored in each GPS tag. Of 10 individuals recaptured in the study, only five had data that could be obtained and only four had a complete dataset. It was found that the GPS tags had a higher accuracy and precision rate than VHF tags, and also produced more fixes than the VHF tags. However, the study recognized the rate of success was very low in this experiment and should be improved upon, plus the high cost of GPS tags could preclude many studies from using them. The combination of GPS and VHF data provided better understanding of location and resources use based on vegetation than VHF or GPS data alone. While visualization is time consuming, it is useful in taking data and making sure the subject is accounted for. As technology advances and GPS tags get smaller (and less expensive), this technique could be applied to a wider variety of species and bring in more detailed data. An additional study used the VHF data of this cohort to make Multi Convex Polygons and Kernel Densities to estimate home ranges and found overlapping areas[8].

Radio Tracking has a variety of attachment methods, some more invasive than others, that result in the production of accurate fixes and home range estimates[9]. The ability to find and observe a set of individuals for an extended period can establish the findings of new behavioral patterns that lead to the better understanding of habitat use and foraging[10]. With each set of data collected on each specific species, the best conservation methods and directions can be determined individually, making decisions on conservation methods easier[11].

The Lucayan Archipelago, a ~1,000 km long series of carbonate islands extending from 20.8 degrees to 27.5 degrees latitude, is politically divided into the Commonwealth of the Bahamas and the Turks and Caicos Islands (a British Overseas Territory). The Turks and Caicos are a series of seven larger islands and several hundred smaller cays and rocky islets distributed across two shallow carbonate banks at the southeastern terminus of the Lucayan Archipelago. These islands are home to several endangered terrestrial reptile species including the Turks Island Boa (*Chilabothrus chrysogaster*; Fig. 1) and the Turks Island Rock Iguana (*Cyclura carinata*). Since the 1960s this region has become an increasingly popular tourist destination and development of the islands has surged. The attention has increased development of many of the islands comprising the country including some of the smaller privately owned islands such as Big Ambergris Cay. This Cay is the last stronghold of the Turks Island Boas and is an ideal place to study them for several reasons. There have been no introduced predatory species, such as cats or rats, that have been allowed to persist on the island, and the island has the highest known density of this species, with over 12 boas per hectare[3,12]. While the island is privately owned, it has been intensively developed since 2004, has the largest private air strip in the entire Caribbean, two restaurants, tennis courts, and a marina that has been built beside formerly natural salina salt flats (Fig. 2).

Although Turks Island Boas have been extensively and intensively studied for over 10 years, very little is known of their use of habitats in areas where they occur, what their home ranges are, and how much they move seasonally[3,12,13]. This becomes especially important as habitat on big Ambergris Cay is cleared for development. To understand the extent development and human influence have on the Turks Island Boas on Big Ambergris Cay, more detailed population biology of the species needs to be characterized. From focal studies of individuals and using radiotelemetry, a more comprehensive view of the species' population and resource needs can be determined. Radiotelemetry can be used to measure seasonal and space use per individual and with multiple individuals make estimates on home ranges. Home range analyses are commonly measured through Kernel Density Estimates (KUDs) and Multiple Convex Polygons (MCPSs). These analyses were recently found to have stronger error margins and lower dependability in accurately measuring space use and home range in reptiles[14]. By using both Kernel Density Estimates, Multiple Convex polygons and Brownian Bridge Movement Methods, a more comprehensive measurement of the spatial ecology of boas can be made. A comparison between analyses can also be conducted to observe how different the estimates from the methods really are.

Through a two cohort, multi-season, multi-year study, the spatial ecology of the Turks Island Boa on Big Ambergris Cay can be measured and valuable data can be added to the understanding of this endangered species. Through radiotelemetry and new movement measurement methods, the impact that development and human influence has had can be more accurately described and can lead to more effective conservation methods.

Figure 1. Turks Island Boa (*Chilabothrus chrysogaster*) female (B23) sunning in a rock pile.

