Radio telemetry and home range analysis of Southern Flying Squirrels at Brookhaven National Laboratory

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Table of Contents

Abstract

Southern Flying Squirrels, *Glaucomys volans*, are small, nocturnal mammals found in mixed hardwood forests along the east coast. In order to manage and protect the natural resources on the Brookhaven National Laboratory (BNL) property, it is crucial to know what habitat is available and how it is being used. Consecutive studies have been conducted over three years during the summer months at BNL to learn more about the home range and nighttime movement of male, female and juvenile squirrels. Sherman box traps were used to capture the squirrels in multiple locations around the laboratory site. Individuals captured were ear tagged and a total of 26 squirrels were fitted with a radio collar. Over the following weeks, these squirrels were tracked using radio telemetry equipment. Daytime locations were pinpointed and recorded in a Trimble® GPS. Triangulation methods were used to estimate locations during nighttime hours. A Geographic Information System (GIS) was utilized to plot all the locations and movements. Analyses of these points offer home ranges and habitat types for each squirrel. Data compiled over the three year study provide average home ranges of adult and juvenile squirrels on site. Male home ranges were found to be larger than female home ranges. The squirrels were found to utilize oak habitat vegetation more often than pine. This data will be compared to the average home range size and movements of squirrels in various regions and habitat types. Small mammal trapping, handling and radio telemetry experience will be beneficial toward future academic and career paths. This research experience allowed for professional growth through interaction and collaboration with scientists in a related field.

Introduction

Mammals are frequently the focus of ecological studies due to their role in the trophic systems. Despite the spotlight, many mammals tend to be overlooked as a part of the ecological system. Southern flying squirrels, *Glaucomys volans*, are small mammals that play an intricate part in the seed dispersal and forest health of mixed-hardwood forest along the eastern coast of the United States as far west as the Mississippi River (Whitaker and Hamilton, 1998). They are adaptable in their habitat use, as long as there is an abundant food source. They have been known to prefer forest habitat with older, declining trees which provide shelter and copious seeds and nuts, but also thrive in

younger recently cut areas due to the large amount of low shrubs bearing berries (Holloway and Malcolm, 2007).

The name “Flying Squirrel” can be misleading, since these mammals do not truly "fly". They received this name for their characteristic ability to glide from tree to tree, which is enabled by a physiological structure called a patagium. This structure consists of two layers of skin that surround a thin layer of muscle, extending from the forelimb to the hind limb. The maximum distance recorded for a southern flying squirrel glide was 45 meters (Thorington and Ferrell, 2006). Witnessing such movements can be difficult due to their habitat and nocturnal lifestyle. They spend a majority of their days in nest and tree cavities roosting. At night, they forage for seeds, nuts, berries and fungi between tree cavities, canopies and the forest floor.

In the summer of 2009, a presence study was conducted at Brookhaven National Laboratory (BNL) to determine if the southern flying squirrel, *Glacoumys volans*, inhabited the woods around the site. This study created a baseline for consecutive years of trapping and radio telemetry work to determine the home ranges of squirrels on site. During the subsequent three summers, a total of 26 squirrels were collared (six in 2010, nine in 2011 and 11 in 2012) and tracked over ten weeks. Extensive analysis of home range and telemetry work was conducted to determine correlations with various ecological factors. This compiled data will be compared to previous and ongoing studies conducted in other regions to determine differences in home range in different habitats.

Materials and Methods

During the summer months of 2010, 2011 and 2012, Sherman box traps were set up in various locations around the laboratory site. An average of 18 traps was mounted in

a random manner on a variety of tree species (mainly White Oak, Scarlet Oak and Pitch Pine). The traps were mounted about 1.7 meters above the ground, secured with a modified circular bracket screwed into the tree trunk. Zip ties were used to stabilize the traps in the modified bracket to prevent sliding and tilting. The traps were equipped with cotton nesting material called nestlets and bait. The bait for the first two years was a mixture of peanut butter and oats shaped into small balls, but for the final year the method was enhanced. Wax paper was used to contain the bait and keep the traps cleaner. The peanut butter and oat mixture was wrapped in a wax paper square with the ends twisted to surround the bait. One end of the wax paper was then pinched in the trap door that remains closed to keep the mixture off the floor of the trap and decrease mess (Veselka and Collins, 2011).

The traps were baited and opened in the late afternoon and checked in the early morning. If the trap was still open and the bait was present, the trap was closed for the day and reopened in the afternoon. If the trap was closed, the zip tie was cut and the trap was taken down to check for the presence of an animal. These traps were brought back to the road to be processed. The entire trap was placed in a sealed container charged with anesthetic isoflurane. Once the squirrel was sufficiently sedated, it was removed from the trap into a clear bag to be weighed and sexed. Body length, tail length and hind foot measurements, as well as evidence of breeding or any other markings were recorded after the squirrel was fitted with an ear tag. If the individual was large enough to bear the weight of a radio collar, an ATS model M1420 radio collar was secured around its neck.

The collars were prepared prior to deployment by threading fishing line through small plastic tubing and tying a simple figure eight knot through holes in the side of the

transmitter. The plastic tubing was used as a buffer between the fishing line and the animal to prevent the line from cutting into the squirrel's neck. The plastic tubing was coated in a plasti dip and cayenne pepper mixture in order to dissuade the squirrels from chewing through the collar. An additional layer of plasti dip was applied so that the cayenne pepper would not cause any irritation (Adams et al., 1996/ Madden et al., 1982). The fishing line was tied at an appropriate length to allow the squirrel to breathe and eat without obstruction, but tight enough that the squirrel would not be able to slip the collar off. A three element Yagi antenna and R-1000 Telemetry receiver (Communication Specialist, Inc) were used to test the functionality of each collar before it was deployed. The squirrel was placed in a plastic tank with bait until the sedative wore off. Once the animal was alert, it was brought back to the tree in which it was captured and released.

Trapping continued until all the collars were deployed. A total of 24 collars were deployed during this three year study (six in 2010, eight in 2011 and 10 in 2012). Collars that were chewed or slipped off were redeployed to new individuals, depending on the wear and remaining lifespan on the collar. During day time hours (nesting period), pinpoint tracking was used to locate a squirrel down to a certain tree. These locations were recorded in a Trimble® Geo XT™ 2008 series global positioning system (GPS) unit running ESRI®'s ArcPad® 8.0. During nighttime hours (foraging hours), triangulation methods were used to estimate the squirrels location. Once the receiver picked up the direction of the strongest signal, a compass was used to determine the heading of the signal. Points and compass headings were recorded in the GPS at three different locations in order to make a triangle in which with squirrel is located. Each group of headings was found within a 20 minute period in order to minimize the effects of the animal's

movement. This method was used not only for safety reasons, but also in order to decrease interference with the squirrels' movements.

All the points were uploaded and analyzed in ESRI ArcGIS ArcInfo 9.2. Nighttime point headings were elongated and locations were determined and added to the daytime points. Hawth's Analysis tools extension for ArcGIS was used to create paths between each location by date and time for each individual frequency. A minimum convex polygon was formed to estimate each squirrel’s home range and show distribution around the laboratory site. Analysis of largest movements, total movements and vegetation types were conducted, as well as home range size comparison to additional variables (i.e. gender and relative age). Each year's data was compiled and compared to determine the average home range for squirrels on the laboratory site and evaluated in order to draw further conclusions about distribution.

Results

The average home range of squirrels successfully tracked (more than 2 weeks) in 2010 was 3.34 ha, 5.59 ha in 2011, and 6.87 ha in 2012 as determine by the minimum convex polygon (Table 1). The average home range of all the adult males was 8.73 ha and the average home range of males successfully tracked was 10.23 ha. The average home range of all the adult females was 1.97 ha and the average home range of females successfully tracked was 2.38 ha. The average home range of all the juvenile males was 3.03 ha and the average home range of juvenile males successfully tracked was 3.40 ha. The largest home range was 24.56 ha and belonged to a male squirrel. The largest home range belonging to a female squirrel was 6.12 ha. A total of 26 collar frequencies were tracked (Table 1).

In 2010, seven individuals were captured over 160 trap nights for a capture success rate of 4.38% (Table 2). Trapping was only performed in June until all the collars were deployed. All of the squirrels tracked in 2010 had home ranges that overlapped because a family group was captured (Figure 1). Two adult females were captured and collared, but the remaining four collars were deployed to juvenile males. One female, squirrel 281, was only tracked for 4 days before she chewed through her collar. This occurred prior to nighttime movements being recorded, therefore insufficient data was collected, preventing the accurate determination of a home range. She had the western-most territory and began moving south when the collar detached. The directional distribution of squirrel 281 locations was 3.71 ha at two standard deviations and 0.93 and one standard deviation (Table 3). This female's largest movement was 156.1 meters in 19 hours 20 minutes (Table 4). Her home range consisted of 17.2% Pitch Pine/ Mixed Oak-Heath forest and 82.8% Scarlet Oak-Heath forest (Table 5).

