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HOW DOES THE ABUNDANCE AND DISTRIBUTION OF RESOURCES AFFECT FEMALE RACCOON HOME RANGES IN AN URBAN PARK?

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THESIS ABSTRACT

Urban development fragments the natural landscape and, as a result, remaining natural habitats, which are much reduced in size, are island-like and often embedded in an inhospitable matrix. While these changes are generally considered to have a negative impact on wildlife, the process of urbanization also creates new habitats in which some species appear to thrive despite the altered conditions and increased human density. The raccoon (*Procyon lotor*) is an ideal model for investigating the effects of urbanization on spatial patterns of habitat use because they are known to inhabit all landscapes along the urban to rural gradient. When studying wildlife in urban environments the techniques used need to be validated as urban ecology is a new field. Besides being good models for urban studies, raccoons can serve as ideal subjects to design studies that validate telemetry data in urban environments. This study had two objectives: 1) to evaluate the accuracy of telemetry in an urban setting; 2) to determine how the distribution and abundance of resources and habitat affect the home range of raccoons in a diverse urban park. A combination of radio telemetry and geographical information systems (GIS) was used in this study. To validate the telemetry system 33 known locations were evenly distributed by habitat type to calculate mean error, bias and precision. In the raccoon portion of the study, telemetry locations were collected on 10 female raccoon for one year. Home range size and placement, as well as overlap with resources and habitats were calculated. To our knowledge this is the first study to attempt to quantify telemetry accuracy in an urban area. Signal reflection & electronic noise appear to cause telemetry error at the study site. Raccoon home ranges were small and stable with considerable overlap; however core home ranges were not clustered. Anthropogenic food sources were strongly associated with home range, and raccoons showed a preference for the mixed habitat type. These data add to our understanding of the challenges of working in urban areas while contributing new information on the ecology of urban raccoons.

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CHAPTER 1

INTRODUCTION – STUDYING WILDLIFE IN URBAN SETTINGS

Urbanization and its effects on wildlife

Conversion of land for agriculture and for commercial/residential building is the number one cause of species endangerment in the United States (Czech, 2000). In the last several decades human impacts on wildlife have escalated, primarily due to building in suburban and urban areas. For the first time in history more people live in urban than in rural areas (Forman, 2008). Referred to as urbanization, this process involves increases in human population density, more intense land use (Marzluff, 2001), and changes in the landscape due to development (Luniak, 2004). Urban areas vary, but all have a characteristic central core area that consists primarily of hardscape (buildings, roads, etc.) for a mix of industrial, residential and transportation purposes. Moving away from the urban core the amount of hardscape begins to decrease and areas become more residential, gradually being replaced with more natural areas. A clear gradient or continuum is notable, and habitat changes can be seen in these concentric rings from the natural areas to the urban core (Forman, 2008). This "rural to urban gradient" was first described by McDonnell and Pickett (1993) and has become a tool for ecologists to quantify the changes due to urban impacts (e.g., see Alberti, 2001). The consequences of small patch size were originally thought to be a phenomenon that affected only islands (theory of island biography, MacArthur, 1967). Investigations into the effects of fragmentation, however, have revealed similarities between the predictions for islands and those for forest fragments (Bierregaard, 1992). Evidence that small fragments correlate with decreased species richness in tropical forests has now been demonstrated in all ecosystems studied. Decreased fragment size, changes in composition of the landscape and lack of connectivity are associated with the loss of species diversity and local extinctions (Rosenblatt, 1999; Turner 1996). In urban settings increased fragmentation causes the landscape to become a mosaic of patches (e.g., remnant forest patch, industrial patch, fields, etc.) that make the distribution of resources more discontinuous compared to rural landscapes (Alberti, 2001). These landscape changes cause animals, which do not readily cross unsuitable matrices or patch types, to aggregate. Such aggregation may result in increased population densities and smaller home ranges in urban areas when compared to rural areas.

DeStefano (2003) used the term “two-edged sword” when referring to the trade-offs for wildlife concomitant with ecosystem changes in the urban/suburban areas. Ecologically, urban areas have altered ecosystems with documented changes in temperature, resource availability, light, noise and habitat productivity (Kaye, 2006). Hardscape creates an impervious surface that absorbs heat, repels water, and causes sound waves to bounce. This results in surface water being re-routed into underground pipe systems (Kaye, 2006; Forman, 2008), noise being magnified, and temperatures being higher (Kaye, 2006) within the urban core (urban heat island effect, Munn, 1969). Land use changes cause alterations in soil type and chemistry which has a direct effect on plant productivity. Yet despite these negative changes, positive changes also emerge. For example, urban and suburban areas generally have more artificial lakes, increased temperatures may act as a buffer against cold winters, hardscape can provide additional shelter and there is often more access to food for urban dwelling wildlife.

The effects of urbanization on native communities have been most studied in birds. Comparative studies of the structure and composition of bird communities demonstrate a decrease in species richness and an increase in bird biomass in urban areas (Marzluff, 2001). Decreasing species richness as a result of urbanization also has been shown in plant (Thompson, 1999), insect (Kozlov, 1996) and mammal communities (Dickman, 1987). Increase in biomass and decrease in richness reflects increased abundance of species that have adapted to living in human-dominated ecosystems, which has been termed synanthropization (Luniak, 2004). Blair (2001) explained this phenomenon by classifying three categories of species: urban exploiters, adaptors and avoiders. Species like rats and rock doves are examples of urban-exploiter species; these are non-native species which are totally dependent on human presence and thrive in urban environments. In contrast urban adaptors are species that can tolerate disturbance, and although they are thought to directly benefit from human presence, they have a flexible ecology so as to be able to forage on their own, if necessary. These species are generally medium-sized mammals or birds such as coyotes and robins. Avoider species, such as elk and ground nesting birds, are sensitive to humans and the associated disturbances, and, as the name implies, they avoid urban areas, preferring rural and large natural areas (McKinney, 2002). Thus, in urban areas the decrease in diversity results from a loss of native species, whereas the resulting increase in biomass is caused by the success of a few abundant species that can adapt to or prefer disturbed habitats.

Challenges of working in an urban setting: radio telemetry

Urban ecology is a relatively new discipline because most biologists historically preferred to study wildlife in more natural habitats. However in the last four decades there has been an increasing focus on working in urban or suburban habitats. Most of these studies have utilized existing field techniques, although some have had to be modified for working in areas with higher densities of people. For some techniques, such as trapping, the challenge of working among the general public requires modification to the technique. In urban areas traps can be moved, closed or stolen by people who do not want to have animals trapped (pers. observ.), and care must be taken not to trap pets or accidently injure children. However for other techniques like radio telemetry, it is not as obvious what, if any, modifications need to be made in urban areas. Telemetry has been a popular method for tracking wildlife in non-urban areas since the early 1960's. However, telemetry is subject to error which decreases accuracy, and the factors that contribute to telemetry error are many. Therefore, understanding and quantifying these factors are an important step to reduce error and improve our ability to interpret telemetry data in biologically meaningful ways. Some of these factors are environmental, such as topographical relief, type and amount of heterogeneous vegetation (Hupp, 1983), line of sight or signal reflection (Garrott, 1986), and electromagnetic effects (Swenson, 1973;

Cudak, 1991) which may contribute to loss of accuracy and precision (i.e., repeatability of measurements). Non-environmental factors, such as type of equipment (Pace, 1988), design and placement of receiving stations that affect distance to the animal (Garrott, 1986, White, 1990) and technician skill (Springer, 1979) also are known to contribute to sampling error. While these same factors apply to using telemetry in urban areas, it is likely that some of the factors may cause additional challenges not encountered in more remote habitats.

Signal reflection can occur when an object such as a building or patch of vegetation comes between the transmitter (collar) and the receiving station. The radio signal hits the object in its path, altering the direction and distance traveled to the receiving station. The likelihood of reflection increases with the distance the signal travels, the patchiness of the site and the amount of hardscape, since these increase the chance that the signal will encounter an object(s) prior to reaching the receiving station. Signal reflection is made more complex if the objects between the collar and the receiving station include "non-visible" obstructions (e.g., a metal bridge below the antenna height will not appear to obstruct the signal, but the conductive nature of the metal can cause bounce even below the sight line), since radio waves occur on different wavelengths than visible light (Cochran 1980). Unlike some of the other factors that create telemetry error, non-visible obstructions make signal reflection almost impossible to control when designing the study or to detect after the fact. The amount of fragmented land- and hardscape found in urban environments suggests that errors due to signal reflection will be higher in urban settings compared to non-urban areas where most telemetry studies have traditionally occurred.

Telemetry studies in urban areas are also challenged by the quantity of electronic noise, which due to inadequate measurement methods, is also difficult to control when designing the study. Electronic noise is generated by electronic equipment, such as computers, microwave ovens, electric power lines, garage door openers, engines, and potentially cell phones that emit radiation within the electromagnetic spectrum (Cudak, 1991; Swenson, 1973; Withey, 2001). This type of "noise" has been documented to interfere with telemetry signals (Parker, 1996). Baseline readings for electronic noise in a crop field with no equipment nearby were reported to be 300K (Kayser: number of waves per centimeter) (Cudak, 1991). Yet several small towns (less than 2000 people) and larger cities (40,000-100,000 people) in Illinois had readings between 500 and 17000K in 1973 (Swenson, 1973) and again when the study was repeated in 1991 (Cudak, 1991). The typical frequency bands used for wildlife telemetry in the United States are 148-152 MHz. Both studies tested several frequencies (144-412 MHz), and the greatest electronic noise was measured at 148 and 222 MHz, frequencies that bracket the assigned wildlife frequencies. To our knowledge no study has specifically tested for the effect of electromagnetic noise on wildlife telemetry data, but understanding the effect of electromagnetic noise will be valuable for the success of future telemetry studies.

Literature reviews (e.g., publications in the Journal of Wildlife Management by Saltz 1990 and Withey 2001) suggest that error measurements are often not reported in telemetry studies. Combining the results from both reviews reveals that 27% of all published telemetry studies from 1986-1999 did not report error measurements (Wiley, 2001). In these studies it is unclear if error measurements are not collected or simply not reported in all studies. Error measurements allow for customized settings of bearing thresholds (Saltz, 1990), as well as provide an opportunity to identify sources of error on a study site or with a system; when identified, such errors may be able to be controlled or even eliminated prior to data collection. Therefore, these data are extremely important in telemetry studies, since estimated locations can rarely be verified (except by walking in on larger mammals); without some sort of validation we cannot evaluate the uncertainty in our location results, especially at finer habitat scales. Studies by Lee (1985) and Garrott (1986) created a template for researchers to be able to quantify accuracy and measure error at each study site. Recommendations by White (1990) and Saltz (1990) include the documentation of the mean area, standard deviation of confidence ellipses (or error polygon, if only two bearings are used) and documentation of methods used for data censorship in all telemetry publications. Given that conditions in urban areas are more likely conducive to increased error due to signal reflection and electromagnetic noise, it is vital that biologists working on urban study sites test for telemetry error and attempt to document the factors causing this error where possible.