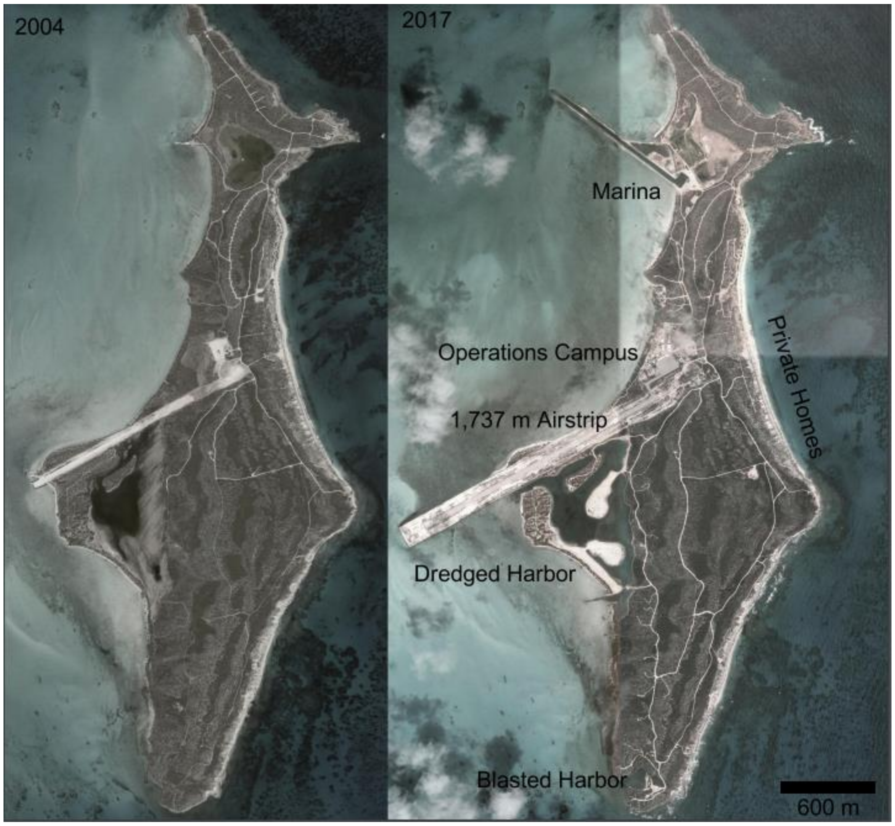

Figure 2. Development has increased dramatically on Big Ambergris Cay since 2004 (left) and 2017 (right) including the addition of private homes, a private airstrip, marina, tennis courts and restaurants.

2. Methods

2.1 Study Location

This study occurred on the privately-owned island of Big Ambergris Cay, Turks and Caicos Islands. The Turks and Caicos Islands are a British Overseas Territory politically separate from the Bahamas, the other country represented in the 1,000 km long Lucayan Archipelago located between Florida, USA and the island of Hispaniola. Big Ambergris Cay is located on the Caicos Bank, a mostly-submerged carbonate platform with several larger and many smaller emergent islands. Big Ambergris Cay is located on the southeast margin of the Caicos Bank (21.2977° N, 71.6347° W), and has some of the highest elevations of any island on the Bank (maximum 29m above sea level), is 5.4 km long, 2 km wide, and has an area of ~400 hectares. The island consists of multiple habitat types developed over a limestone and sand base, with the vegetation consisting of subtropical scrub forest, whiteland scrub coppice, *Cocothrinax* palm forest, mangroves, and rocky cactus fields. Big Ambergris Cay has the highest known density of Turks Island Boas (*C. chrysogaster*), and one of the highest densities of any species of West Indian Boa, with more than 12 boas per hectare[15]. This population has been under intense annual study since 2007, and more than 1,200 boas have been captured, measured, and marked[13].

2.2 Medical Procedures

Medical procedures described below were carried out by a licensed veterinary medical doctor, and no mortality was observed over the course of the study. Some medical information is intentionally withheld, as it is being written for publication elsewhere[16]. All procedures described herein were approved by the IACUC Committee at the University of North Carolina Asheville.

2.2.1 cohort A: August 2018-January 2019

Surgical procedures and the anesthesia regimen for Cohort A can be found in a previous study[17]. In brief, large adult females (> 250 g in mass) were captured and placed in cloth sacks. Each animal was anesthetized by a licensed veterinarian using an intramuscular injection of ketamine. A sterile field was established, and a short incision was made down to the peritoneal cavity. A gas-sterilized implantable radio transmitter and battery (coupled together and covered with inert surgical-grade rubber) were inserted into the peritoneal cavity on the left side of the animal about ⅔ of the way posterior. A cutting catheter was used to create a subdermal channel about 8 inches anterior of the incision site, through which the antenna of the transmitter was strung. The incision site was then sutured closed and covered with surgical glue and bacitracin ointment. Each animal also received an intramuscular injection of meloxicam to prevent subsequent inflammation as well as an injection of ceftiofur crystalline free acid as an antibiotic. Two types of transmitters were used in Cohort A: smaller "button" transmitters with a battery life of six months, and larger "barrel" transmitters with a battery life of 1 year. Each snake was individually marked with an internal passive integrated transponder (PIT) tag, which is implanted subdermally using a sterile, single-use large-gauge needle.