Squirrel 310, the other female, was tracked for 37 days (Table 6). Her home range was estimated to be 0.83 ha using a minimum convex polygon. The directional distribution of her home range was 0.97 ha at two standard deviations and 0.24 ha at one standard deviation (Table 3). Her largest movement was 104 meters in 21 minutes (Table 4). The minimum convex polygon created to determine Squirrel 310's home range covers 36% Scarlet Oak-Heath forest, 8.2% Successional habitat and 55.8% Red Maple/Scarlet Oak-Mesic Heath forest (Table 5). Her territory changed very little in both size and location during the study.

Squirrel 370 was a juvenile male in the same location as the previous squirrels. He was tracked for 35 days and a minimum convex polygon of 5.28 ha was created

(Table 6). His directional distribution was 7.49 ha at two standard deviations and 1.87 ha at one standard deviation (Table 3). His largest movement was 182 meters over an hour period (Table 4). His home range consisted of 3.3% Pitch Pine/ Mixed Oak-Heath, 17.4% Scarlet Oak-Heat, 3.8% Successional, 58.7% Red Maple / Scarlet Oak-Mesic Heath, 2.5% Pitch Pine/ White Oak and 14.2% Red Maple- Blackgum Wet forest (Table 5).

Squirrel 400 was a juvenile male tracked for 36 days with a minimum convex home range of 4.25 ha (Table 6). This directional distribution was 11.63 ha at two standard deviations and 2.91 ha at one standard deviation (Table 3). His largest movement was 162.1 meters in 50 minutes (Table 4). His home range consisted of 7.4% Pitch Pine/ Mixed Oak-Heath, 27.1% Scarlet Oak-Heath, 5.7% Successional, 58.3% Red Maple/ Scarlet Oak-Mesic Heath and 1.5% Red Maple-Blackgum Wet forest (Table 5). He had the most movement over the summer and was seen to be moving away from his original nesting and foraging area from week to week (Table 2).

Squirrel 431 (Juvenile Male) had a minimum convex polygon home range of 2.41 ha after being tracked for 18 days (Table 6). His directional distribution was 5.02 ha and 1.25 ha at two standard deviations and one standard deviation, respectively (Table 3). His largest movement was 209.3 meters in 56 minutes (Table 4). His home range had 2.7% Pitch Pine/ Mixed Oak-Heath, 41.5% Scarlet Oak-Heath, 4.1% Successsional, 46% Red Maple/ Scarlet Oak-Mesic Heath, 4.2% Red Maple-Blackgum Wet forest and 1.6% road (Table 5). Squirrel 370, 400 and 431 were seen to be using the same day hides which supported the evidence that their territories heavily overlapped (Figure 2).

The sixth squirrel tracked in 2010 was squirrel 460 which was tracked for 35 days and had a minimum convex polygon home range of 3.94 ha (Table 6). He was also a

juvenile male and had a directional distribution of 3.69 ha at two standard deviations and 0.92 ha at one standard deviation (Table 3). He had the largest movement out of all the squirrels in 2010 at 226.1 meters in 42 minutes (Table 4). His home range was comprised of 23.5% Pitch Pine/ Mixed Oak-Heath, 52.1% Scarlet Oak-Heath, 3.6% Successional, 20.4% Red Maple/ Scarlet Oak-Mesic Heath and 0.5% % Red Maple-Blackgum Wet forest (Table 5).

In 2011, 82 squirrels were captured over 602 trap nights beginning in June and ending in August, producing a success rate of 13.62% (Table 1). The highest success rate was in August (37.12%) when trapping was being conducted in order to recapture collared individuals to retrieve the collars.

The first squirrel collared was an adult male that was only tracked for 4 days before the collar was found (Table 6). He had chewed through the collar, but since it had only been deployed a few days and the battery life remained high, the collar was later redeployed. The original squirrel was given the frequency id 759 (originally 760). Squirrel 759, located between East Margin Rd and the East Fire Break, had a home range of 0.008 ha because of its insufficient tracking data (Figure 4). His home range was determined using a minimum convex polygon. His directional distribution was 0.55 ha at two standard deviations and 0.14 ha at one standard deviation (Table 3). His largest movement was 162.91 meters within a 24 hour period (Table 4). The vegetation composition of his home range consisted of 96.04% Pitch Pine/ Mixed Oak- Heath and 3.6% Scarlet Oak-Heath forest (Table 5).

Squirrel 790 was an adult female with a minimum convex home range of 1.93 ha between First Ave and Crescent Path (Figure 4). She was only tracked for 2 days before

her signal disappeared from the area (Table 6). The collar was found a week after deployment approximately 800 meters from her home range. Since the collar was such a great distance and still intact when it was found, it was assumed to have been removed due to predation. Her directional distribution was 10.44 ha and 2.61 ha at two and one standard deviations, respectively (Table 3). Her largest movement before the collar was lost was 190.99 meters within 3 hours (Table 4). Her home range consisted of 9.81% Pitch Pine/ White Oak, 48.53% Pitch Pine/ Mixed Oak-Heath, 29.41% Planted White Pine forest and 12.25% road (Table 5).

On the east side of the property, two squirrels were tracked on the corner of Treatment Plant Rd and the East Fire Break (Figure 4). Squirrel 700 was a juvenile male with a minimum convex home range of 1.21 ha after being tracked for 38 days (Table 6). His directional distribution was 1.83 ha at two standard deviations and 0.46 ha at one standard deviation (Table 3). The largest movement he had was 245.36 meters in an hour (Table 4). His home range consisted of 12.24% Pitch Pine/ White Oak, 80.37% Red Maple/ Scarlet Oak-Mesic Heath forest and 7.39% road (Table 5).

His home range overlapped with an adult female, squirrel 671, who was also tracked for 38 days (Figure 4). Her home range created with a minimum convex polygon was 2.99 ha (Table 6). Her directional distribution was 6.82 ha and 1.71 ha at two and one standard deviations, respectively (Table 3). Her largest movement was 129.77 meters in 48 minutes (Table 4). The vegetation that made up her home range was 25.44% Pitch Pine/ White Oak, 7.02% Pitch Pine/ Mixed Oak-Heath, 24.56% Scarlet Oak-Heath, 38.28% Red Maple/ Scarlet Oak-Mesic Heath forest and 4.99% road (Table 5). These collars were not retrieved despite recapture trapping efforts conducted in the area.

In the northeastern corner of the lab, three squirrels were successfully tracked for more than two weeks (Figure 4). Squirrel 730 was an adult male, tracked for 22 days with a minimum convex home range of 9.68 ha (Table 6). His collar was retrieved about 3 weeks after deployment still intact on a fallen tree, possibly removed by predation. He had the largest home range seen during the summer of 2011 and a directional distribution of 20.38 ha at two standard deviations and 5.1 ha at one standard deviation (Table 3). His largest movement was 542.48 meters in 2 hours and 5 minutes (Table 4). His home range extended across East Margin Rd into the Gamma Forest and then over Forest path into the forest southward as the summer went on (Figure 4). This area consisted of 63.8% Pitch Pine/ Mixed Oak-Heath, 23.67% Scarlet Oak-Heath, 9% Red Maple/ Scarlet Oak-Mesic Heath forest and 3.53% road (Table 5).

Squirrel 730's home range overlapped with a juvenile male's, squirrel 610, home range near the Gamma Forest. Squirrel 610 was tracked for 15 days and had a minimum convex home range or 3.13 ha before his collar had been chewed off and retrieved (Table 6). His directional distribution was 5.77 ha at two standard deviations and 1.44 ha at one standard deviation (Table 3). His largest movement was 135.48 meters in 53 minutes (Table 4). His home range crossed over East Margin Rd and was composed of 40.61% Pitch Pine/ Mixed Oak-Heath, 56% Scarlet Oak-Heath, and 3.39% road (Table 5).

The three remaining squirrels were located on the west side of the property. Squirrel 580 was located within the White Pine Forest that extended Upton Rd to West 4th and White Pine Rd (Figure 5). He was tracked for 31 days and had a minimum convex home range of 7.68 ha (Table 6). His directional distribution was 18.71 ha at two standard deviations and 4.68 ha at one standard deviation (Table 3). He was a very active

squirrel with a maximum movement of 150.35 meter in 39 minutes that was observed after two other large movements (Table 4). His home range consisted of 19.58% Pitch Pine/ White Oak, 5.78% Pitch Pine/ Mixed Oak-Heath, 66.28% Planted White Pine forest and 8.37% road (Table 5). Collar 580 was retrieved during recapture trapping in August.