Raccoons, the ultimate urban adaptor and model for urban telemetry studies

The raccoon (*Procyon lotor*) is an ideal model organism for investigating the effects of urbanization on spatial patterns of habitat use because they are known to inhabit all landscapes along the urban to rural gradient. Raccoons are considered solitary having little contact among adults except during mating (Frizell, 1978), although more recent studies suggest that this the level of sociality may be more complex than previously believed. Both sexes can have overlapping home ranges (Frizell, 1978, Gehrt, 1998; Ratnayeke, 2002; Prange, 2004) which also suggests some level of sociality. Spatial organization is thought to be resource-based for females, with males spacing themselves around females (Sandell, 1989; Gehrt, 1998). They are primarily nocturnal with an omnivorous diet. Most studies of raccoons have occurred in rural and agricultural areas. Several studies have documented adult survival rates of 47-84% (Clark, 1989; Gehrt, 1999; Mankin, 1999). Raccoons are still legally harvested in some rural and agricultural areas with associated annual mortality rates of 78% in Iowa and 81% in Illinois, respectively (Clark, 1989; Mankin, 1999). Both sexes are capable of reproduction at one year of age; however, few yearling males have the chance to mate (Stuewer, 1943, Sanderson, 1973). In Illinois and Iowa, 85-91% of adult females harvested were pregnant (Clark, 1989; Mankin, 1999). Reproduction appears not to alter circadian rhythms, den location, home range size and use of habitat types in females studied in rural Minnesota (Schneider, 1971). Raccoon densities in rural or agricultural areas range from 2-20 individuals/km^2 (Lotze, 1979). Home range size for males ranged from 129 ha in forest-land in Mississippi (Chamberlain 2002) to 1627 ha in rural North

Dakota (Fritzell, 1978). Females appear to be philopatric (Ratnayeke, 2002) and can have overlapping home ranges (Frizell, 1978, Gehrt, 1998; Ratnayeke, 2002). Trees appear to be the preferred den sites for both sexes, although rock outcroppings and ground nests were also used (Enders, 1993; Nixon, 2001, Henner, 2004).

Information about raccoons in urban areas is not as comprehensive as it is for non-urban areas. However, work by several authors (Riley, 1998; Hatten, 2000; Gehrt, 2001, 2002a-c; Hadidian, 2002) have begun to provide insights into the flexibility of raccoon ecology by contrasting results from urban areas to those from rural settings. The majority of studies of raccoons in suburban/urban environments focus on disease and/or parasitology. Increased rates of disease and parasite transfer have been linked to high densities due to both intra- and inter-species contact at food sites where animals aggregate (Riley, 1998; Mitchell, 1999; Totten, 2002). Studies have found that raccoon densities are higher in urban areas with densities ranging from 35-125 individuals/km^2 (Riley, 1998). This increase in density is attributed to greater food availability, increased availability of den sites and lack of hunting pressure (Dickman, 1987). Urban raccoon populations also seem to be more stable than rural populations, with individuals having smaller home range sizes (Hoffman, 1977). It has been proposed that this stability and small home range size can be attributed to greater availability of food resources and the fragmentation of the urban landscape (Hatten, 2000), which constrain animal movement. In a study in Illinois comparing an urban forest preserve with a rural park, Hatten (2000) found that the home range size of raccoons in the urban preserve ranged from 36-111 hectares, whereas in the rural park the home range size was much larger, ranging from 141-238 hectares during the same time period. Studies on resource use in urban settings are scant but growing in number. Hadidian (1991), who studied raccoons in Rock Creek Park in Washington, D.C., found that although raccoons did utilize man-made structures, 69% of all dens were located in trees. Bozak (2007) provided the first empirical evidence supporting the commonly stated belief that raccoons are successful in urban environments primarily due to the availability of anthropogenic food sources. Results from her compositional analysis showed that within the home range, raccoons utilized the human use habitat class at the urban study site the most, in contrast to the suburban and rural sites where the human use habitat class was ranked 3 and 4 respectively. Despite the work of several researchers examining urban raccoon populations in several areas, there remain serious gaps in our knowledge of the ecology of urban raccoons. In particular, we have little understanding of how key resources influence the location and size of home ranges, what factors influence habitat use, or how the effects of spatial scale might alter observed habitat use patterns given the mosaic of the urban landscape. Further work is needed to elucidate variation in behavior and ecology between rural and urban raccoons to understand why raccoons are such successful urban adaptors.

In the second chapter of this thesis, we present a series of tests using a mobile telemetry system at our study site, Forest Park (Saint Louis, MO). The purpose of these tests was to evaluate the accuracy of telemetry under the conditions at our study site, a large urban park. To the best of our knowledge this is the first attempt to document the factors that affect telemetry signals and quantify error measurements in an urban setting. In the third chapter we present our findings of how the abundance and distribution of resources affect home ranges of female raccoons utilizing radio telemetry and GIS technology. Our hope is that insight gained at this study site will contribute to the growing body of knowledge of raccoon behavior and ecology in urban settings.

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CHAPTER 2

MEASURING ACCURACY OF RADIO TELEMETRY IN FOREST PARK, A LARGE URBAN PARK

Introduction

Since its initial use in the early 1960s as a technique to study individual small mammals in wild populations (porcupines: Marshall, 1962; raccoons, rabbits and hares: Mech 1965; rabbits, skunks and raccoons: Cochran, 1963), radio telemetry has revolutionized the study of ecology and wildlife biology. As with any technology, however, telemetry is subject to error which results in decreased accuracy. The factors that contribute to telemetry error are many. Understanding and quantifying these factors is an important step to reduce error and improve our ability to interpret telemetry data in biologically meaningful ways.

Early studies that examined telemetry error emphasized that animal location data should be treated not as discrete points but rather as points with a surrounding area defined by the intersection of the error arcs. These areas, termed “error polygons” by Heezen (1967), provided one of the first methods to measure the amount of error associated with each point. Subsequently, Springer (1979) demonstrated that larger confidence intervals are associated with larger error polygons. Lee (1985) developed a method to test the accuracy of these estimated locations using known reference points. Quantification of the errors at each study site sensu Lee (1985) may allow for the identification of the sources of these errors so that they can be mitigated, where possible, which aids in the interpretation of results. Telemetry error can be caused by both environmental and non-environmental factors. Non-environmental factors, such as equipment (Pace, 1988), design and placement of receiving stations (Garrott, 1986, White, 1990), and technician skill (Springer, 1979) can be more easily tested and controlled in the experimental design. Environmental factors, such as changes in wind, temperature (Heezen, 1967) or topographical relief (Hupp, 1983; Kufeld, 1987), type and amount of heterogeneous vegetation (Hupp, 1983; Chu, 1989), signal reflection (Garrott, 1986), and electromagnetic effects (Swenson, 1973; Cudak, 1991) are harder to control and can result in loss of both accuracy and precision (i.e., repeatability of measurements). Many environmental factors, however, are consistent and tangible within a study site (e.g., topography and vegetation); therefore, these factors can be documented and accounted for in telemetry studies. Factors such as signal reflection and electronic noise, in contrast, are more difficult to detect, due to their transient nature and are almost impossible to control when designing the study.

Signals transmitted by radio collars are a form of electromagnetic radiation as are light waves and microwaves. Radio waves have a unique wavelength or frequency; however, all forms of electromagnetic waves have similar properties. Thus, when a wave of any type encounters an obstruction during transmission, it will be absorbed, reflected, refracted or diffused. This occurs to differing degrees depending on the wavelength and the properties of the object in the path of that wave. Unfortunately the object is not always a visible line of sight (LOS) obstruction, but can be a non-visible

(NLOS) obstruction (Cochran 1980), which provides challenges for telemetry. Many authors have demonstrated that telemetry radio waves appear to be affected by signal reflection (bounce) or refraction (bending), generally referring to this phenomenon as signal reflection or "bounce". Lee (1985) concluded that outliers of a persistent nature may be caused by this signal reflection. Distance between the animal and the receiving station, the amount of heterogeneity at the study site and the amount of urbanization all increase the chances of bounce. Bounce also causes a loss of signal strength due to increased distance and may cause misinterpretation of the direction of the strongest signal, both of which increase the location error and contribute to signal loss (Samuel, 1996).

Electronic noise is another possible source of error and signal loss. Such noise comes from electronic equipment that emits radiation within the electromagnetic spectrum, such as computers, microwave ovens, electric power lines, garage door openers, engines, and potentially cell phones (Cudak, 1991; Swenson, 1973; Withey, 2001). This type of noise has been documented to interfere with telemetry signals (Parker, 1996) but has not been systematically studied. Electronic noise is more likely to occur in urban areas due to the increased number of transmitters that operate at a wide variety of specified frequencies. Telemetry receivers should not be receiving signals at these frequencies, but some of these non-telemetry transmitters also emit spurious electromagnetic waves, including radio waves (Cudak, 1991; Swenson, 1973). Baseline readings for noise in an Illinois crop field with no electronic equipment nearby were reported to be 300K (Kayser: number of wave numbers per centimeter) (Cudak, 1991). Readings from several small towns (less than 2000 people) were only slightly above baseline at 500K. Yet larger cities with populations of 40,000-100,000 people were as high as 17000K in both 1973 and in 1991 (Swenson, 1973; Cudak, 1991). Further, the greatest electronic noise measured in both studies was at 148 and the 222 MHz, which could be of concern to biologists because these frequencies bracket the typical frequency bands used for wildlife telemetry in the United States (148-152 MHz) (Swenson, 1973; Cudak, 1991). Swenson (1973) also noted that transmitters must work at higher power to be received in urban areas due to the noise generated by spurious signals which suggests that signal strength of wildlife collars need to be stronger than those used to monitor animals in rural habitats.

There are three methods for identifying that a bounced signal exists; two of these are mentioned by Lee (1985), including checking for bearings that do not intersect (if only two bearings) and eliminating bearings that do not fit with the known pattern of an individual animal. These methods are highly subjective, whereas the third method described by Garrott (1986) involves the collection of three or more bearings and utilizes a statistical estimator which rigorously excludes outliers. Lenth (1981) developed three probability model estimators (maximum likelihood, Huber and Andrews). The maximum likelihood (MLE) estimator is based on the Von Mises model. This model, which uses most if not all of the bearings, is not as robust to outliers caused by situations such as signal reflection. Both the Huber and Andrews estimators are based on M-estimation methods where each bearing is weighted and fit based on comparisons relative to the other bearings (Lenth, 1981). The Huber and Andrews estimators accept or reject a bearing based on a series of iterative calculations, but Andrews was found to be more robust than Huber and both are more conservative, in that they exclude more outliers than MLE (Lenth, 1981; Garrott, 1986; White, 1990). Garrott (1986) tested the three Lenth estimators at a site with known signal reflection. He calculated 95% confidence ellipses using each estimator for each estimated location and then compared those ellipses to the location of the actual beacon. He found that the Andrews estimator preformed the best, yielding smaller confidence ellipses and covering the actual location 78% of the time. Further, Andrews was also the most rigorous estimator, excluding more bearings (outliers) than either MLE or Huber. Garrott (1986) concluded that the Andrews estimator was the most appropriate estimator for sites with high signal reflection.