2.2.2 cohort B: August 2019-March 2020

The same surgical procedures used on Cohort A were followed for Cohort B, which consisted of 6 newly-captured female snakes. Subjects in this cohort were all fitted with barrel trackers due to their higher success rate in Cohort A which were removed in March of 2020.

2.3 Radio Telemetry

The first cohort of snakes labeled T1-13 had button and barrel transmitters and were tracked intermittently from Summer of 2018 to Winter of 2019 with a total of 13 snakes (Table 1). Only seven snakes remained actively involved for the duration of the study. After this cohort study was completed, the transmitters were removed and the boas were returned to the last location they were found.

The second cohort labeled B-E with various numbers had barrel transmitters and were observed from the Summer of 2019 to the Spring of 2020 with a total of six snakes. The transmitters were also removed after the study was completed and the snakes were returned to the last location they were found.

2.4 Data Collection

Over the course of six days, non-radio-transmitting boas were captured nightly for early morning processing where phenotypic measurements and observations were taken. Each afternoon at dusk, we used golf carts to travel the island and look for boas in and around the road. We stopped at ruin sites to look in rock piles that the boas used as shelter. Each individual was bagged upon capture and the site was flagged with the capture number also on the bag. During these nightly catches, we took radio tracking fixes while we were out. Snakes were kept overnight and processed the next morning. Measurements, photographs and sexes were recorded for each individual. Measurements included Snout-Vent length, Tail length, and Mass (g). PIT tags read if the snake was a recapture. Each individual was returned after processing to the location they were caught the night before. While returning the snakes the next day, we took radio tracking fixes again.This occurred in March of 2020.

2.4.1 spatial movement models

Data was analyzed using R v 4.0.4 implemented in RStudio v.1.1.447[18,19]. Data for most analyses consisted of *.csv* formatted data matrices which included columns of snake identity as well as the latitude and longitude for each telemetric location obtained. The models used in this study were chosen to compare end results. The traditional Multi Convex Polygons and Kernel Density models are being challenged by new dynamic models such as the Brownian Bridge Movement model, which incorporates different weights for spatial habitat use by accounting for time steps between observations[14]. In Crane et. al (2020), the significance of terminology and consistency in the realm of herpetological research was made clear while challenging researchers to consider new methods of data analysis. It was suggested that Brownian Bridge Movement Models provided a more dynamic, accurate and discerning way to plot the ranges for an individual. For the purposes of this paper, 95% values will be considered as space use and 50%

values will be considered as home ranges. The goal of using each model was to compare the end results and observe the differences.

2.4.2 total distances traveled

The Total Distances traveled were calculated in R studio for each boa in meters and kilometers using the *SpatialLines()* function in the package sp[20]. This calculation allowed for the comparison of the total movement between all females in the study.

2.4.3 brownian bridge movement models

Brownian Bridge Movement Models are a home range and space use estimations that focus on using movement to make a model[21,22]. This model measures the probability of space use between each location. There is a tighter measurement on where the species is likely to occur than in other estimation models. This model was chosen to represent the data to compare the results with the other traditional models and observe the differences. Calculations were done in RStudio using the *bbmm()* function in the R package BBMM 3.0[23]. Output files were created with spatial grid information in a polyline format that could then be imported into ArcGIS Pro. Files made in RStudio were transferred to ARGIS to lay over a map base that showed where on the island these models were located and help visualize the space used. We used 95% and 50% ranges for this study, corresponding to the spatial use and home range, respectively.

2.4.4 kernel densities

Kernel Densities are a traditionally used estimation model that represents the probability of space the individual has used the most, indicating the home range. Densities for both 95% and 50% contour values were calculated in R using the *kernelUD()* function in the package adehabitatHR[24]. The smoothing (h) factor used to smooth spatial contours was estimated using the function h_{ref} in R Studio. We used 95% and 50% contour values, corresponding to the spatial use and home range, respectively.