South of squirrel 580 on the West Fire Break, Squirrel 461 and squirrel 760 had overlapping home ranges (Figure 5). Squirrel 461 was an adult female that was tracked for 38 days near Well 7 and extending west toward William Floyd Parkway. She had a minimum convex home range of 6.12 ha (Table 6), a directional distribution of 13.17 ha and 3.29 ha at two and one standard deviations (Table 3), respectively, and her largest movement was 152.18 meters in 35 minutes (Table 4). She had the largest movement in the shortest amount of time for 2011. The vegetative composition of her home range was 2.57% Pitch Pine/ White Oak, 76.88% Pitch Pine/ Mixed Oak-Heath, 9.41% Scarlet Oak-Heath, 0.45% Successional habitat and 10.69% road (Figure7). During daytime tracking, squirrel 461 was observed roosting in a low snag with at least 4 other individuals. Her collar was retrieved during recapture trapping in August.

Squirrel 760 was an adult male in the same area as squirrel 461, but his home range extended eastward toward Woods Rd (Figure 5). His minimum convex home range was 8.32 ha after 38 days of tracking (Table 6). His directional distribution was 17.02 ha at two standard deviations and 4.26 ha at one standard deviation (Table 3). His largest movement was 279.78 meters in 2 hours and 6 minutes (Table 4). The vegetative composition of his home range was 7.59% Pitch Pine/ White Oak, 69.54% Pitch Pine/ Mixed Oak-Heath, 15.04% Scarlet Oak-Heath, 0.77% Successional habitat and 7.06% road (Table 5). His collar was not retrieved.

In 2012, 26 squirrels were captured over 224 trap nights producing an 11.61% capture success rate, beginning in May and resuming in August (Table 1). The highest capture success rate was in the beginning of June at 18.57%. Out of the 26 squirrels captured, a total of 11 were collared. Four squirrels were collared and tracked on Upton Rd just north of the South Gate exit to the Long Island Expressway (Figure 6).

Squirrel 920 was an adult female that was tracked for 13 days with a minimum convex home range of 0.05 ha (Table 6) before the collar was retrieved. Since the collar was loose when it was deployed and intact upon retrieval, it was assumed the squirrel was able to slip the collar off. She had a directional distribution of 0.25 ha at two standard deviations and 0.06 ha at one standard deviation (Table 3). Her largest movement was 224.98 meters over 4 days and 6 hours (Table 4). She was located in the same tree many days in a row and it was assumed, since her mammary glands were visible upon capture that she might have been caring for young. Her home range vegetation was composed of 86.43% Pitch Pine/ Mixed Oak-Heath, 12.25% Scarlet Oak-Heath forest and 1.31% road (Table 5).

Squirrel 190 was a juvenile male tracked for 65 days on Upton Rd with a minimum convex home range of 2.22 ha (Table 6). His directional distribution was 5.57 ha at two standard deviations and 1.39 ha at one standard deviation (Table 3). His largest movement was 117.61 meters in 40 minutes (Table 4). During the last few days of tracking, squirrel 190 was tracked to the same tree which was then colonized by a wasps hive. Since squirrel 190 hadn't moved from that tree and was not recaptured we are assuming that he slipped the collar within the tree cavity and it cannot be retrieved. The vegetation composition of his home range was 6.13% Pitch Pine/ White Oak, 13.84%

Pitch Pine/ Mixed Oak-Heath, 58.82% Scarlet Oak-Heath forest, 16.03% grass and 5.18% road (Table 5).

Squirrel 250 was an adult male, tracked for 64 days in the same location as the previous squirrels (Figure 6). His minimum convex home range was 6.46 ha (Table 6) and his directional distribution was 11.84 ha and 2.96 ha at two and one standard deviations, respectively (Table 3). His largest movement was115.6 meters in 34 minutes (Table 4). His collar was not retrieved during recapture trapping and is assumed to have been slipped in an adjacent tree to squirrel 190. The vegetative composition of his home range was 2.19% Pitch Pine/ White Oak, 35.99% Pitch Pine/ Mixed Oak-Heath, 48.65% Scarlet Oak-Heath forest, 8.66% grass and 4.5% road (Table 5).

Squirrel 925, an adult male, is the last squirrel tracked in this location (Figure 6). His collar was redeployed to him after being slipped by Squirrel 920. He was tracked for 44 days and had a minimum convex home range of 8.21 ha (Table 6). He had a directional distribution of 25.56 ha at two standard deviations and 6.14 ha at one standard deviation (Table 3). His largest movement was 110.4 meters in 29 minutes (Table 4). The vegetative composition of his home range was 1.76% Pitch Pine/ White Oak, 18.08% Pitch Pine/ Mixed Oak-Heath, 72.71% Scarlet Oak-Heath forest, 5.43% grass and 2.03% road (Table 5). Squirrel 925's collar was retrieved during recapture trapping, but unfortunately due to unforeseen inclement weather trap checking was delayed. The rain had left him very wet and resulted in a mortality mostly likely due to hypothermia.

Traps were deployed in two locations on the east side of the property along the East Fire Break and the Peconic River. Two squirrels were collared from each area (Figure 7). Squirrel 220 was captured along the East Fire Break, but was only tracked for

6 days before his signal was lost. This resulted in a very small minimum convex home range of 0.006 ha (Table 6), a directional distribution of 0.05 ha at two standard deviations and 0.01 ha at one standard deviation (Table 3). His largest movement was 31.82 meters in 23 hours because the signal was lost before nighttime telemetry work could be conducted (Table 4). Because of his small home range, his vegetative composition was 100% Scarlet Oak-Heath forest (Table 5).

Squirrel 160, an adult female, was also collared on the East Fire Break (Figure 7). She had a minimum convex home range of 2.32 ha (Table 6), a directional distribution of 7.33 ha at two standard deviations and 1.83 ha at one standard deviation (Table 3). She was tracked for 58 days and her collar was never retrieved. Her largest movement was 113.74 meters in 23 hours (Table 4). Her home range consisted of 0.77% Pitch Pine/ White Oak, 56.83% Pitch Pine/ Mixed Oak-Heath, 40.94% Scarlet Oak-Heath forest and 1.46% road (Table 5).

Squirrel 160's home range overlapped with the home range of Squirrel 880, who was trapped along the Peconic River, east of the East Fire Break (Figure 7). These two squirrels were actually often tracked in the same tree. Squirrel 880 was an adult male that was tracked for 57 days and had a minimum convex home range of 6.59 ha (Table 6). He had a directional distribution of 16.87 ha at two standard deviations and 4.22 ha at one standard deviation (Table 3). His maximum movement was 321.66 meters in 32 minutes (Table 4) and was the largest movement observed during the summer of 2012. His home range consisted of 14.15% Pitch Pine/ White Oak, 32.81% Pitch Pine/ Mixed Oak-Heath, 43.18% Scarlet Oak-Heath , 4.12% Cattail Marsh, 1.84% water and 3.90% road (Table 5).

Squirrel 930 was also captured along the Peconic River (Figure 7). This adult female was tracked for 19 days, but was found in the same tree for over a week with no nighttime movement from the tree. It is assumed that either the squirrel was predated or slipped the collar high up in the tree. Her minimum convex home range was 0.02 ha (Table 6) and her directional distribution was 0.09 ha at two standard deviations and 0.01 ha at one standard deviation (Table 3). Her largest movement was from her trap location to the tree in which the collar landed which was 47.48 meters over 25 hours and 32 minutes (Table 4). Her home range was composed of 60.68% Pitch Pine/ Mixed Oak-Heath, 10.68% Scarlet Oak-Heath and 28.63% road (Table 5).

Three squirrels were collared in the forest within the Relativistic Heavy Ion Collider (RHIC) ring on site (Figure 8). Squirrel 950 was an adult female tracked for 53 days with a minimum convex home range of 1.07 ha (Table 6). She had a directional distribution of 2.61 ha at two standard deviations and 0.65 ha at one standard deviation (Table 3). Her largest movement was 135.14 meters within 72 minutes (Table 4). The vegetative composition of her home range was 62.3% Pitch Pine/ White Oak, 22.80% Pitch Pine/ Mixed Oak-Heath, 8.32% Scarlet Oak-Heath forest and 6.58% road (Table 5).