This study was designed to examine the sources of telemetry error in an urbanized study site. To the best of our knowledge, this is the first attempt to document the factors that affect telemetry signals and quantify error measurements in this type of "noisy" environment. The objectives of this study were: 1) to test and quantify bearing accuracy sensu Lee (1985), and 2) test the three Lenth (1981) estimators sensu Garrott (1986) at an urbanized study site. We predicted that the urbanized location and fragmentation of habitats for multiple land uses at the study site would result in a high likelihood of both signal reflection and electromagnetic noise compared to any previously published study evaluating telemetry error. Results from this study are relevant to other wildlife studies in urban areas and is especially timely as a result of urbanization, and the increase in urban-adapted species; studies of such species in urban environments are increasing (Luniak, 2004).

Methods

Study Area

Forest Park is a 526 hectare urban park located between the western border of the city of Saint Louis, Missouri (356,587 people in 2009, U.S. Census Bureau) and the eastern edge of the greater Saint Louis metropolitan area (estimated 2.8 million people, U.S. Census Bureau). Established in 1876, the park has undergone major landscape modification, due in part to the 1904 World's Fair which was held on the site, and subsequent heavy use by the public. Forest Park is the fifth most visited urban park in the US, with more than 12 million visitors in 2009 (Saint Louis City website, 2010). The park contains five of the region's major cultural institutions: the Zoo, Art Museum, History Museum, Science Center and the Municipal Opera, in addition to four golf courses, ball fields, picnic areas, fishing, bicycling/jogging paths and an ice skating rink. Despite the multiple land uses within the park, several portions are still in a natural state with approximately 18% in wooded habitats.

Telemetry

Data were collected in summer 2006 (12-13 June, 6 and 11 July) and again in fall 2007 (27 - 28 October, and 1 November). The mobile telemetry system (Brinkman, 2002; Balkenbush, 1988) consisted of a minivan (1995 Ford Aerostar) outfitted with a 4.3-meter mast (Figure 1a) that could rotate 360°, and two 4-element yagi antennas placed on each end of a aluminum boom (2-m wide) mounted on the mast. The last 0.3 m of the mast was constructed of PVC to prevent interference with the electronic boat compass (Sailcomp 103AC, KVH, Middletown, RI) that was mounted to a PVC coupling at the top of the mast (Cox, 2002). The compass was attached to a digital display inside the van (Figure 1b). The receiver (R2000) was connected to a null/peak box (Spencer, 1987), both manufactured by Advanced Telemetry Systems (ATS, Isanti, MN), and a set of headphones (model H10, David Clark Co., Worchester, MA).

Figure 1a – Telemetry Vehicle with null/peak antenna system and electronic boat compass on the top of the mast.

Figure 1b – Inside of telemetry vehicle with receiver, null/peak antenna box (white) and compass display (under van radio).

The locations where the van was parked to record bearings (receiving stations) were identified by name, marked with survey paint, and recorded using a GPS unit (GeoExplorer 3, Trimble, Sunnyvale, CA or Mobile Mapper CX, Magellan, Smyrna, TN). In 2006, data were collected from five receiving stations located on the four corners and the center of the park. In 2007, for two of the dates only the original five receiving stations were used, but on the other two dates five additional locations were used; these additional locations were added to augment location "holes" found in the 2006 testing (Figure 2a). Random locations were generated in ArcGIS (Version 9.3, ERSI, Redlands, CA) using a georectified orthoquad map of the site (Metropolitan Sewer District, 2007 .9m resolution). For the purposes of this study 33 of these random locations were selected to represent each of the four habitat types [eight forest, nine mixed (savannah/open canopy), eight zoo, eight open fields] identified in the park (Figure 2b). Each location was numbered, marked with a survey flag (Forestry Suppliers, Jackson, MS) and the exact GPS location was recorded with an accuracy of +/- 2.5 m using 3D with differential post-processing correction at the local base station (GeoExplorer 3, Trimble, Sunnyvale, CA).

On the day of each test, magnets were removed from six radio collars (Advanced Telemetry Systems, Isanti, MN) and allowed to activate for at least 20 minutes before the trial began. Five of the collars were used in both years; collar 561 was only used in 2006 and 214 only used in 2007. Each collar was secured to a 2L soda bottle filled with water to simulate impedance mimicking radio waves that would need to penetrate an animal's body while wearing the collar (Hupp, 1983). These collar/bottle units, hereafter referred to as beacons were placed within 1.5 cm or less of the flag at the known location selected to be used for that test. Because the test was designed to be non-modulating (i.e., the beacon was not moved during the test), all beacons were fixed at the location.

Following the methods of Lee (1985) and Garrott (1986), five readings were taken for each of the six beacons at each receiving station (5x6 = 30/receiving station). The technician taking the readings was blinded to the collar frequency (number and order) and the compass bearing readout to eliminate technician bias sensu Lee (1985). To accomplish this, an assistant ran the receiver, recorded the compass bearings and took any relevant notes about signal strength and other conditions. Data were recorded on a data sheet and later entered into GTM telemetry software (Sartwell, 2001) provided by the Missouri Department of Conservation.

Figure 2a - Map of Forest Park with receiving stations (by year).

Figure 2b: Map of Forest Park with habitat types and beacon locations used for the telemetry tests.

Data Analysis

We defined accuracy as described by Lee (1985) in which accuracy was sub-divided into: 1) error (absolute difference between the true bearing and the estimated bearing), and 2) precision (the variation of the estimated bearings); further bias was defined as a consistent error. Data from all locations were analyzed for mean error with histograms generated sensu Lee (1985) to evaluate error as a function of year, receiving (van) station location, habitat type and frequency. Precision of measures was also calculated and analyzed for the same four factors. To examine differences between the effect of transmitter frequencies with regard to error and precision we used one-way ANOVA. Consistent differences in error or precision measures, if found, would indicate that certain transmitter frequencies may be subject to greater interference in urban settings than others. Given heterogeneity in both time and space of electronic noise at our site, we did not expect to see a consistent bias in error or precision with transmitter frequency.

We used a general linear model ANOVA with Tukey-Kramer post-hoc tests to assess the effect of receiving station location, habitat and the interaction of these factors on mean error and precision; distance from location to beacon was a covariate in ANOVA models. Non-significant factors were dropped from the model. Straight-line distance and bearing between the beacon location and the receiver station were calculated using ArcGIS. However, unlike Garrott (1986) line of sight was not measured due to the varying topography of the study site.

The GTM software generated 31 points to create a virtual confidence ellipse (rather than the more traditional hollow polygon shaped ellipse), for every estimated location. Confidence ellipses were calculated using equations from White and Garrott (1990) as a sub-routine in GTM for all three of the Lenth (1981) estimators (MLE, Huber and Andrews) at standard deviation of 10.4. We used these ellipses to determine which of the three Lenth (1981) estimators was best at our study site. To do this we calculated the frequency for when the actual bearing was found within the 95% confidence ellipse for each estimator sensu Garrott (1986).

Results

Bearing error and precision

The four tests conducted in the summer of 2006 resulted in a signal being heard 72% (430 of 600) of the time (Figure 3). Error for all bearings (including outliers) ranged from -170 to 130 degrees with 27.4% having absolute errors within 0-3 degrees, 33.5% within 4-10 degrees, 19.5% within 11-20 degrees, 9.8% within 21-50 degrees, 3.5% within 51-100 degrees, and 6.3% over 101 degrees (Figure 4). These results differed from those collected during the four tests conducted in 2007; in these tests signals were only heard 42% (376 of 900) of the time and the error for all bearings was more platykurtic (Figure 3). In this case, 16.2% had absolute errors within 0-10 degrees, 14.4% within 11-20 degrees, 28.2% within 21-50 degrees, 20% within 51-100 degrees, and 21.2% over 101 degrees (Figure 4).

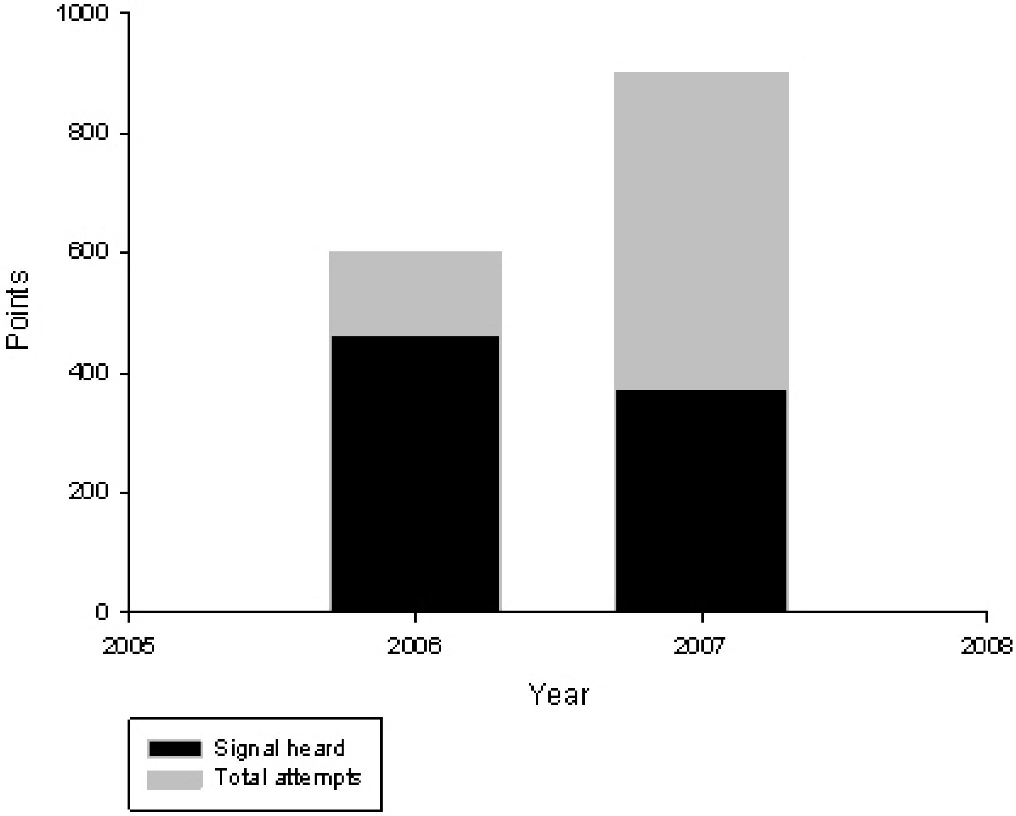

Figure 3 – Number of beacon locations detected by the observer during telemetry tests compared to total attempts by observer for 2006 and 2007.