2.4.5 multi convex polygons (MCP)

Multi Convex Polygons are another traditionally used estimation model that uses shapes to triangulate and include 95% of the location fixes that best represent the data set. Each individual boa had its own MCP file calculated through RStudio and uploaded to ARGIS to place the figures on a map showing the island.

Table 1. Number of fixes and tracking dates of each boa in the study.

Snake	Date initiated	Last date fixed	Total # tracking days	Total fixes
B23	08/04/19	03/13/20	16	27
C42	08/05/19	03/12/20	16	27
D45	08/06/19	03/12/20	15	26
D51	08/06/19	03/13/20	16	27
E9	08/07/19	03/09/20	11	19
E40	08/07/19	03/13/20	14	25
T1	07/25/18	07/31/18	7	7
T2	07/27/18	08/08/19	25	40
T3	07/25/18	08/06/19	11	16
T4	07/28/18	01/06/19	20	36
T5	07/29/18	01/10/19	21	35
T6	07/29/18	08/09/18	12	20
T7	07/29/18	01/06/19	17	28
T8	07/30/18	08/07/19	17	28
T9	07/30/18	08/09/18	10	18
T10	07/30/18	01/10/19	21	36
T11	07/31/18	08/09/18	10	18
T12	07/31/18	01/10/19	20	36
T13	08/02/18	03/15/19	18	32

3. Results

3.1 Cohort Morphology

Each subject included in the study was successfully fitted with a transmitter (Table 2). The mass (g) and snout vent length (SVL) was recorded. The mean mass of all 19 female boas was 467.94 g $\pm$ 92.21 g and the mean SVL was 1062 $\pm$ 48.79 mm. The mean mass of Cohort A was 471.38 $\pm$ 120.88 g and the mean SVL was 1040.15 $\pm$ 60.79 mm. The mean mass of Cohort B was 460.5 + 144.71 g and the mean SVL was 1110.16 $\pm$ 85.15 mm.

Table 2. Transmitter type, mass, and snout-vent lengths (SVL in mm) of 19 female *Chilabothrus chrysogaster* individuals that underwent implantation for tracking via radiotelemetry (mean SVL = 1062.26 ± 948.79 mm, mean mass = 467.94 g ± 92.21 g).

ID	Transmitter Type	Mass (g)	SVL (mm)
Cohort A			
T1	button	162	820
T2	barrel	182	815
T3	button	166	830
T4	barrel	900	1355
T5	barrel	855	1315
T6	button	227	900
T7	barrel	320	1030
T8	button	259	949
T9	button	276	953
T10	barrel	505	1170
T11	button	271	920
T12	barrel	330	990
T13	button	1675	1475
Cohort B			
B23	barrel	1135	1500
C42	barrel	234	1001
D45	barrel	580	1190
D51	barrel	280	1025
E9	barrel	256	940
E40	barrel	278	1005

3.2 Tracking duration and Fixes

Over the course of six days, I spent approximately 36 hours tracking the six boas in Cohort B with two sets of fixes per day. I obtained a total of 72 radio fixes for all six boas, split evenly into diurnal fixes and nocturnal fixes (Fig. 3). Additional fixes were obtained before and after my arrival on the island. The mean number of fixes per boa was 26 overall. Cohort B had a mean number of fixes of 25 and Cohort A had a mean number of fixes of 27. Boa E9 in Cohort B had fewer tracking days and fixes due to the lack of movement in initial tracking days.

During radio tracking expeditions, fixes were recorded at the strongest signal or when the snake was visualized. All snakes were visualized throughout the week except E9 who stayed underground in a burrow throughout the extent of tracking. When not visible, the signal pointed to underground activity and burrows, but each snake was visualized after going underground for a fix.

Figure 3. Plotted fixes on an aerial map, each color representing one individual and each point representing one location fix. This is the simplest way of visualizing home ranges, but does not weight the frequency of spatial use nor the proximity of spatial use if used to infer a home range.

3.3 Spatial Movement Models

3.3.1 total distances traveled

The mean total distance traveled was 1.29 $\pm$ 0.47 Km. The total distance traveled for Cohort A was 1.56 $\pm$ 0.68 km. The total distance traveled for Cohort B was 0.71 $\pm$ 0.042 km.

Table 4. Total Distance Traveled (km) for each boa (mean total distance = 1.29 ± 0.47 m).