Squirrel 960 was another adult female in this area that was tracked for 57 days and had a minimum convex home range of 3.53 ha (Table 6). Her directional distribution was 6.97 ha at two standard deviations and 1.74 ha at one standard deviation (Table 3). Her largest movement was 256.37 meters in 66 minutes (Table 4). Her home range was composed of 45.31% Pitch Pine/ White Oak, 9.07% Pitch Pine/ Mixed Oak-Heath, 11.42% Scarlet Oak-Heath, 16.77% Red Maple/ Scarlet Oak-Mesic Heath forest, 6.14% grass, 8.81% water and 2.48% road (Table 5).

Squirrel 130 was the only male tracked in the RHIC ring (Figure 8). He was tracked for 53 days and had the largest home range seen during this three year study with a minimum convex home range of 24.56 ha (Table 6). He had a directional distribution of 69.75 ha and 17.44 ha at two and one standard deviations (Table 3), respectively. His largest movement was 350.27 meters in 61 minutes (Table 4). His home range, which spanned throughout most of the RHIC ring as well as outside it, was composed of 34.09% Pitch Pine/ White Oak, 24.47% Pitch Pine/ Mixed Oak-Heath, 21.27% Scarlet Oak-Heath , 2.88% Cattail Marsh, 3.97% Successional habitat, 4.13% grass, 5.76% water and 3.43% road (Table 5). None of the collars in the RHIC ring were retrieved despite recapture trapping efforts.

Discussion

In 2011, trapping was done in June and July without great success. When recapture trapping was performed in August of 2011, 49 individuals were captured over 132 trap nights. This yielded the largest capture success rate seen during this study at 37.12%. This made the seasonality of trap capture success worth looking at to see if there was a specific time of the summer that trapping would be the most advantageous. Unfortunately, the trap success by month for the previous and following year did not yield the same results, therefore showing no correlation between seasonality and trap success. In 2012, there was greater trapping success in May (12.07%) and June (18.57%) than there was in August (5.21%).

While tracking these animals, we began to assume that the longer they were tracked the larger their home range would be. Looking back at the home ranges of these squirrels, it was not the case (Table 6). Squirrel 610 was tracked for 15 days and had a

home range of 3.13 ha, which was larger than the home range of squirrel 700 who was tracked for 38 days and had a home range of 1.21 ha. The same was seen in 2012 where squirrel 190 was tracked for 65 days, the longest amount of time any squirrel was tracked. He had a home range of only 2.22 ha. Other juvenile males were tracked for shorter time, like squirrel 580 tracked for 31 days and had much larger home ranges (7.68 ha for squirrel 580). This shows that, despite the original assumption, there is no correlation between the amount of time a squirrel is tracked and the magnitude of their home range.

Home range size appears to have a stronger correlation with gender and age. The average home range of adult males is three times the average home range of juvenile males; 10.23 ha compared to 3.40 ha. Both of these averages are larger than the home range average of adult females (2.38 ha). This trend was seen for all three years of this study and there are many reasons that can influence this finding.

Juvenile males tend to have smaller home ranges than adult males because they are still foraging closer to their nest area. As time goes on, they begin to venture farther from their nest area and develop their own territories. They disperse because moving away from the family group will decrease competition and increase their resource availability (Buckallew, 2010). They may also be pushed from their original home range when the mother has a new brood and is no longer caring for the juveniles. The majority of squirrels tracked in 2010 were juvenile males whose home ranges overlapped with one another as well as with two adult females. They were assumed to be a family group because of their close proximity and the juvenile status of the squirrels tracked. Squirrel 400 had an overall northern movement that supports our idea that juvenile males move

away from their original home ranges. Over several weeks he was observed moving away from the other squirrels in the area (Figure 3).

In opposition to the movements of juvenile males, adult females are seen staying closer to favored nesting areas with abundant food sources so that they can forage and care for their young (Taulman and Smith, 2004). The females seen in this study had the smallest home ranges on average when compared to adult and juvenile males. This supports what has been stated in previous studies where female home ranges have varied between 1.95 ha and 5.88 ha (Bendel and Gates, 1987/ Taulman and Smith, 2004). This average doesn't mean that all females have small home ranges. In 2011, female squirrel 461 had a home range of 6.12 ha, which was larger than all the squirrels tracked in 2010. This outlier increase the overall average of female home ranges in 2011 (Table 1).

Males are known to have the largest home ranges. There are many reasons why adult males would have much larger home ranges than juvenile males and adult females. Males could be traveling farther at night to forage in more remote food source areas in order to decrease competition with females who are staying closer to nests (Taulman and Smith, 2004). This would allow breeding females to care for young and forage easily for food without having to travel too far. This would also contribute to the smaller home range size of females in the area. Males may be traveling farther to find females, as well. Since females do have smaller home ranges, males may have to expand their own home ranges in order to interact with multiple breeding females. The lowest home range for a male successfully tracked during this study was 3.13 ha, which falls toward the lower range seen in previous studies. According to these studies, males home range averages can vary between 2.45 ha and 16.03 ha (Taulman and Smith, 2004). Squirrel 130 tracked

in RHIC was seen to have a home range of 24.56 ha, which was more than twice the size of previously tracked squirrels in this study. Upon further investigation, this home range size has been seen before in males, when one study had a year of home ranges average up to 26.71 ha (Taulman and Smith, 2004). Squirrel 130's home range is plausible. The factors behind his outsized home range are speculative. He had been observed moving a great distance one night across the road away from the RHIC ring. He could have moved this far to forage in an area that was less populated to decrease competition or to forage on a more remote resource. He eventually moved back to the main part of his home range later that night. These movements are possible, but can also be contributed to discrepancies due to low frequency signal during triangulation.

Large movements, not unlike the one observed of squirrel 130, have been witnessed in many other squirrels. Some, more than others, seem like an exorbitant amount of movement in a very short amount of time. In 2011, Squirrel 461 was a female and had the largest movement (152.18 meters) in the shortest time (35 minutes). This is a large distance for such a small animal to cover quickly. In 2012, a bigger movement was observed of squirrel 880 when he moved 321.66 meters in 32 minutes. It is speculated that they may have been chased by a predator or competitor from the area in which they were foraging. Both squirrels were seen moving back closer to the center of their home ranges after these movements. Not enough data was collected to see whether these movements were part of a trend that the squirrels traveled to one end of their home range during certain nights more so than others.

There is a chance that these movements are caused by inaccuracies during triangulation. The squirrel could have been moving while the headings were being

recorded which would cause the triangle formed later in the Geographic Information System (GIS) to be either too large or not very accurate. These discrepancies can also be equated to the reliability of the collar frequencies when the battery of the collar began to die. The collars were guaranteed for 30 days, but would continue working pasted that point. Tracking extended well beyond the guaranteed point, with some squirrels being tracked for over 60 days. As the collars began to die, the frequencies would begin to drop (149.960 dropped to the strongest signal at 149.9595 or lower).

In certain areas with multiple collars with similar frequencies, the dying collars created some confusion and made tracking more difficult. Some collars would lose a signal during triangulation when a heading was being determined and would come back strong moments later. During this time, the squirrel could have moved or the strongest signal could have been missed. This increases the likelihood that the strongest heading was not the one recorded. Even during the first few weeks, collar frequencies could have been decaying. When collar 920 was recovered, the antenna had been cut in half by chewing which would have decreased the signal strength of the collar. The terrain also played a role in the discrepancies in signal strength. The three element Yagi antenna and receiver pick up the collar frequency at its strongest when the signal is on a horizontal plane. This is rarely the case when squirrels are in tree canopies or cavities high off the ground. The signal strength of a collar closer to the antenna by being closer to the ground is much higher than the strength of a signal from a collar high in the tree. This also creates issued when doing triangulation at night. Many roads where the signal was being recorded are at a lower elevation than the trees. The receiver does not pick up signals the same way it would if the elevation was the same. Terrain and trees can also block the

signal. It is easier to get a signal when the path between the collar and the receiver is not interrupted by tree trunks, branches or hills. Alternative plotting systems can be used to decrease the likelihood of these inaccuracies when the triangulation points are determined in the GIS.

A previous study stated that female ranges do not overlap, but have been seen to overlap with at least two males (Taulman and Smith, 2004). There was not enough data collected within this study to support or reject these claims. The females tracked in the south along Brookhaven Ave in 2010 did overlap slightly, but the females tracked within RHIC (Squirrel 950 and Squirrel 960) during 2012 did not. Each of these females did however overlap with males. The females on Brookhaven Ave overlapped with the juvenile males in this area, but this could be attributed to them possibly being from the same family group. In RHIC, squirrel 130 overlapped with both females (Figure 8), but his home range did expand over much of the area within the RHIC ring. All the female home ranges could possibly overlap with multiple males or other females in the area and these other individuals were not collared. Seeing that other individuals were trapped in these areas suggests that their home ranges do overlap with additional individuals that were not seen.