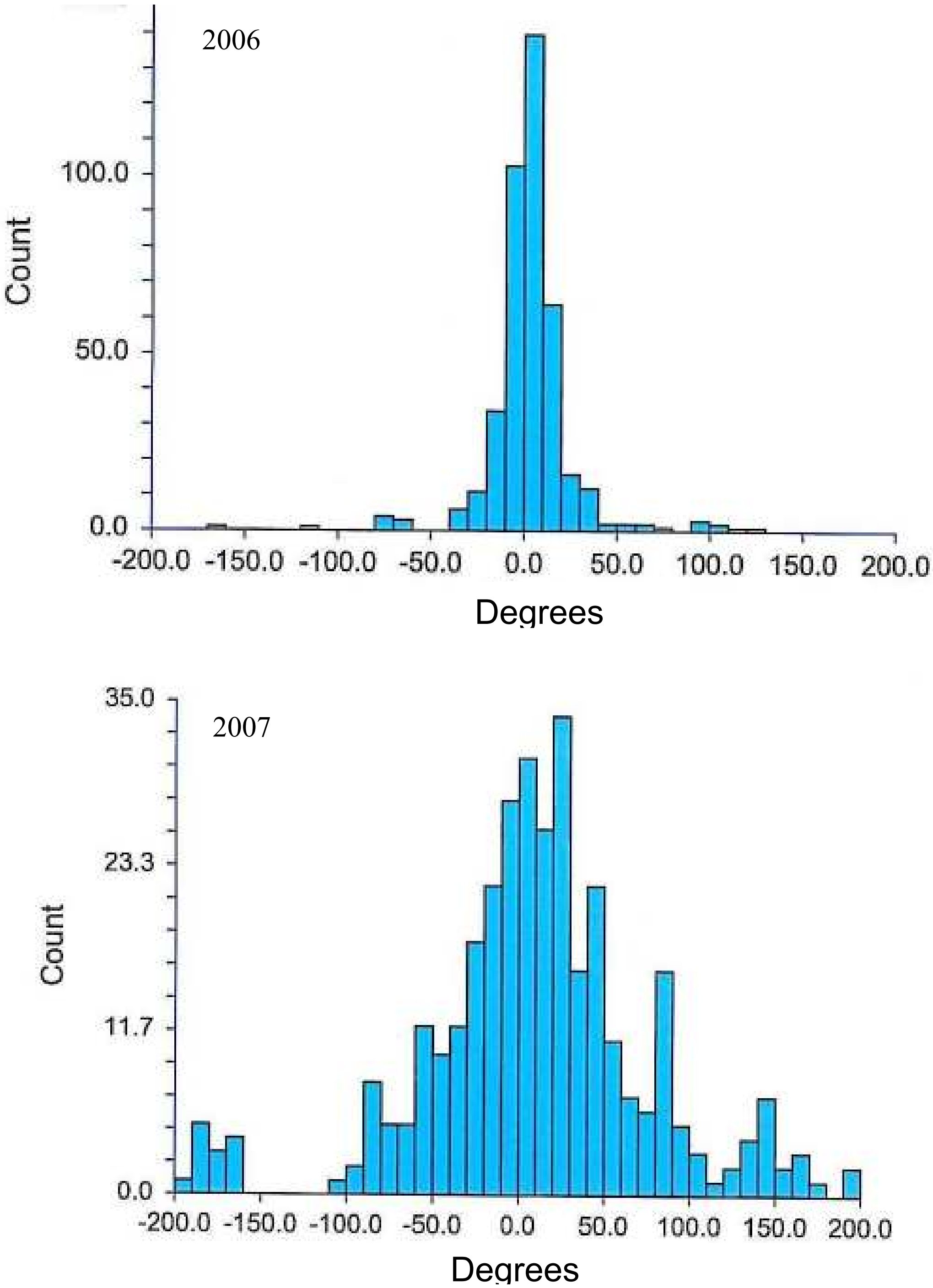

Figure 4 – Mean error by year (all bins equal 10 degrees). Note: Different scales used on the Y axes.

Histograms were generated using absolute error values by receiver location (Figure 5), collar frequency (Figure 6) and habitat type (Figure 7) to look for outliers and bias caused by environmental or non-environmental factors, including signal reflection and electromagnetic noise. In 2006 we defined an outlier as an error greater than 50 degrees, and in 2007 greater than 100 degrees. No bias was detected in either year. Mean errors for the receiving stations with the outliers removed ranged from -10.8 to 19.1 degrees in 2006 and from -18.4 to 40.5 degrees in 2007. Mean error also was measured by beacon location to assess the influence of habitat type. In 2006, mean error ranged from -8.8 to 14.1 degrees, with open habitats having the smallest mean error (-2.1to 7.5), forest and zoo having almost identical results (-0.78 to 10.6 and -8.8 to 2.8, respectively) and mixed habitat having the greatest error range (-1.4 to14.1). In contrast, the open habitat had the greatest mean error range (8.1 to 85.7) in 2007, followed by mixed habitat (-50.4 to19.5); forest and zoo habitats had similar mean errors (range -7.2 to 36.9 and -20.6 and 22.7, respectively). Bearing precision ranged from a standard deviation of 1.30 to 106.76 in 2006 and from 1.25 to 189.08 in 2007 by receiving station location.

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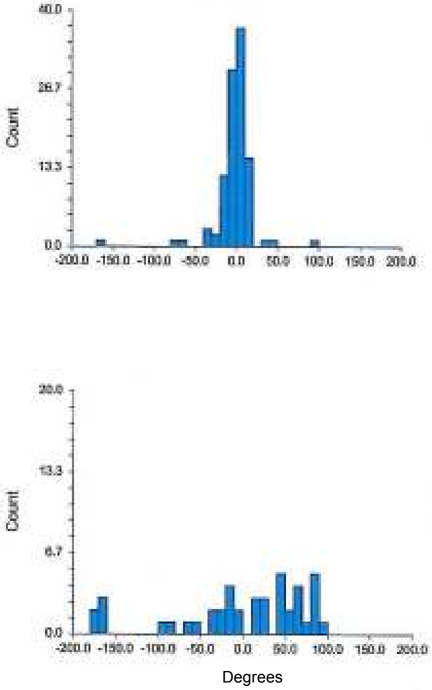
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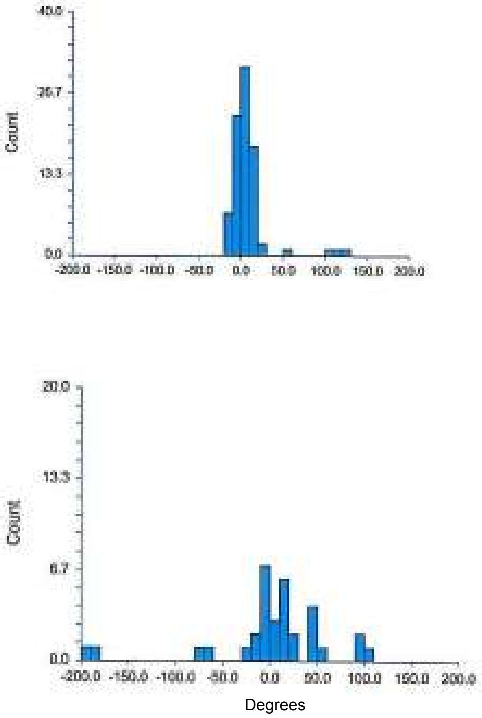
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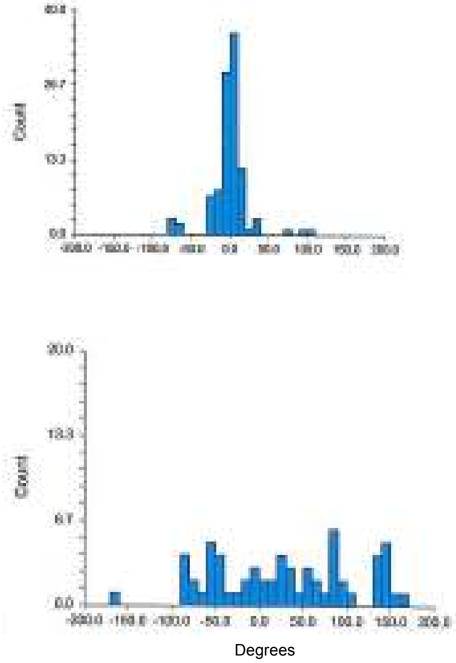
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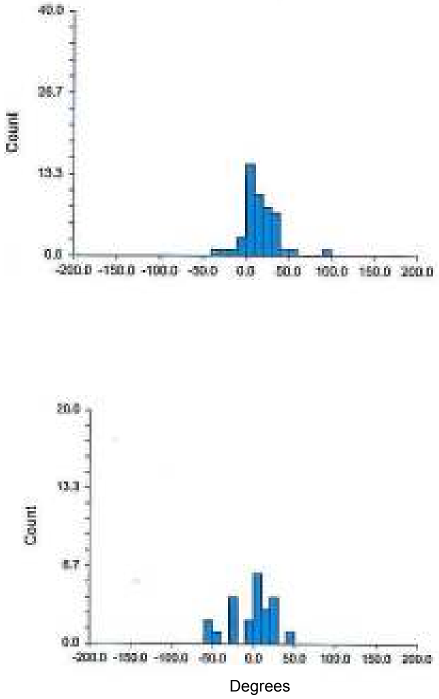
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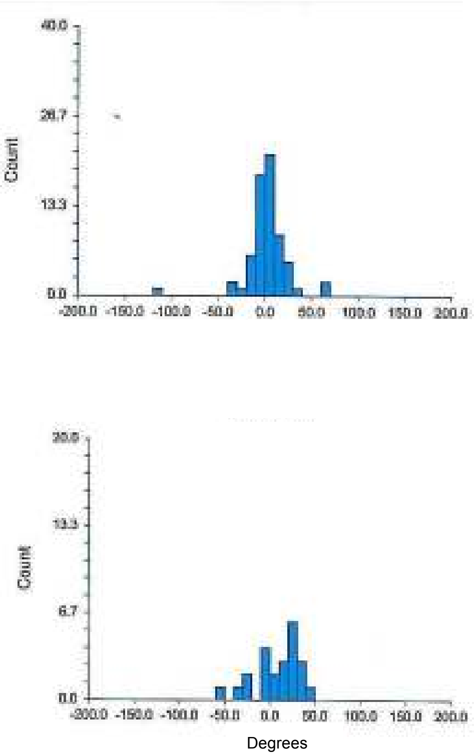
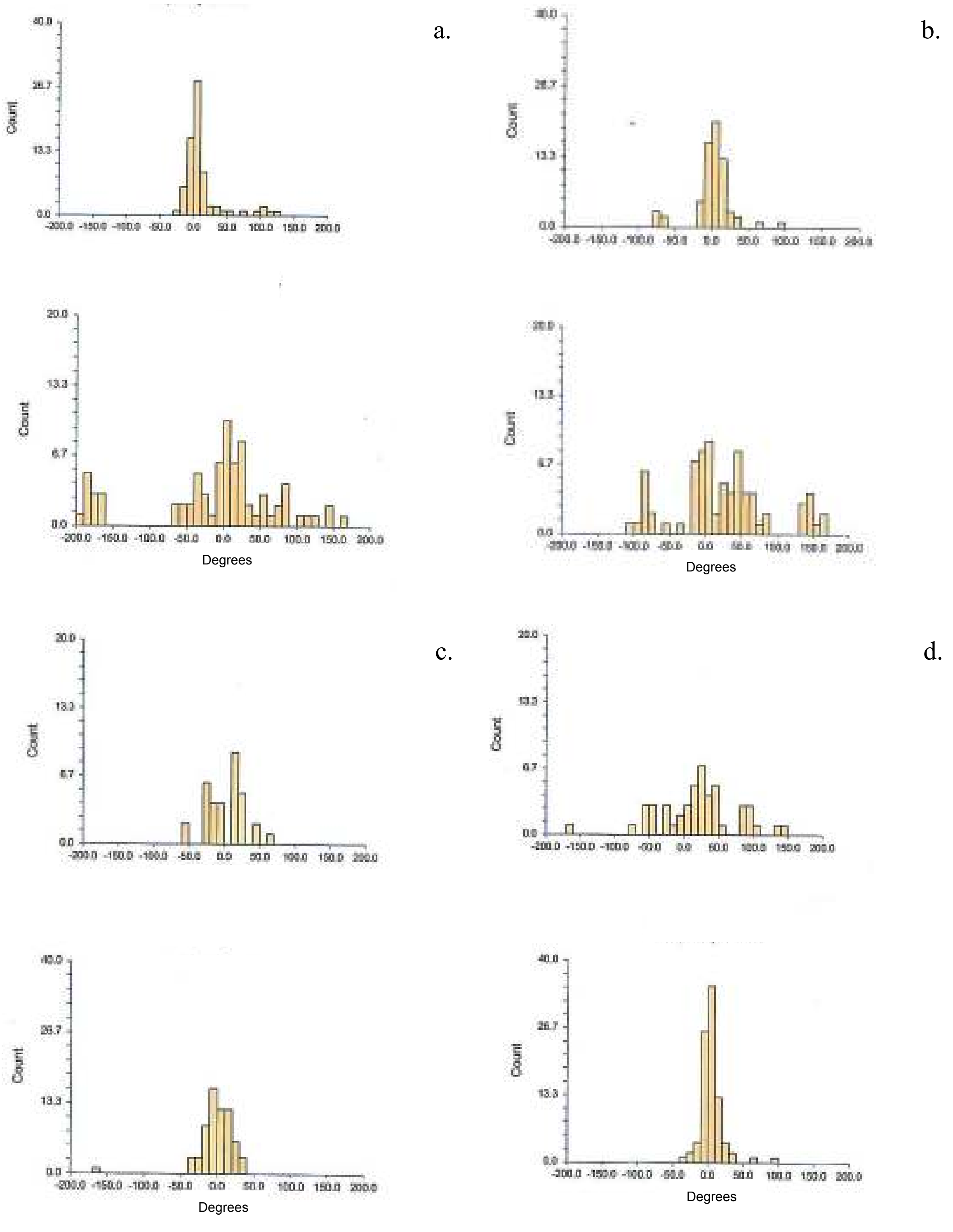