Name	Distance (km)
B23	0.67
C42	0.55
D45	0.74
D51	0.85
E40	0.77
E9	0.65
T1	0.045
T10	0.68
T11	0.86
T12	1.18
T13	9.42
T2	3.25
T3	0.19
T4	0.99
T5	0.99
T6	0.72
T7	0.59
T8	0.69
T9	0.71

3.3.2 kernel densities

The Kernel Densities were calculated for each individual (Table 5). The mean 50% KUD overall was 2.545 ± 1.45 ha. The mean 50% KUD for Cohort A was 3.26 ± 2.19 ha and 1.10 ± 0.27 for Cohort B. The mean 95% KUD overall was 13.17 ± 8.27. The mean 95% KUD of Cohort A was 17.68 ± 12.36 ha and 4.15 ± 0.98 ha for Cohort B. Kernel Densities for each boa were graphed using R studio (Fig. 4).

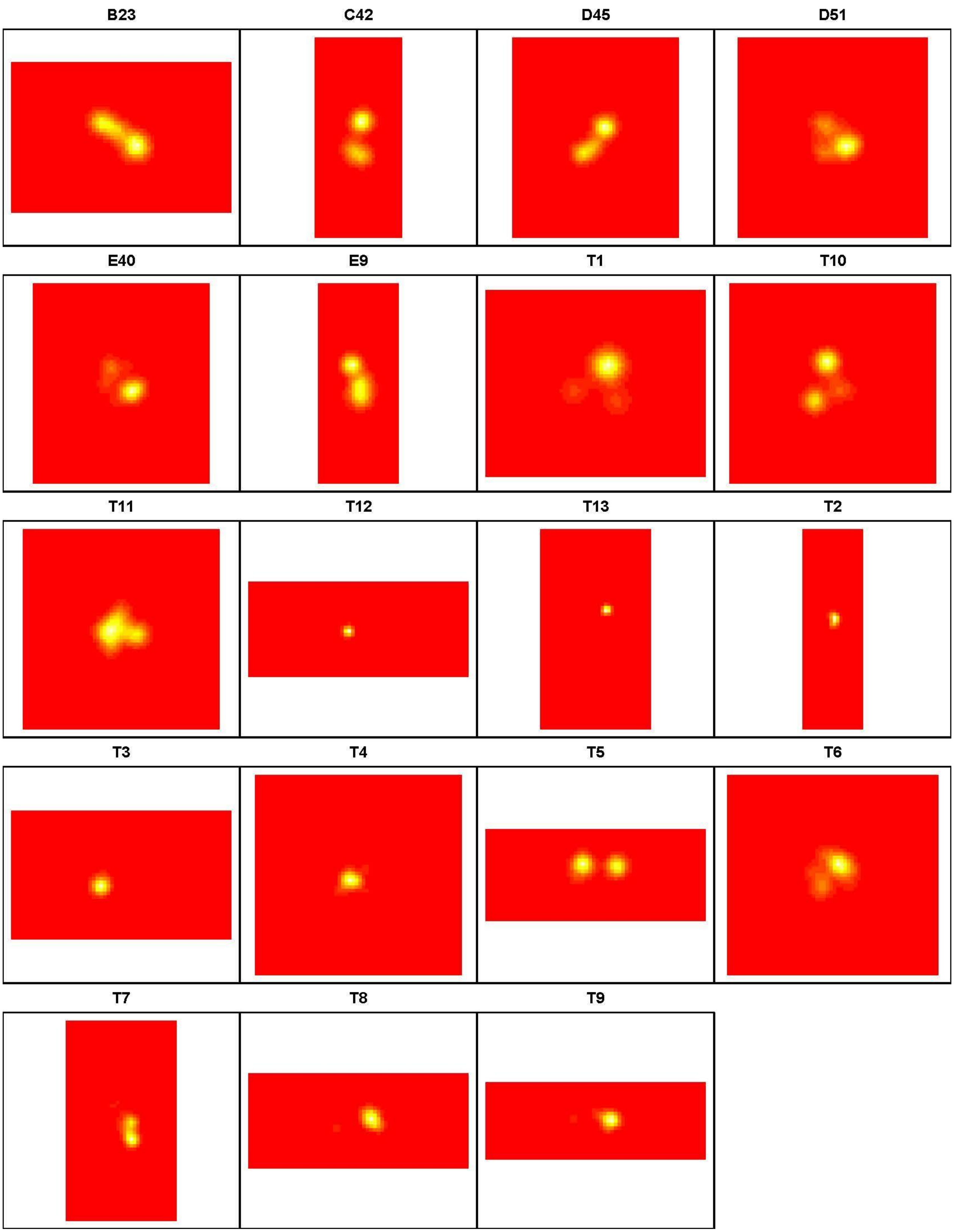

Figure 4. Shadow imprints showing 50% occupancy regions from a kernel density estimate model. Kernel Density home ranges were calculated from these interpolated surfaces in R.