Vegetation types were analyzed to determine whether an abundant food source allowed for a squirrel to have a smaller home range because they would not have to venture as far to forage. This was not the case for the squirrels tracked in this study. At first we looked at squirrel 580, whose home range (7.68 ha) consisted of mostly planted white pine forest and three other secondary vegetation types. His vegetative composition was compared to other males in areas with diverse and abundant food sources. Squirrel

130 had the largest home range in 2012 (24.56 ha), but also had a more diverse food source made up of six different vegetation types. Squirrel 760 also had a diverse food source but had a home range of 8.32 ha that was made up of five vegetation types. All the vegetation data is in Table 5.

Squirrels that were not tracked successfully had much smaller home ranges that were composed of one or two types of vegetation. Their home range, consisting of such a homogenous vegetation type, is not contributed to their lack of need to forage further for resources, but because they were not successfully tracked for more than two weeks. This is related to the idea that the longer a squirrel is tracked does not necessarily correlate with the size of their home range. The size of their home range is then compiled by vegetation types and no correlation can been seen between the diversity of these areas and the size of the home range. Home ranges are based solely on gender, age and individual activity profiles.

During the summer of 2012, we were interested to see if there was a maximum distance across a roadway that squirrels would not cross, resulting in a fragmentation of their home range. Quickly, it was determined that the width of the road ways was not a limiting factor to many squirrels home range. Squirrels were observed crossing Upton Rd easily and frequently. Upton Rd was approximately 43 meters from trunk to trunk and 22 meters between the canopies. This was similar to the East Fire Break which was about 47 meters from trunk to trunk. This area also had a lot of low pitch pine trees along the road way that added extra cover, but squirrels did not cross this road. This could be because of the electrical wires along this road provide an obstacle that prevents the squirrel from gliding easily.

Other types of interference may have impacted squirrel movements. During 2011, two squirrels (671 and 700), were tracked along Treatment Plant Rd but did not cross north of it. This road was only 21.5 meters from trunk to trunk and 4 meters between the canopies with the canopy overlapping in many areas. The squirrels could have easily extended their home ranges across this road, but did not. This could have been a result of human interference during nighttime telemetry work, as the vehicle was used along the road and points were recorded there. Territoriality can also be a major factor dissuading these squirrels from extending their home ranges. Other squirrels may inhabit the forest north of this road, preventing the tracked squirrels from utilizing the habitat.

Availability of water did not seem to be a factor in squirrel home ranges and foraging movements. Many squirrels were tracked in habitats where water was readily available, such as the Peconic River and the recharge basins in the RHIC ring. Squirrels did not appear to establish their home ranges based on where water was available and no major movements were observed to infer that they move to and from water often. Their lack of motivation attributed to water is most likely due to the fact that this species receives a majority of its water intake from its diet.

This study has shown the presence of a healthy population of Southern Flying Squirrels at BNL and provided an average home range for the species as well as males versus females. The home ranges determined in this study have drawn a parallel with previous publications.

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Appendix

Table 1. Home Range Averages

Year	2010	2011	2012	Average
Number of Squirrels	6.00	9.00	11.00	8.67
Average home range of all squirrels	3.34	4.56	5.00	4.30
Average home range of squirrels successfully tracked (>2 weeks)	3.34	5.59	6.87	5.27
Average range of all adult males	n/a	6.00	11.46	8.73
Average home range of males (successfully tracked)	n/a	9.00	11.46	10.23
Average home range of all adult females	0.83	3.68	1.40	1.97
Average home range of females (successfully tracked)	0.83	4.56	1.74	2.38
Average home range of all juvenile males	3.97	4.01	1.11	3.03
Average home range of juvenile males (successfully tracked)	3.97	4.01	2.22	3.40

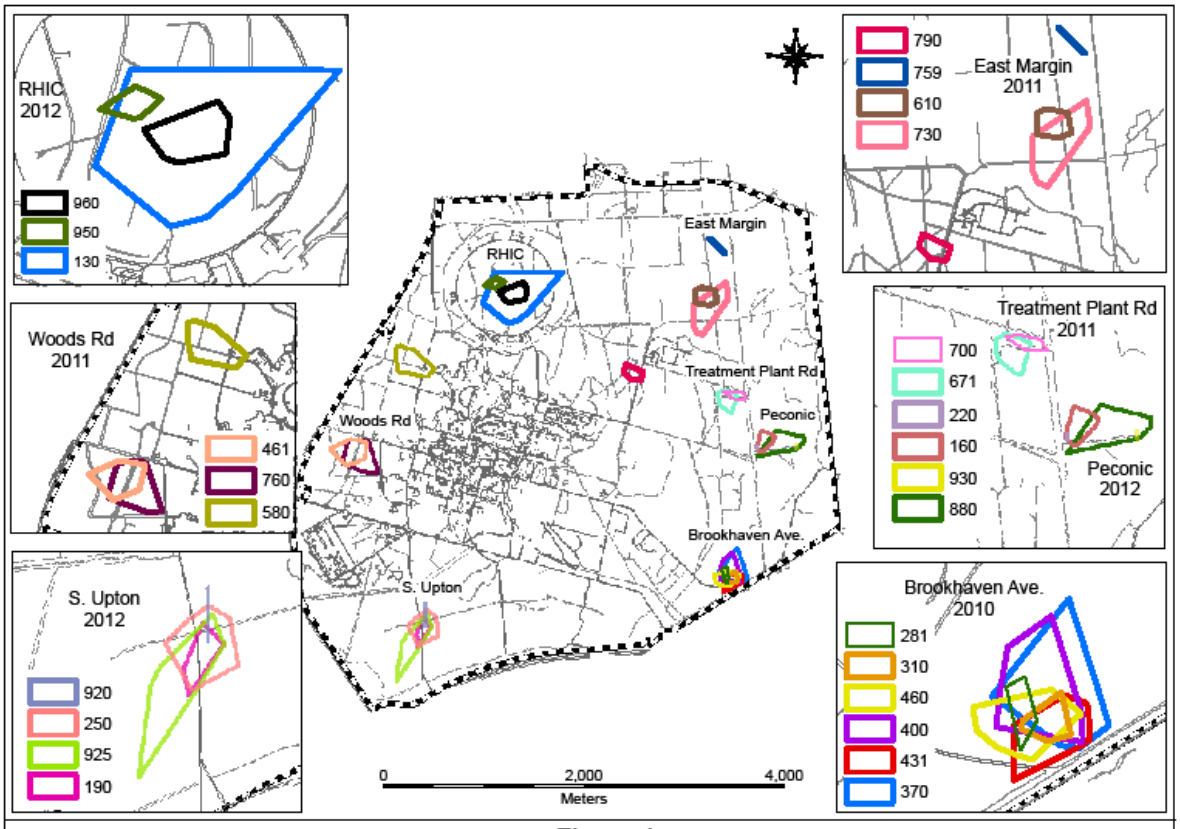

Figure 1
2010 - 2012 Southern Flying Squirrel Home Ranges

Table 2. Trap Capture Success by year

Year	Trap Nights	# of captures	% Capture
2009	480	31	6.46
2010	160	7	4.38
2011	602	82	13.62
2012	224	26	11.61