Figure 5 – Error histograms from the five receiving stations used in both years: a. Art Museum. b. Metrolink Bridge, c. Muny, d. Science Center, e. Skinker with 2006 on top and 2007on the bottom for each station. Note: different scale on the Y axes between years.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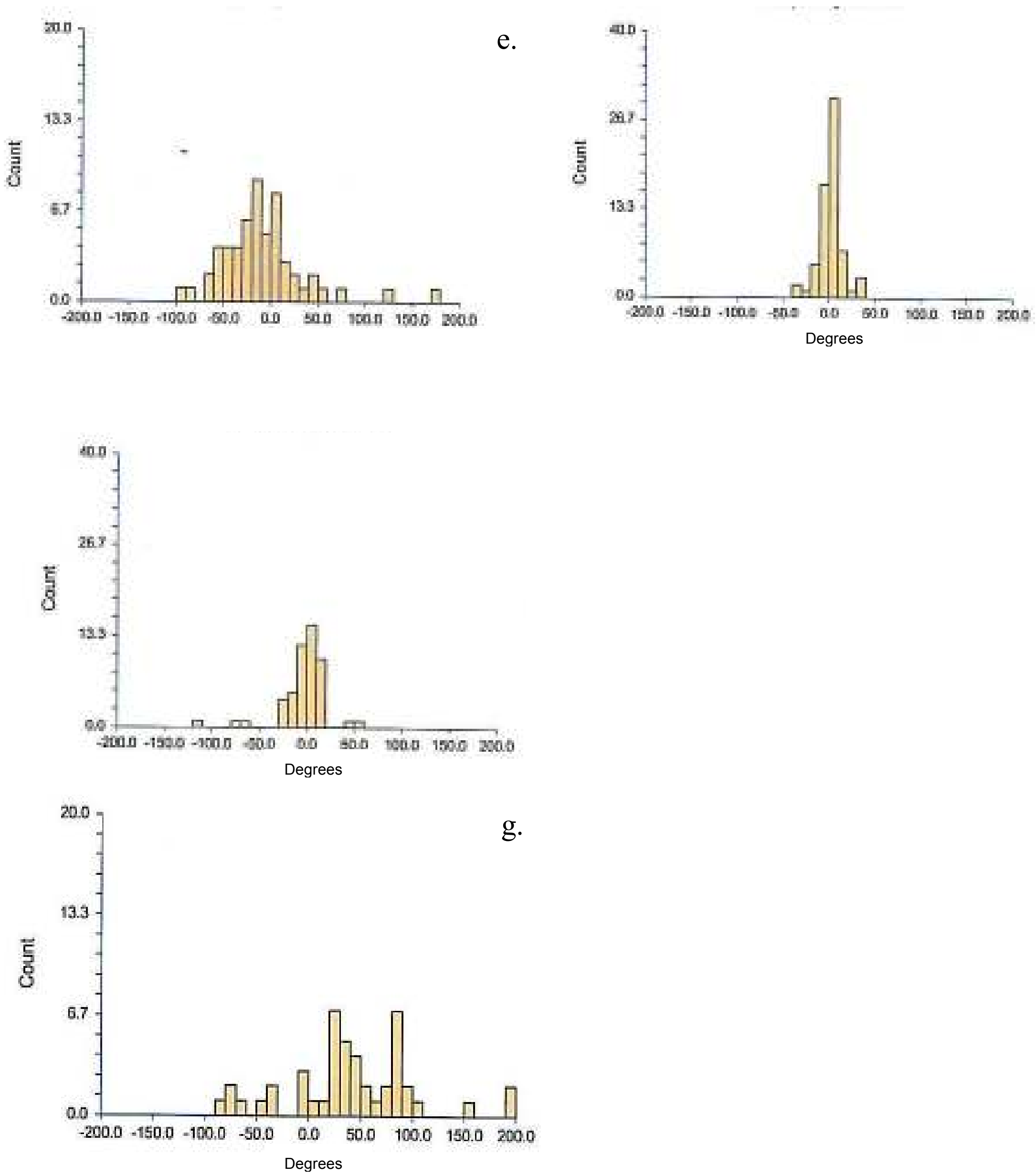

Figure 6 – Error histograms from the eight radio collars used in the experiments in both years: a. 324. B. 486, c. 643, d. 723, e. 805, f. 562 (2006 only) and g. 214 (2007 only) with 2006 on bottom and 2007 on the top for each set unless noted. Note: different scale on the Y axes between years.

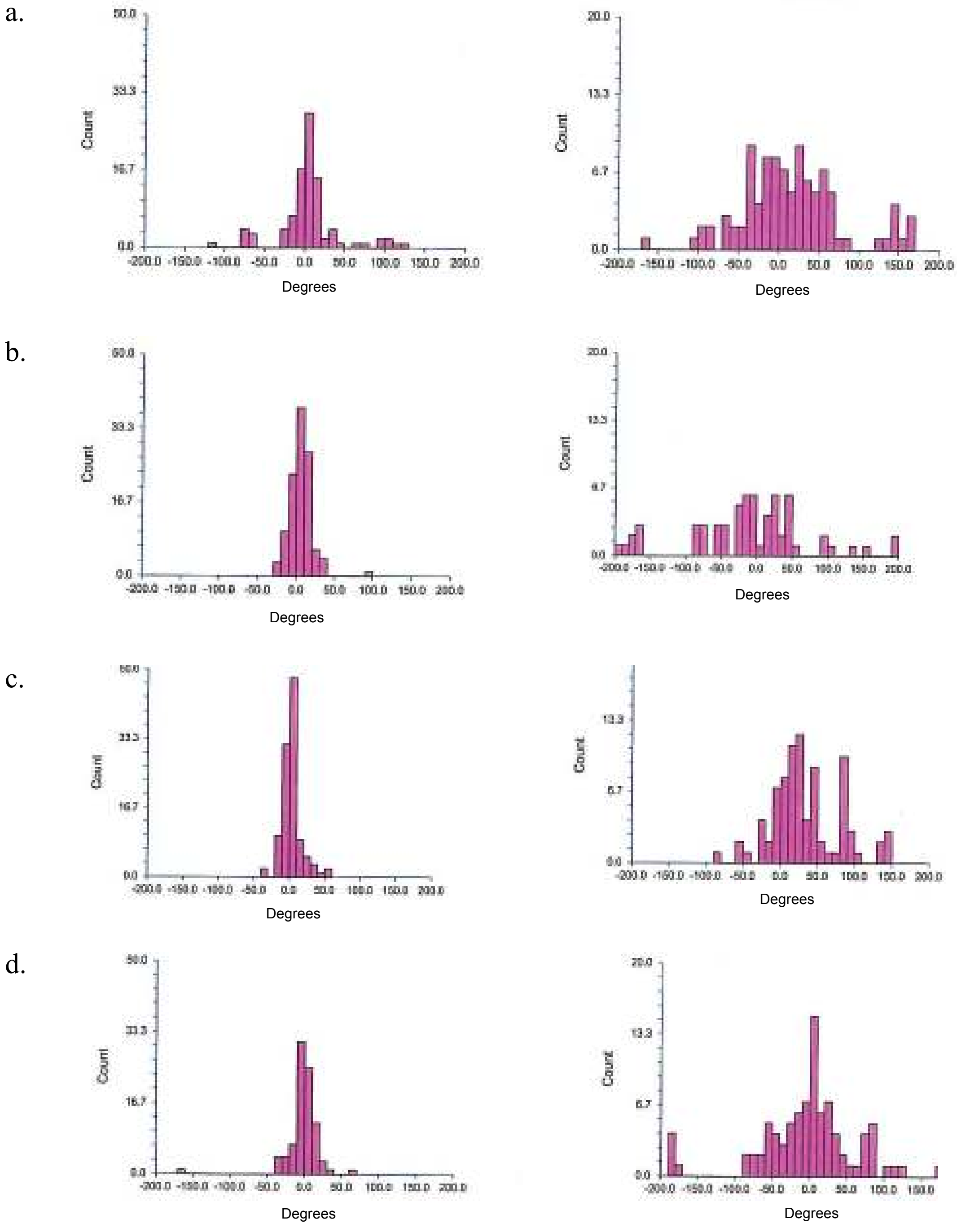

Figure 7 – Error histograms from the four habitats in both years: a. Forest b. Mixed, c. Open, d. Zoo with 2006 on the right and 2007on the left for each type. Note: different scale on the Y axes between years.

We found no difference in mean error as a function of transmitter frequency in either 2006 or 2007 ($F_{4,40} = 0.14$; $P \geq .13$). These results suggest that transmitter frequencies are not differentially affected by electronic noise, at least within the range of frequencies used in this study (150.214-150.805 MHz). Therefore, the effect of frequency was not included in subsequent ANOVA models.