3.3.3 multi convex polygons

Each individual (except T1) had MCPs created and placed on the map with the according number of corresponding hectares (Figures 5-6). The mean areas were calculated from the area covered by each boa (Table 5). The mean area covered by Multi Convex Polygons was 0.704 ± 0.096 ha. The mean MCP area for Cohort A was 0.65 ± 0.13 ha. The mean MCP area for Cohort B was 0.813 ± 0.125 ha.

Figure 5. Multi Convex Polygon models showing inferred home ranges for boas: C42, T2, T4,T5, T7, and T11 on the northern side of the island.

Figure 6. Multi Convex Polygon models showing inferred home ranges for boas: B23, D45, D51, E9, E40, T3, T6, T8, T9, T10, and T12, and T13 on the south side of the island.

3.3.4 brownian bridge movement models

Plots show 95% and 50% space use and home ranges (Figures 7-8). The average space use was 2.98 $\pm$ 0.68 ha (Table 5). The average home range was 4.38 $\pm$ 2.78 ha. The average home range for Cohort A was 6.23 $\pm$ 4.13 ha and 0.675 $\pm$ 0.18 ha. The average space use for Cohort A was 3.09 $\pm$ 1.16 ha and 2.85 $\pm$ 0.69 ha for Cohort B.

Table 5. Average area estimation capturing 95% and 50% of boa occupancy outside of the density fields of *Chilabothrus chrysogaster* movement. Density was calculated via kernel density analysis in RStudio (mean 95% = 13.17 ± 8.27 ha, mean 50% = 2.545 ± 1.45 ha). T3, T5, T7, T10, T12, and T1 ceased movement in January due to anthropogenic associated mortalities, difficulty in recovery, transmitter sloughing/removal, or gravidity, and are therefore representative of partial data. Home range analyses were calculated through Minimum Convex Polygons and Brownian Bridge Movement Models (MCP mean 95%= 0.704 + 0.096 ha) (BBMM mean 95%= 2.98 ± 0.68 ha ha, mean 50%= 4.38 ± 2.78 ha).

ID	Area of 50% of boa occupancy KUD (ha)	Area of 95% of boa occupancy KUD (ha)	Minimum Convex Polygon (ha)	Brownian Bridge Movement Model 50% (ha)	Brownian Bridge Movement Model 95% (ha)
T2	1.01	5.79	1.74	1.97	7.36
T3	0.08	0.55	0.01	0.07	0.5
T4	0.25	1.33	0.47	0.41	1.87
T5	7.37	33.27	0.62	15.42	—
T6	0.35	1.39	0.46	0.61	—
T7	0.9	4.49	0.62	2.54	—
T8	0.22	1.06	0.16	0.19	0.82
T9	0.41	2.18	0.38	0.94	—
T10	1.19	5.03	0.9	1.51	5.9
T11	0.49	1.67	0.56	0.71	2.14
T12	0.46	4.74	1.08	0.75	—
T13	26.46	150.71	0.8	0.06	49.68
B23	1.89	6.62	0.94	0.11	1.79
C42	1.27	5	1.03	0.27	1.68
D45	1.84	7.05	1.15	1.28	5.51
D51	0.74	2.76	0.89	0.71	2.64
E9	0.58	2.1	0.42	0.97	2.66
E40	0.3	1.37	0.45	0.71	1.81

Figure 7. Brownian Bridge Movement models showing inferred home ranges for boas B23, D45, D51, E9, E40, T3, T6, T8, T9, T10, and T12, and T13 on the south side of the island. Note the similarities and differences between BBMM models in filled polygons, and MCPs in red shaded polygons.

Figure 8. Brownian Bridge Movement models showing inferred home ranges for boas: C42, T2, T4,T5, T7, and T11 on the northern side of the island. Note the similarities and differences between BBMM models in filled polygons, and MCPs in red shaded polygons.