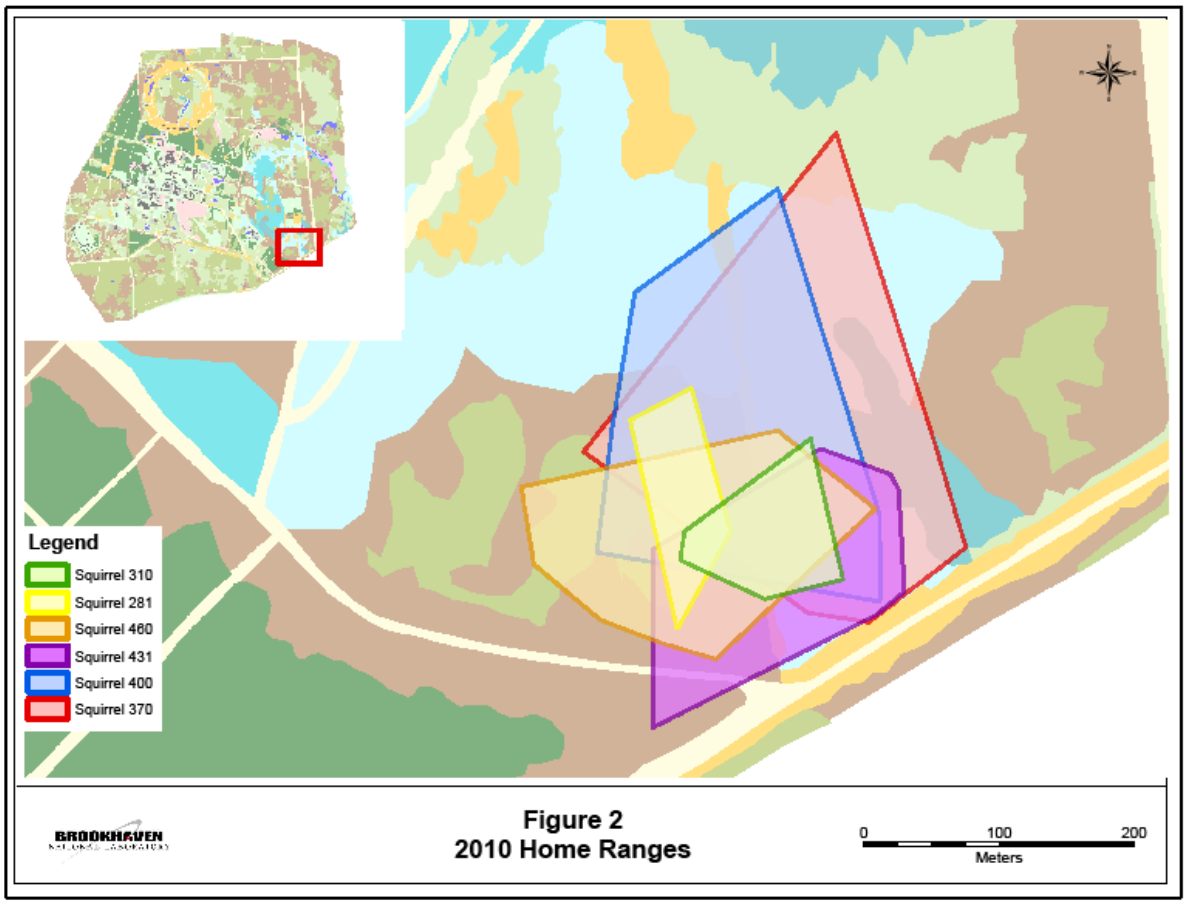

Figure 2
2010 Home Ranges

Table 3. Total Directional Distribution at one and two standard deviations

Year	Frequency	Gender	Total Directional Distribution 2 Standard Deviations	Total Directional Distribution 1 Standard Deviation
2010	281	Female	3.71	0.93
	310	Female	0.97	0.24
	370	Juvenile Male	7.49	1.87
	400	Juvenile Male	11.63	2.91
	431	Juvenile Male	5.02	1.25
	460	Juvenile Male	3.69	0.92
2011	461	Female	13.17	3.29
	671	Female	6.82	1.71
	790	Female	10.44	2.61
	760	Male	17.02	4.26
	759	Male	0.55	0.14
	730	Male	20.38	5.1
	610	Juvenile Male	5.77	1.44
	580	Juvenile Male	18.71	4.68
	700	Juvenile Male	1.83	0.46
2012	920	Female	0.25	0.06
	160	Female	7.33	1.83
	930	Female	0.09	0.01
	950	Female	2.61	0.65
	960	Female	6.97	1.74
	250	Male	11.84	2.96
	880	Male	16.87	4.22
	130	Male	69.75	17.44
	925	Male	25.56	6.14
	190	Juvenile Male	5.57	1.39
	220	Juvenile Male	0.05	0.01

Table 4. Largest movements by frequency

Year	Frequency	Gender	Largest movement (meters)	Time Elapse	Meters per Minute
2010	281	Female	156.1	19 hrs 20 min	0.13
	310	Female	104	21 min	4.95
	370	Juvenile Male	182	1 hr	3.03
	400	Juvenile Male	162.1	50 min	3.24
	431	Juvenile Male	209.3	56 min	3.74
	460	Juvenile Male	226.1	42 min	5.38
2011	461	Female	152.18	35 min	4.35
	790	Female	190.99	3 hrs	1.06
	671	Female	129.77	48 min	2.70
	730	Male	542.48	2 hrs 05 min	4.34
	760	Male	279.78	2 hrs 06 min	2.22
	759	Male	162.91	24 hrs	0.11
	580	Juvenile Male	150.35	39 min	3.86
	700	Juvenile Male	245.36	1 hr	4.09
	610	Juvenile Male	135.48	53 min	2.56
2012	920	Female	224.98	4 days 6 hrs	0.04
	160	Female	113.74	23 hrs	0.08
	930	Female	47.48	25 hrs 32 min	0.03
	950	Female	135.14	72 min	1.88
	960	Female	256.37	66 min	3.88
	250	Male	115.60	34 min	3.40
	880	Male	321.66	32 min	10.05
	130	Male	350.27	61 min	5.74
	925	Male	110.40	29 min	3.81
	190	Juvenile Male	117.61	40 min	2.94
	220	Juvenile Male	31.82	23 hrs	0.02

Year	2010										
Frequency	**281**	**310**	**370**	**400**	**431**	**460**					
Pitch Pine/ White Oak Forest			2.5								
Pitch Pine/ Mixed Oak-Heath Forest	17.2		3.3	7.4	2.7	23.5					
Scarlet Oak-Heath Forest	82.8	36	17.4	27.1	41.5	52.1					
Red Maple/Scarlet Oak-Mesic Heath Forest		55.8	58.7	58.3	46	20.4					
Planted White Pine											
Cattail Marsh											
Successional		55.8	58.7	58.3	46	20.4					
Red Maple – Blackgum Wet Forest			14.2	1.5	4.2	0.5					
Grass											
Water											
Road					1.6						
Year	**2011**										
Frequency	**461**	**671**	**790**	**760**	**759**	**730**	**610**	**580**	**700**		
Pitch Pine/ White Oak Forest	2.57	25.44	9.81	7.59				19.58	12.24		
Pitch Pine/ Mixed Oak-Heath Forest	76.88	7.02	48.53	69.54	96.04	63.80	40.61	5.78			
Scarlet Oak-Heath Forest	9.41	24.26		15.04	3.96	23.67	56.00				
Red Maple/Scarlet Oak-Mesic Heath Forest		38.28				9			80.37		
Planted White Pine			29.41					66.28			
Cattail Marsh											
Successional	0.45			0.77							
Red Maple – Blackgum Wet Forest											
Grass											
Water											
Road	10.69	4.99	12.25	7.06		3.53	3.39	8.37	7.39		
Year	**2012**										
Frequency	**920**	**160**	**930**	**950**	**960**	**250**	**880**	**130**	**925**	**190**	**220**
Pitch Pine/ White Oak Forest		0.77		62.30	45.31	2.19	14.15	34.09	1.76	6.13	
Pitch Pine/ Mixed Oak-Heath Forest	86.43	56.83	60.68	22.80	9.07	35.99	32.81	24.47	18.08	13.84	
Scarlet Oak-Heath Forest	12.25	40.94	10.68	8.32	11.42	48.65	43.18	21.27	72.71	58.82	100
Red Maple/Scarlet Oak-Mesic Heath Forest					16.77						
Planted White Pine											
Cattail Marsh							4.12	2.88			
Successional								3.97			
Red Maple – Blackgum Wet Forest											
Grass					6.14	8.66		4.13	5.43	16.03	
Water					8.81		1.84	5.76			
Road	1.31	1.46	28.63	6.58	2.48	4.5	3.90	3.43	2.03	5.18	

Table 5. Percentage vegetative composition of home ranges

Table 6. Gender, Time Tracked and Home Ranges

Year	Frequency	Gender	Time Tracked	Minimum Convex Polygon Home Range (Hectares)
2010	281	Female	4 days	n/a
	310	Female	37 days	0.83
	370	Juvenile Male	35 days	5.28
	400	Juvenile Male	36 days	4.25
	431	Juvenile Male	18 days	2.41
	460	Juvenile Male	35 days	3.94
2011	461	Female	38 days	6.12
	671	Female	38 days	2.99
	790	Female	2 days	1.93
	760	Male	38 days	8.32
	759	Male	4 days	0.008
	730	Male	22 days	9.68
	610	Juvenile Male	15 days	3.13
	580	Juvenile Male	31 days	7.68
	700	Juvenile Male	38 days	1.21
2012	920	Female	13 days	0.05
	160	Female	58 days	2.32
	930	Female	19 days	0.02
	950	Female	53 days	1.07
	960	Female	57 days	3.53
	250	Male	64 days	6.46
	880	Male	57 days	6.59
	130	Male	53 days	24.56
	925	Male	44 days	8.21
	190	Juvenile Male	65 days	2.22
	220	Juvenile Male	6 days	0.006