In the general linear model ANOVA that tested for the effects of receiving station location, habitat, distance and their interaction on precision, we found that precision differed as a function of receiver location both with ($F_{4,88} = 5.26$; $P = 0.0009$) , and without ($F_{4,88} = 4.27$; $P = 0.004$) the interaction term, but not habitat or distance to beacon in 2006 . Post-hoc tests revealed that precision was significantly lower at readings taken from the Skinker location when compared to other receiving locations. In 2007 we found no significant differences in precision measures as a function of receiving location, habitat distance or the interaction of these factors (Table 1).

In ANOVA tests that included mean error as the response variable, the interaction term was dropped from the model as it was non-significant. In 2006, location ($F_{4,\ 86} =3.95$; $P = .0056$) had a significant effect on mean error, but mean error was not affected by habitat or distance to the beacon (Table 1). Post-hoc tests revealed that mean error at the Science Center location was significantly greater than all other locations except the Skinker location. In 2007 mean error was affected by location ($F_{9,\ 76} =2.18$; $P = 0.0353$), but not habitat or distance (Table 1). Post-hoc tests showed that mean error at the Art

Circle location was significantly greater than at the Metrolink Bridge and World's Fair Pavilion locations, but not different from any other locations.

		SS	***df***	**MS**	***F***	***P***
Precision						
	Distance (covariate)	4035.8	1	4035.8	3.50	0.0658
	Habitat	5558.2	3	1852.7	1.61	0.1963
	Location	**24279.1**	**4**	**6069.7**	**5.26**	**0.0009**
	Interaction	25308.0	12	2109.0	1.83	0.0610
Precision						
	Distance (covariate)	2640.9	1	2640.9	2.03	0.1578
	Habitat	10168.5	3	3389.5	2.61	0.0573
	Location	**22194.6**	**4**	**5548.6**	**4.27**	**0.0035**
Mean Error						
	Distance (covariate)	56.9	1	56.9	1.46	0.2300
	Habitat	55.8	3	18.6	0.48	0.6988
	Location	**615.5**	**4**	**153.8**	**3.95**	**0.0057**

Table 1a – Results of the General Linear Model ANOVA for 2006

		SS	***df***	**MS**	***F***	***P***
Mean Error						
	Distance (covariate)	1042.7	1	1042.7	2.16	0.1468
	Habitat	2124.9	3	708.3	1.47	0.2324
	Location	**9483.2**	**4**	**1053.7**	**2.18**	**0.0353**

Table 1b – Results of the General Linear Model ANOVA for 2007

Location estimates

Of the confidence ellipses generated by GTM for each estimated location, the Andrews estimator eliminated more bearing locations because of poor geometry (triangulation) than either the MLE or the Huber. These three estimators produced a different number of estimated locations depending on the model used since each model has different calculations. Therefore the number of ellipses generated also differed. In both years, the MLE and Huber estimators each generated the same number of ellipse points and the Andrews estimator generated fewer points (Table 2a). The mean area of the ellipse varied considerably by estimator which is important because larger ellipses indicate greater amounts of error. In 2006, MLE had the smallest ellipse areas, followed by the Andrews, with the Huber having the largest ellipses. The MLE estimator again had the smallest mean ellipse area in 2007, however this was followed by the Huber and then by the Andrews (Table 2a). It is notable that although the Andrews estimator generated fewer ellipses than either MLE or the Huber, and had larger ellipse sizes than MLE (both years) and the Huber (2007), it was the estimator where the ellipses covered the actual points more often than either of the other estimators (Table 2b).

2006	Maximum Likelihood (MLE)	Huber	Andrews
# of points	2635	2635	2480
Mean	31.4	287.9	97.8
Standard Deviation	62.7	2429.3	459.61
Range	0-519	0-22,552	0-3,766

2007	Maximum Likelihood (MLE)	Huber	Andrews
# of points	8525	8525	6944
Mean	19.3	51.1	111.0
Standard Deviation	183.2	183.2	792.0
Range	0-340	0-2,415	0-11,042

Table 2a – Comparison of the confidence ellipse sizes (95% in ha) for each of the three Lenth estimators with a standard deviation of 10.4.

2006	Maximum Likelihood (MLE)		Huber		Andrews	
Ellipse Area (ha)	N Points	Coverage %	N Points	Coverage %	N Points	Coverage %
0-1	14	7.0	10	0	11	27.3
1-5	8	12.5	7	14.2	4	0
5-10	4	25.0	7	28.6	4	25.0
10-20	17	41.1	19	42.1	19	47.4
20-50	32	43.8	34	55.8	35	60.0
> 50	8	37.5	5	40.0	9	55.5

2007	Maximum Likelihood (MLE)		Huber		Andrews	
Ellipse Area (ha)	N Points	Coverage %	N Points	Coverage %	N Points	Coverage %
0-1	21	4.8	13	0	12	0
1-5	7	0	8	0	10	0
5-10	8	12.5	9	22.2	9	22.2
10-20	12	0	12	0	11	0
20-50	5	0	7	0	8	25.0
> 50	5	0	9	0	8	0

Table 2b – The number and percent of beacons that were included within the confidence ellipse areas (95% in ha) for each of the three Lenth estimators with a standard deviation of 10.4.

Discussion

Bearing error and precision

In this study we tested for accuracy and precision of bearing readings sensu Lee (1985) and found no evidence of bias by receiving station, habitat or frequency. The range of total mean error in 2006 was similar to that of Lee (1985) (-170 to130 compared to -131 to 164 degrees, respectively), but different from our range in 2007 of -232 to 223. Both Lee (1985) and Garrott (1986) established that for their studies in non-urban areas outliers were values of mean error above 10 degrees, whereas in our study we established the threshold for outliers to be 50 degrees for 2006. Although neither author mentions it specifically, the authors appeared to have used 80% as a guideline for setting the thresholds, since 82.8% of Lee's (1985) and 80% of Garrott's (1986) errors were 10 degrees or less. In contrast to our study, where 61% of mean error fell between 0-10 degrees while 90.2% of mean error fell between 0 and 50 degrees in 2006. In 2007, 78.9% of the mean error fell between 0 and 100 degrees.

We found greater error in bearing measures in 2007 than 2006. This was an unexpected result because the technician who took the readings was considerably more experienced by the time the second (2007) series was conducted. In addition, in 2006 the tests were conducted during the summer, while in 2007 tests were conducted in late fall/early winter; we expected more signal reflection in some cases due to foliage on the trees in 2006. We examined the effects of frequency, habitat, location, distance in our analysis and found no bias with any of these factors. Furthermore, precision was also similar between years. Therefore we believe the increased bearing error in 2007 were likely the result of differences in signal refection and electronic noise between years. Lee (1985) also suggested that signal reflection and electronic noise were likely the primary sources of mean error in his study.

Location estimates

As predicted by Lenth (1981) and Garrott (1986) the Andrews estimator was the most rigorous of the three estimators, eliminating more points due to poor geometry (triangulation) than either the MLE or Huber estimator. In 2006, this effect was minor (an additional 151 points eliminated), however in 2007 this accounted for more than 1000 points being removed (1581 point difference). This effect was likely more pronounced in 2007 given the suspected problems with signal strength, signal reflection and electromagnetic noise. Despite the order of magnitude difference between the numbers of locations removed by the Andrews estimator in 2007, proportionally it still produced the most ellipses to cover actual beacon locations in both years. Garrott (1986) also measured the distance between the actual location and the ellipse centroid which he used as another measure of estimator reliability; these data were not available in this study.

Signal Quality

It is difficult to assess the impact electronic noise may have had on the test results, especially in 2007, as we could find no other validation tests of telemetry systems conducted in urban environments. It was not uncommon to hear taxi or police transmissions during our tests, and certain receiving stations appeared to have a higher level of interference (e.g., Science Center). Swenson (1973) and Cudak (1991) found that electromagnetic noise was higher in the winter which is consistent with our results where greater error was found during the winter (2007), although without replication it is not possible to determine if indeed the differences in our study are due to seasonal effects. Greater error in 2007 also may have been due to decreased strength of the signal from the collars as signals are expected to diminish with the age of the collar (L. Kuechle, per comm.). Reduced signal strength could explain the reduction in the number of bearings recorded and the broader range of mean error in 2007. All radio collars used in the test were purchased at the same time, and it is possible that, even with the magnets used to disable the collars between trials, signal strength may have deteriorated with time. These same collars were tested in 2010 by the manufacturer and found to have lost between 4 and 9 dBm of signal strength. In areas with increased electronic noise, such as urban areas, increased signal strength is needed to ensure signals are received above background electromagnetic noise (Swenson 1973). Given the proliferation of electronic mobile devices in the last decade, it is reasonable to believe that electronic noise has increased, especially in large cities. There are no data on whether the increase in the number of electronic devices in use in the last decade (Withey, 2001) since Cudak's study (1991) has caused a concomitant increase in electronic noise. It is also not known if the effect of electronic noise is greater in larger cities like Saint Louis (Champaign-Urbana, IL was the largest city measured by Swenson (1973) and Cudak (1991) with a population above 100,000 people).

Concluding remarks

Since the mid-1980s, the methods to validate telemetry systems at specific study sites have been available to all wildlife biologists (Lee, 1985; Garrott, 1986, White, 1990). This allows biologists to quantify and identify sources of error that result in decreased accuracy. However there are no published standards for acceptable levels of telemetry errors (Saltz, 1990). Rather, the amount of error is left to the discretion of the researcher based on the objectives of the study (e.g., seasonal migrations of reindeer vs. fine-scale habitat use by rattlesnakes [White, 1990; Whitey, 2001]). While an experienced biologist is likely to be able to determine the degree of error that will be biologically meaningful based on the experimental design, those with less experience with telemetry could benefit from a recommendations to identify and correct bias, such as setting the error threshold at 80% of mean error.

Although many authors who have quantified accuracy and measured error have declared outliers to be outside a smaller degree range than we did in this study, this is likely due to a lower degree of signal reflection and electromagnetic noise when compared to a large urban setting such as experienced in our study. More studies are needed to verify these findings, especially as ecological research utilizing telemetry has been increasing in urban areas.

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CHAPTER 3

LIVING IN URBAN ENVIRONMENTS: DO RACCOONS FOCUS ACTIVITIES IN RESOURCE HOTSPOTS PROVIDED BY HUMANS?

Introduction

In less than 30 years, more than half of the world's human population will live in urban areas (Shochat, 2006). This shift in habitation patterns and the concomitant land transformation is referred to as urbanization (Marzluff, 2001). Urbanization has negative impacts on wildlife through decrease in species richness in plant (Thompson, 1999), insect (Kozlov, 1996) and vertebrate communities, including mammals (Dickman, 1987). Urban development fragments the natural landscape; as a result, remaining natural habitats, which are much reduced in size, are island-like and often embedded in an inhospitable matrix. These changes impact resources available to organisms and connectivity among populations, which directly contribute to population declines, local extinctions and loss of species diversity in the urban landscape (Rosenblatt, 1999; Turner 1996; Alberti, 2001).