4. Discussion

Over the course of two years radio tracking data from 19 female Turks Island Boas was compiled to complete this comprehensive analysis. The importance of this study lies in the importance of improving conservation methods on Big Ambergris Cay and other islands in the Turks and Caicos. As development continues on these islands, these home ranges and space use estimates can be used to avoid the further decline of the population. Measurements taken from snakes captured throughout nightly searches can be used to estimate the population health and dynamics. Most of these individuals were smaller than the radio tagged females, we did however find one female who was a similar size of the radio tagged individuals. Most individuals collected were found in rock piles which could be explained by cooler weather pushed in by a storm during the week of study for Cohort B. Observations of target snakes during radio tracking fixes were frequent, but sometimes the individual was underground. All radio tagged individuals were observed multiple times throughout the week except E9. It is not uncommon for individuals to stay underground for an extended period of time that early in the year and there was no immediate concern that E9 had become deceased. With all the data, three movement models were used to compare the accuracy and determine the model of best fit.

Using Multi Convex Polygon models and Brownian Bridge Movement Models, we can observe some overlap in space use among individuals, but not home ranges. The averages of home ranges and space use was larger for Cohort A than Cohort B in all movement models. This could be due to the inclusion of T13 which had an abnormally large movement range. T13 did not have enough data to be included in the 95% BBMM calculation, which still resulted in Cohort A having a larger value. Boas were distributed along the North and South ends of the island due to opportunistic catching. Within the Kernel Densities, two distinct areas can be made out as in T5, C43, D45, E9 and B23. Under closer evaluation, these concentrated areas contained fixes from different seasons.

4.1 Model Comparisons

We decided to specify terms such as home ranges as 50% estimation and space use as 95% estimation for consistency and more accurate terminology. Violation of home range estimates in development or human impact would have a stronger impact on the species than in space use. Kernel Density Estimates showed concentrated areas of density for space use and home range (Table 5). These models fade as density decreases and shape around the fixes. While this model is not dynamic, two distinct areas were observed in multiple boas which correlated with summer and winter fixes (Figure 4). This separation of two seasonal locations has not been previously noted and should be further investigated. The majority of both 50% and 95% area estimates were lower than the Brownian Bridge estimates but higher than the Multi Convex Polygons (Table 5). This model included more data determined relevant than the Brownian Bridge which could explain these differences. While this type of estimate is less dynamic, it provided a way to visualize the concentration of the most fixes instead of the limits of the ranges.

Multi Convex Polygon models are geometric and were inclusive but lacked shaping around fixes (Figures 5,6). These models estimated general home ranges that included the maximum amount of relative fixes and connected the points. This model had the overall lowest home range estimates between the three models (Table 5). The lack of shaping around fixes and prediction of home range relative to each fix could explain these results. While not incorrect, this model loses accuracy compared to the Kernel Density and Brownian Bridge estimates for home range that are more inclusive.

The Brownian Bridge models create a dynamic model that fit the relative fixes. Each model was shaped around the fixes instead of straight lines connecting the points (Figures 7,8). This produces more accuracy and dependability when estimating home range and space use, because boas do not immediately move from one point to the next. These estimates were often larger than KUD estimates for home range (Table 5). This could be explained by the estimation of range based on each fix, expanding and downsizing where most probable. This model also excludes more data fixes than KUD. The amount of data does affect the relevance of models produced. Space use estimates for T5,T6,T7,T9,T12, and T13 lacked enough data for a relevant model. By using all three models, a comprehensive and more accurate representation can be made of both space use and home ranges.

4.2 Future Directions

Undoubtedly, additional boas and additional tracking fixes will serve to tighten estimates of home ranges on Big Ambergris Cay. However, such work is expensive and time consuming, and in two years the data presented in this manuscript are the extent of what can be reasonably achieved.

An interesting follow up study could be to research the seasonality of home ranges on the island. It was apparent that some boas, such as the largest female (T13) used two main areas of the island during separate seasons. More frequent fixes and greater seasonal consistency of radio tracking would provide more data to begin to resolve this. With this in mind, consistency is the biggest factor while taking tracking data. But, it is worth noting that these home ranges are very small compared to, say, a jaguar, and therefore differences in seasonal habitat use are probably separated by only a few tens of meters total. So, more data might tighten these estimates, but would not go far in fundamentally changing the habitat use parameters we are able to calculate with these data. Due to the low amount of data on this species, any additional data would be helpful in the conservation of the Turks Island Boa.

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