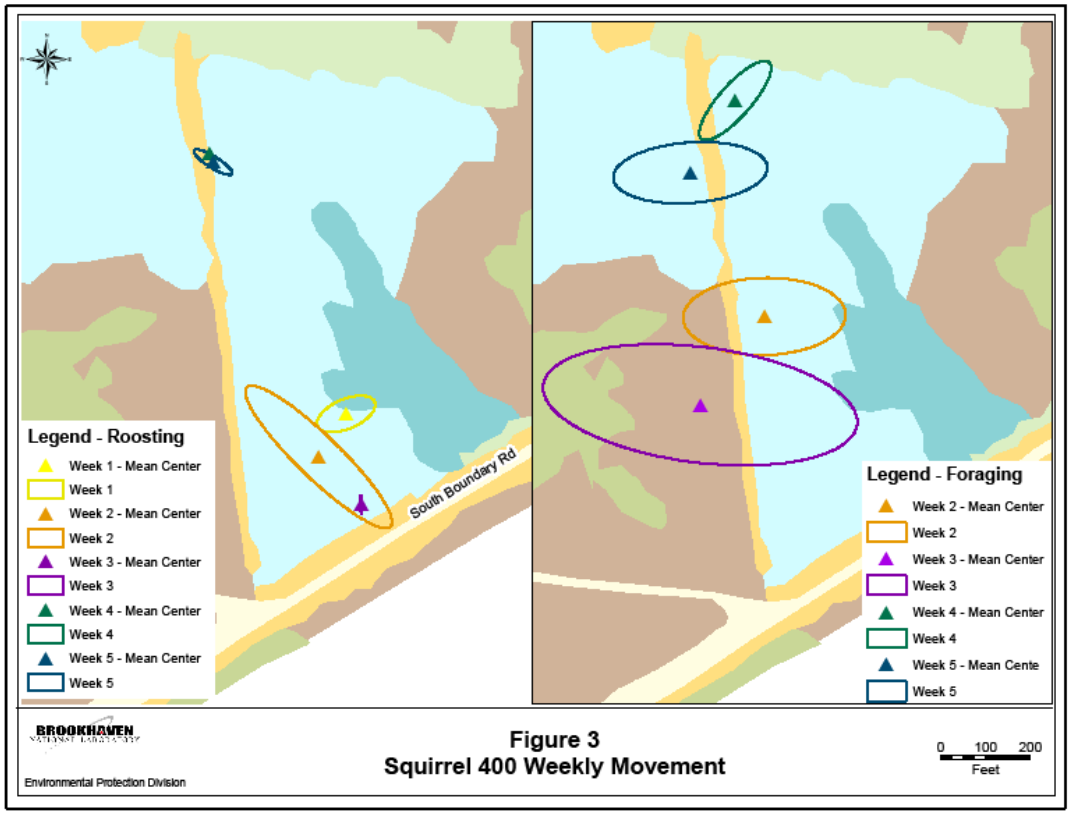

Figure 3
Squirrel 400 Weekly Movement

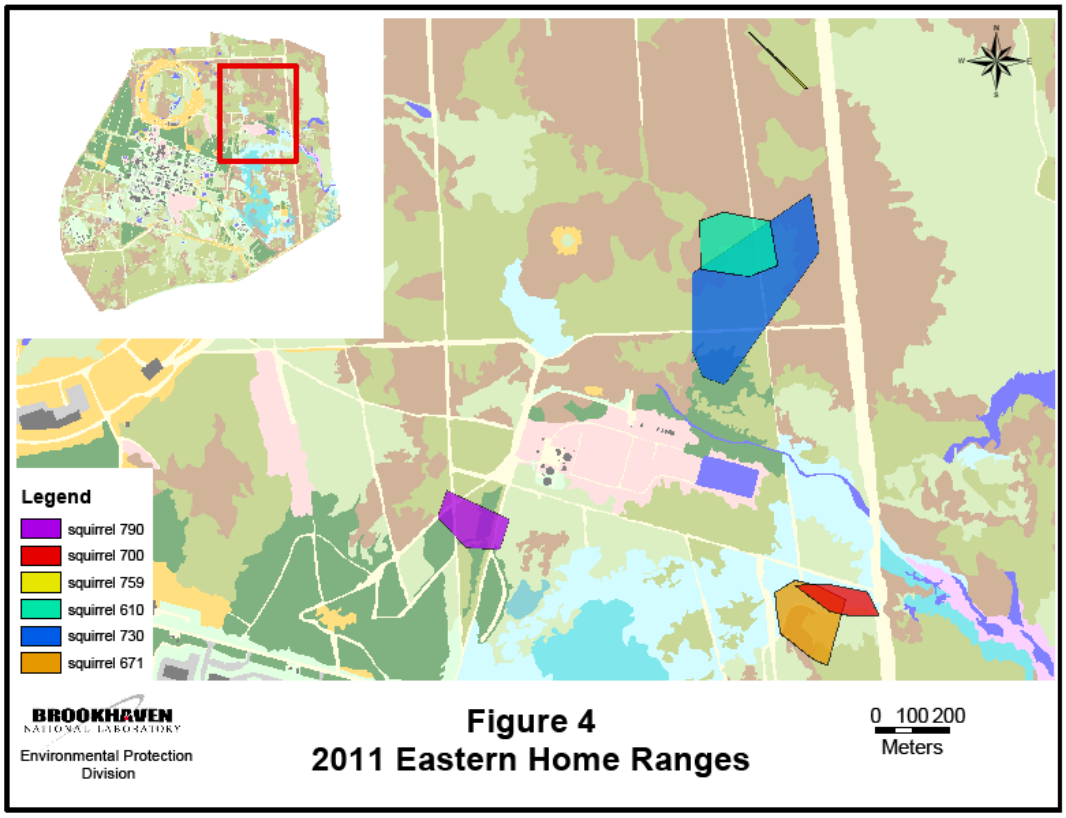

Figure 4
2011 Eastern Home Ranges

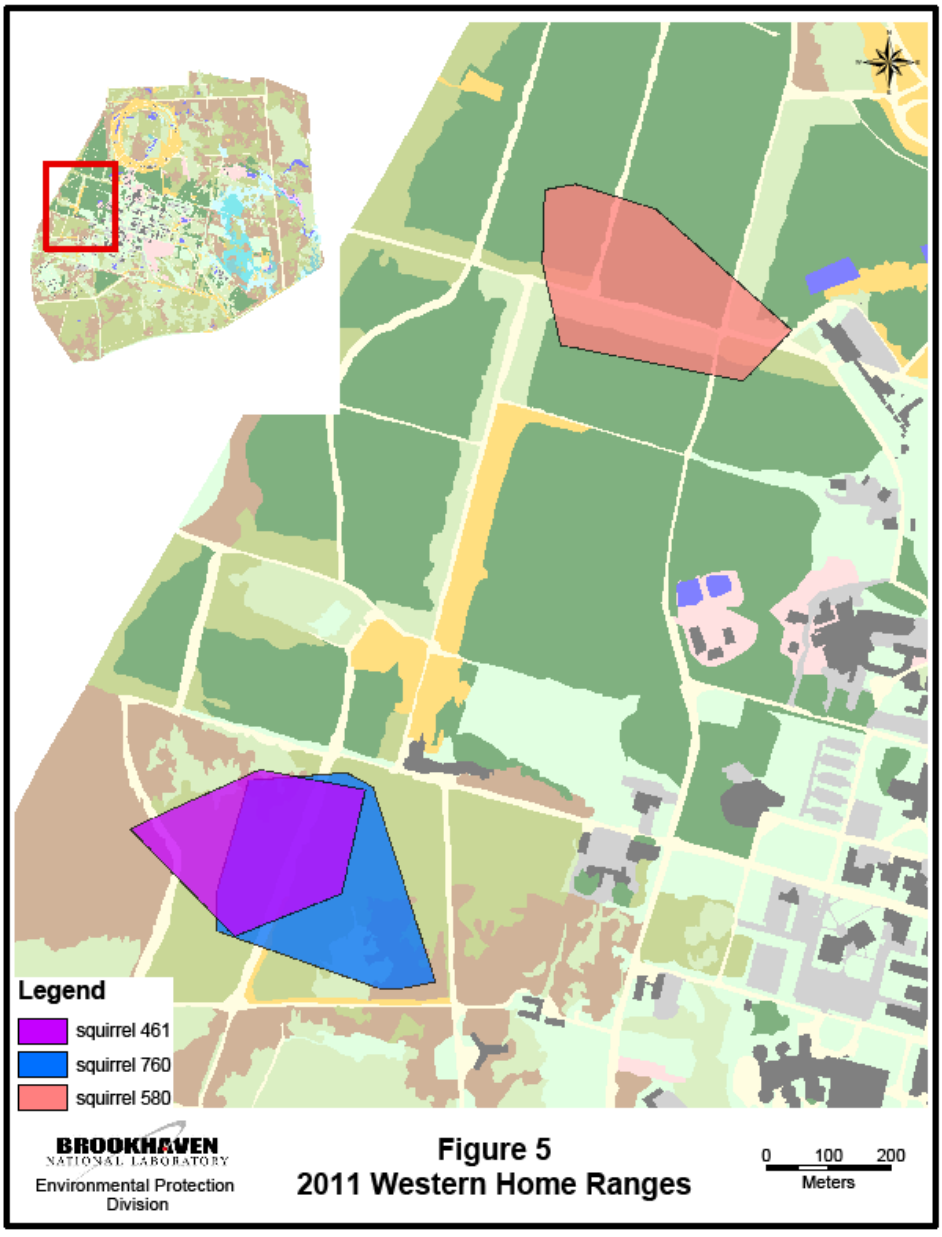
Legend
squirrel 461
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Figure 5
2011 Western Home Ranges
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Meters