However, the process of urbanization also creates new habitats in which some species appear to thrive despite the altered conditions and increased human density. Species such as Canada geese, house sparrows, grey squirrels, opossums and coyotes, may occur in high densities in urban areas (Blair, 2001; McKinney, 2002; DeStefano, 2003; Gehrt, 2010). These urban "adaptor" species are able to utilize man-made structures for shelter, are food generalists, have few natural predators remaining and are tolerant of living in proximity to humans (Blair, 2001; McKinney, 2002).

Biologists have traditionally located their studies in areas with low human densities, while studies conducted in urban areas tend to focus on the negative impacts to wildlife (DeStefano, 2003). However, within the last two decades much has changed. Urban environments are now recognized as “human dominated ecosystems” (Vitousek, 1997) that merit study; for example, the National Science Foundation recently invested several million dollars in research at two long-term ecological research (LTER) sites in urban areas (Grimm, 2000). These LTER sites located in Baltimore and Phoenix are designed to understand the long-term ecological dynamics of urban environments by including investigations targeted at: abundance/distribution studies, studies of exotic invader species, population demographics, source/sink dynamics, and paired studies along the rural to urban gradient (Grimm, 2000). Similar approaches have been undertaken in other cities. For example, the Chicago Wilderness Project focuses on population dynamics of several species (raccoon, opossum, coyote, and skunk) along the rural to urban gradient. These types of studies on-going in Baltimore, Phoenix and Chicago are the first steps to a better understanding of why and how urban adaptor species are successful and should also provide valuable insight as to why other species fail to thrive under such conditions.

The raccoon (*Procyon lotor*), a primarily nocturnal animal, is known to inhabit all landscapes along the urban to rural gradient. Hadidian (2010) contends that raccoons are "arguably the most widespread and abundant of all the urban carnivores in North America". Raccoons are considered solitary animals that have little contact with conspecifics except during mating (Frizell, 1978), although new evidence suggest this level of sociality may be more complex than previously believed. Females appear to be philopatric and both sexes can have overlapping home ranges (Frizell, 1978, Gehrt, 1998; Ratnayeke, 2002; Prange, 2004) which also may suggest some level of sociality. Additionally, Gehrt observed unrelated male social groups (Gehrt, 1998 and 2002), all of which merits further examination of raccoon social behavior. Spatial organization is thought to be resource-based for females with males spacing themselves around females (Sandell, 1989; Gehrt, 1998). Raccoons mate in the winter (January to March) and give birth in the spring to litters of 2-4 offspring after a 6-week gestation (Gehrt, 2003; Sanderson 1973). Offspring are with the female for approximately 4 months (late spring – summer), and consequently, females need ready access to resources to adequately provide for offspring and herself during these periods (Montgomery, 1969).

Most studies that involve raccoons have occurred in rural and agricultural areas. Raccoons are still legally harvested as a fur-bearing species throughout the United States in rural and agricultural areas with associated mortalities of 78-81% annually reported in Iowa and Illinois (Clark, 1989; Mankin, 1999). Raccoon densities in rural or agricultural areas range from 2-20 individuals/km^2 (Lotze, 1979). Home range sizes for males are reported to range from 129 ha in forest-land in Mississippi (Chamberlain 2002) to 1627 ha in rural North Dakota (Fritzell, 1978). Trees appear to be the preferred den sites for both sexes, although rock outcroppings and ground nests were also used (Enders, 1993; Nixon, 2000, Henner, 2004).

Information on raccoon population ecology from urban or suburban areas is not as comprehensive as it is for rural areas. However, work by several authors (Riley, 1998; Hatten, 2000; Gehrt, 2001, 2002a-c; Hadidian, 2002) has begun to provide insights into the ecology of raccoons in urban and suburban areas. One challenge has been that there is no single agreed upon definition for suburban or urban (McInyre, 2000) so that the comparison and interpretation of results collected in these human-dominated environments is complex. Therefore for the purpose of this study, we follow the convention of using the term urban in the generic sense to include suburban and urban areas. Several studies of raccoons in urban areas have focused on disease and/or parasitology (Rosatte, 2000; Evans, 2002) primarily because rabies in raccoons is a zooonotic health concern in the northeastern United States and Canada. Increased rates of disease and parasite transfer have been associated with high densities due to both intra- and inter-species contact at food sites where animals aggregate (Riley, 1998; Mitchell, 1999; Totten, 2002). Studies have found that raccoon densities are higher in urban areas than rural areas, with densities ranging from 35-125 individuals/km^2 (Riley, 1998) This increased density has been attributed to greater food availability, increased number of den sites and lack of hunting pressure (Dickman, 1987). Urban raccoon populations appear to be more stable than rural populations, with individuals having smaller home range sizes (Hoffman, 1977). It has been hypothesized that this stability and small home range size is due to greater availability of food resources, lack of hunting, and the fragmentation of the urban landscape (Hatten, 2000), which may constrain animal movement. In a study in Illinois comparing an urban Forest Preserve with a rural park, Hatten (2000) found that the territory size of the urban preserve ranged from 36-111 hectares, whereas in the rural park territory size ranged from 141-238 hectares during the same time period. Studies on resource use in urban settings also have examined den locations and food sources. For example, Hadidian (1991) found that raccoons in Rock Creek Park in Washington, D.C., primarily used trees as den sites (69% of all dens). Bozak (2007) demonstrated that the anthropogenic food sources (e.g., trash cans and dumpsters at picnic areas) strongly influenced home range size and placement in both sexes during the summer season at the urban preserve site in Chicago, Illinois.

Despite the work of several researchers that have examined urban raccoon populations, there remain serious gaps in our understanding of the ecology of urban raccoons. In particular, we have scant understanding of how key resources influence the location and size of home ranges and what factors influence habitat use given the mosaic of the urban landscape. Furthermore, Dr. Stanley Gehrt, the preeminent researcher of urban raccoons in the United States, suggests that variability among urban areas influences the degree to which ecological drivers affect raccoon habitat use and population dynamics (Gehrt, 2010). He points out that distribution of avian predator species were found to differ among 27 cities in Italy (Sorace, 2009, in Gehrt, 2010). This information suggests that in order to understand why raccoons are such successful urban adaptors work is needed to elucidate variation in behavior and ecology not just between rural and urban raccoons, but also among urban areas.

The goal of this study was to determine how the distribution and abundance of anthropogenic food resources and habitat affect the home range of female raccoons in a diverse urban park. Determining home range size and habitat use is important as habitat quality influences individual fitness (e.g. survival and reproduction) (Orians, 1991). Within an area, different factors are thought to influence decisions regarding habitat selection. Raccoons likely need a mixture of habitat patches and resource elements within their home ranges, and it is unlikely that all required resources would be found within a single patch or be available in that patch year-round in urban areas. A considerable number of theoretical and empirical studies have focused on how individuals settle and occupy habitats. For example, ideal free distribution theory predicts that individuals and resources would be evenly distributed in all patches when such patches are relatively equal in quality (Fretwell, 1970; Orians, 1969). The distribution of animals in rural landscape more likely approximates ideal distribution than in urban environments, where habitat patches are likely more variable and contrast more sharply in quality.

For raccoons, key resources are water, food and den sites (Gehrt, 1998; Sanderson, 1950). In environments where these key resources are scattered or patchy in distribution and may not overlap, raccoons likely need to configure their home range to match the availability of key resources (Ims, 1987, Orians, 1991). Uneven distribution of resources suggests that opportunities for foraging and shelter likely vary substantially among patches. Unless, a single habitat patch contains all needed resources, this variability may increase travel time and energy expenditure between foraging opportunities which likely increases the risk of predation or accidental death (e.g., being hit by a vehicle). Since resting or den sites are also unevenly distributed and may not be in proximity to food resources, trade-offs also likely exist to access key resources (Mysterud, 1998). Additionally, a priori decisions regarding how time is allocated in relation to disjunct resources must be taken into account (Mysterud, 1998). Although raccoons are considered to be solitary carnivores (Sandell, 1998), overlap around critical resources, especially if limited in distribution, has been observed in other solitary species (Brown, 1970), and specifically in raccoons. For example, in rural Texas, Gehrt (1998) found that female raccoons aggregated home ranges around water, a critical resource to female raccoons (Stuewer, 1943; Sanderson, 1987).

Here we examined how female raccoons utilize space within a heterogeneous urban park that contains a diverse mosaic of natural and human-dominated habitats. We hypothesized that female raccoons in this urban environment would make trade-offs to balance access to key resources. Specifically, we predicted that females would aggregate around water and the larger sources of anthropogenic food such as dumpsters. Females would also differentially use the mixed forest-open habitat because of its configuration in the landscape which provides a high perimeter/area ratio and closer proximity to key resources. Lastly, we predicted there will be a seasonal shift in home ranges of females that reflected changes in resource availability and physiological needs.

Methods

Study Area

Forest Park is a 526-hectare urban park located on the western border of Saint Louis, Missouri, a city located at the confluence of the Mississippi, Missouri and Illinois Rivers. The eastern boundary of the city is formed by the Mississippi River, with the 12 county, 11,265 square kilometer Saint Louis Metropolitan area emanating outward from the city core. The Metropolitan area is home to an estimated 2.8 million people, 356,587 of whom live within the 98.2-square kilometer City limits (U.S. Census Bureau, 2009). The topography of the area is rolling upland with sandstone and limestone soil. Once one of the largest cities in the U.S., the city of Saint Louis is considered almost 100% urbanized with few natural areas remaining outside of city parks.

Forest Park is the fifth most visited urban park in the U.S., with more than 12 million people using the Park in 2009(http://stlouis.missouri.org/citygov/parks/forestpark, accessed 5 December 2010). The Park contains five of the region's major cultural institutions: the Zoo, Art Museum, History Museum, Science Center and the Municipal

Opera, in addition to four golf courses, ball fields, picnic areas, fishing ponds, tennis courts, bicycling/jogging paths and an ice skating rink. Established in 1876 the Park has undergone major landscape modification due in part to the 1904 World's Fair which was held on the site and subsequent heavy use by the public. In 2004 a large rejuvenation project was completed that included the addition of several wetland areas and restoration of a stream to the Park, which now connects all existing lakes and lagoons into a system that simulates the layout of the former natural river system (pre-1920s). Despite the multiple land uses within the Park, several portions are still in a natural state with approximately 10% in wooded habitats. The Park has major roadways on all four sides, including an interstate to the south, which forms the boundaries of the study area. Although raccoons have been known to cross busy roadways (Prange, 2003), we believe few animals cross these particular roads because few carcasses were seen on area roadways during the last two years of pilot data collection (Bauman, pers. obs.). The Park is closed to the public between dusk and dawn, but automobile traffic can still access the Park. However, traffic is not heavy throughout the night when raccoons are active in the Park.