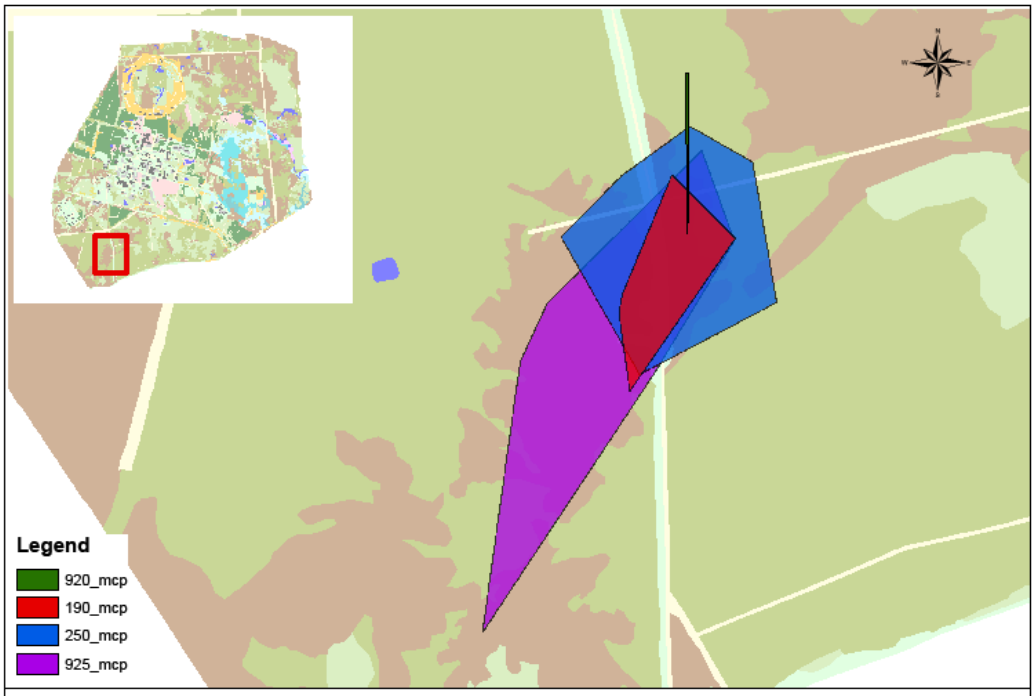

Figure 6
2012 Home Ranges on Upton Rd

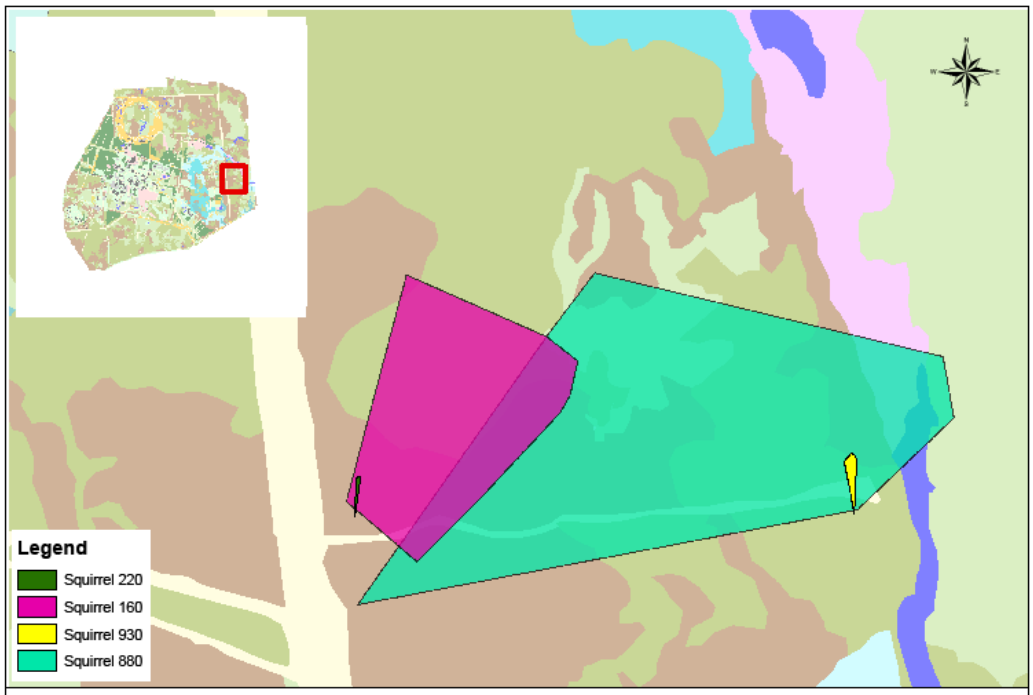

Figure 7
2012 Home Ranges at Peconic River

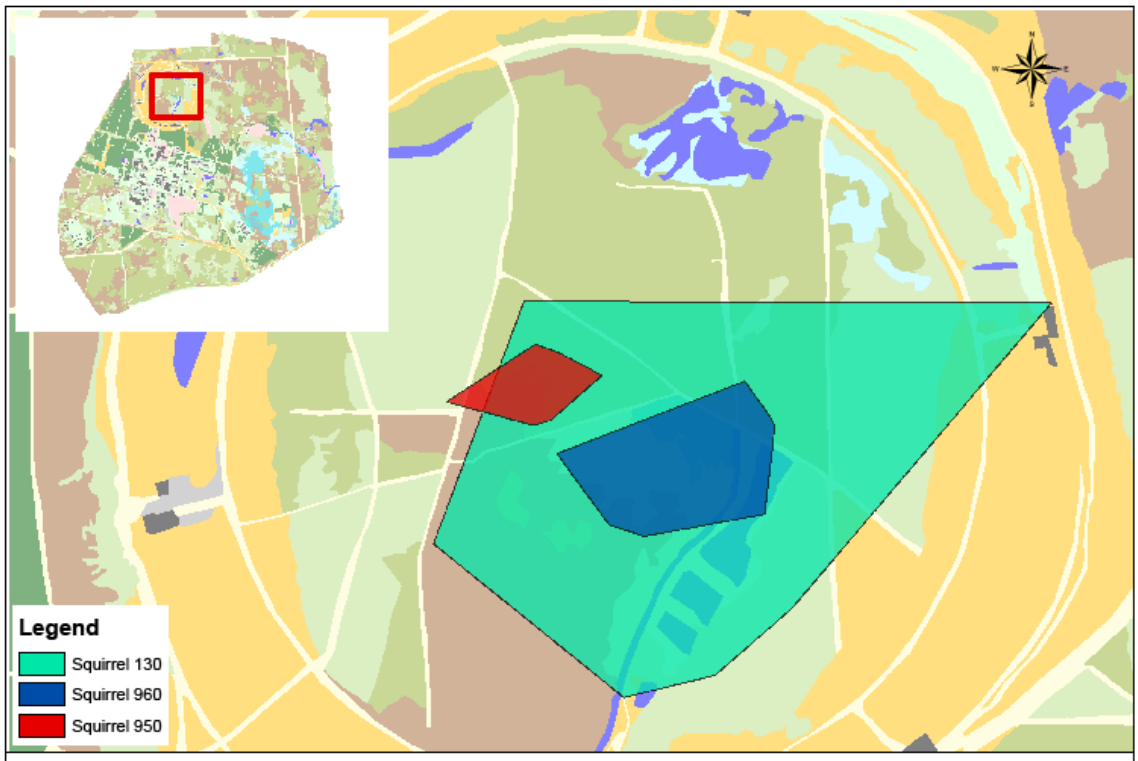

Figure 8
2012 Home Ranges in RHIC