Trapping and Radio Telemetry

Raccoons were trapped using 30 box traps (Tomahawk traps, Tomahawk, WI) baited with fish, canned cat food or marshmallows. The primary trapping effort occurred from 16 May to 3 June 2006 using a grid design for even distribution of traps throughout the study site. Each trap location was 350 meters apart, permanently identified using

GPS (GeoExplorer 3, Trimble, Sunnyvale, CA or Mobile Mapper CX, Magellan, Smyrna, TN) with an accuracy of +/- 2.4 meters using 3D with differential post-processing correction at local base station (GeoExplorer 3, Trimble, Sunnyvale, CA), and marked with a flag (Forestry Suppliers, Jackson, MS). Subsequent trapping (7 June 2006 - 3 July 2007) was done in specific areas of the Park in an effort to get an even distribution of female raccoons from all portions of the Park and to maintain a sample size of 10 radio-collared females throughout the study. Methods for both the grid and the focused trapping efforts were identical. Due to the public nature of the study site, traps were placed at the flagged locations each night at dusk. Each morning at dawn, traps were checked, picked up and stored in a vehicle. All non-raccoons were released at the trap location after logging the species, date and grid location number, whereas all raccoons were transported to the Saint Louis Zoo's Veterinary Hospital for sample collection. Each raccoon was anaesthetized in the trap by hand injection with telazol (tiletamine HCl and zolazepam HCl, 100mg/ml; Fort Dodge), ketamine (ketamine HCl, 100mg/ml; KetaVed, VetCo) or a combination of ketamine/medetomidine (medetomidine HCl, 1mg/ml; Domitor, Pfizer).

Each individual was given a brief examination and general health assessment. Every raccoon was individually identified with a small ear tag (#413, Hasco, Dayton, KY) in each ear (Gehrt, 2001, 2002a; Hatten, 2000) and a microchip (Trovan, Infopet, Burnsville, MN) was inserted between the scapulae. Data on sex, weight and age were recorded. Animals were assigned to one of four age categories: juvenile, sub-adult, middle aged adult or old. Parameters used to estimate age were based on methods previously used by Grau (1970), Sanderson (1973) and Kramer (1999). Standard morphometric measurements for neck circumference, body length (tip of nose to the end of tail) and the tail length (from base to tip) were recorded using a cloth tape measure. Weights were recorded in kilograms (Pesola scale, Baar, Switzerland). A blood sample (10ml) was collected for later examination of disease and genetic analysis. After all the samples were collected, individuals were placed in a kennel (size 100, Petmate, Arlington, TX) to allow them to fully recover from anesthesia prior to release at the trap location within 12-18hrs of capture.

Sub-adult or middle-aged females from different habitat types and locations within the Park were fitted with a VHF radio collar (130 grams, Advanced Telemetry Systems, Isanti, MN). This type of telemetry collar has been used with raccoons previously and has not caused harm nor known to inhibit any natural behaviors (Urban, 1970; Riley, 1998; Hatten, 2000; Gehrt, 2001, 2002a-c; Hadidian, 2002). No juveniles were collared since recapture to remove the collars as the animals grew could not be guaranteed. All females radio collared were from a variety of habitats and locations in the Park; this was done to obtain as unbiased a study population as possible.

From 1 February 2007 until 31 Jan 2008 data on den site locations of collared animals were collected 5 days/week during daylight hours. Night observations were conducted once per month, during which each radio-collared animal was located from a vehicle once every 2 hrs (Hatten, 2000; Hadidian, 2002), an interval that has been demonstrated to represent independent locations in previous studies of raccoons (Gehrt, 1997). A vehicle-mounted telemetry system was used to collect data throughout the study (Brinkman, 2002; Balkenbush, 1988). Verification of raccoon location, when needed, was done on foot using "honing in" telemetry technique. The minivan (1995 Ford Aerostar) was outfitted with a 4.3-meter mast (Figure 1a) that could rotate 360 degrees and two 4-element yagi antennas that were placed on each end of an aluminum boom (2-m wide) mounted to the mast. The last 0.3 m of the mast was constructed of PVC to prevent interference with the electronic boat compass (Sailcomp 103AC, KVH, Middletown, RI) that was mounted to a PVC coupling at the top of the mast (Cox, 2002). The compass was attached to a digital display located inside the van (Figure 1b). The receiver (R2000) used was connected to a null/peak box (Spencer, 1987), both manufactured by Advanced Telemetry Systems (ATS, Isanti, MN), and a set of headphones (model H10, David Clark Co., Worchester, MA).

Figure 1a – Telemetry Vehicle with null/peak antenna system and electronic boat compass on the top of the mast.

Figure 1b – Inside of telemetry vehicle with receiver, null/peak antenna box (white) and compass display (under radio)

Data on raccoon movement were collected using radio telemetry. All of the compass positions were recorded on a data sheet with time and ID; these data were subsequently entered into a triangulation software package (GTM, Missouri Department of Conservation; Sartwell, 2001). Triangulation accuracy and precision of the mobile telemetry system were tested at the study site prior to and during the study. These tests involved placing collars on 2L soda bottles at six of the 33 pre-determined locations throughout the Park. Estimated locations were collected 5 times per transmitter sensu Lee (1985). These values and those of the actual location were then used to calculate mean error, evaluate bias in the receiving stations and measure precision. These results demonstrated that errors greater than 50 degrees were outliers and should be removed. Results also showed that the Andrews estimator at standard deviation of 10.4 was the most appropriate at this site when compared to the other Lenth (1981) estimators (MLE & Huber); these results were applied to this study. Estimated raccoon locations generated by the GTM software were then imported into ArcGIS (Version 9.3, ESRI, Redlands, CA) for analysis. We used GIS technology to estimate 50% and 95% utilization distributions based on recorded locations for female raccoons using all data combined, and diurnal and nocturnal data separately, using the Animal Movement Extension (Version 3.2, ESRI, Redlands, CA; Hooge, 1999). Home range data were also calculated by season to examine any shift in home range size or location. Seasons were defined as fall (September to November), winter (December to February), spring (March to May), and Summer (June to August); the same seasonal definitions used in many other raccoon studies (Hoffman, 1977; Prange, 2004; Bozak, 2007) and also analyzed separately for diurnal and nocturnal data.

To evaluate home range overlap, we used Moran's Index (Moran's I) to test the degree to which raccoons were aggregated in space (Mitchell, 2005). We calculated Moran's I for 95% and 50% utilization distributions of raccoon home ranges for both the diurnal and nocturnal datasets at four different spatial scales (0.25ha, 1ha, 6.25ha and 25ha) as aggregation can be influenced by spatial scale of analysis. To do this, we divided Forest Park into equal area grid cells of 50m x 50m, 100m x 100m, 250m by 250m, 500m x 500m and scored the presence or absence of individual female raccoons based on nocturnal or diurnal data. The data from individual raccoons were then combined to provide a total number of female raccoons per grid cell across all of Forest Park. Moran's I compares the value of each feature to the mean value for the dataset to evaluate if the pattern is clustered, dispersed or random (Mitchell, 2005). For example, if differences in the values of nearby or neighboring features are less than the difference in values for the dataset, the pattern would be clumped.

Food resources

Locations of possible sources of anthropogenic food were gathered using a hand-held Global Positioning System (GPS) unit and differential post-processing correction at local base station. These included: 760 trash cans (71 of which were completely contained on the Zoo grounds), 40 caddies (large rectangular trash cans on wheels used exclusively on the Zoo grounds to hold animal waste, left-over animal food, and garbage prior to transfer to the Zoo's dumpsters) and 22 dumpsters (6 of which are at the Zoo and are used all year; other dumpsters, such as some trash cans in the Park are only used seasonally) (Figure 2). Locations of picnic areas were digitized directly into a GIS database from maps supplied by the Saint Louis Parks Department. There are 25 picnic areas available in the Park, 13 of which are officially monitored and require reservations, as they are in highly desirable locations. Seven of these 13 picnic sites get heavy use year around. All food sources described above existed as georeferenced points in GIS databases. Trash cans, caddies, dumpsters, and picnic areas were defined as food resources for raccoons based on observations of raccoons at these locations on our study site (K. Bauman, pers. obs.). Similar descriptions and observations have been used by other authors in other settings (Rosatte, 2000; Bozak, 2007).

Differing weights (with the lowest being a one) were assigned to each possible source of anthropogenic food. These weighs were intended to reflect the seasonality of that food source, as well as the perceived quantity and quality of the item as a food resource for raccoons. Trash cans were given a value of one to reflect the relatively limited attraction of each individual trash can to a raccoon when compared to other items. Caddies were given a value of two to reflect the larger volume they hold and the fact that they contain food year around. Dumpsters received a value of four (double the value of the next lowest food source) to reflect the relatively large food payoff to a raccoon. It was predicted dumpsters would attract raccoons from the farthest distance. Picnic areas were valued at two because of the seasonal variability of this resource.

We used regression analyses to examine the degree to which the availability of food resources explained the distribution and abundance of female raccoons at a scale of one ha (100 m by 100m). To determine their abundance at this scale, the total number of food resources present in the one ha grid cell were summed after correcting for their relative weights using neighborhood block analysis in ArcGIS. This value-based grid model was created for each food resource (trash cans, caddies, dumpsters, and picnic areas) and all combinations of these. Similar grids created at the same scale, indicating presence of raccoons in each one ha grid for both the diurnal and nocturnal data based on 50% and 95% utilization distributions (?), were combined with each food resource grid to create the final models tested in the regression. We used both an ordinary least squares and a geographically weighted regression (GWR) analysis with number of raccoons as the dependent variable, and the number of various food resources (trash cans, caddies, dumpsters, picnic areas) as predictor variables.

Non-food resources

Locations of non-food resources, such as roads, water sources and delineation of habitat types, were done by digitizing a geo-rectified digital orthoquad image of the study site (Metropolitan Sewer District, 2007 0.9m resolution) at a scale of 1:305m. For the purposes of this study we divided the habitats in Forest Park into 5 types: mixed, wooded, fields, zoo, and water (Figure 2). The dominant habitat type in Forest Park is “mixed” (47.8%); this habitat has an open canopy and is a multi-use area. The next most prevalent habitat is “fields” (29.3%); these include polo, baseball, rugby and football fields, in addition to golf courses. The “wooded” habitat accounts for 10.0% and is defined by closed or mostly closed canopy. The “Saint Louis Zoo” forms an unusual habitat type (7.1%), but the Zoo was included since it has a large volume of anthropogenic food available throughout the year due to the number of visitors; it also has animal food easily accessible and many shelter options. The last habitat type defined was “water” (5.7%) which included any pond or stream in Forest Park (natural or man-made). Unlike other authors (Bozak, 2007), we did not define a separate category for human-use areas such as buildings, parking lots, and public attractions (except for the Zoo, which was analyzed separately, as mentioned above). At our study site, human use was less than 6% of the total area. We were able to analyze picnic areas separately. This methodology differed from that of Bozak (2007) because in her study picnic areas were classified as synonymous with human use. We analyzed relative habitat use of raccoons in each habitat. These analyses were done separately for 95% and 50% home ranges based on diurnal or nocturnal data.

Since water is considered a valuable resource for raccoons, we quantified raccoon locations for the water habitat independently in addition to the analysis done on all habitat types in the Park (including water). We examined raccoons’ association with water resources following methods of Bozak (2010). We created a 10m buffer around all water sources and determined the frequency of raccoons inside and outside the buffer using the diurnal and nocturnal telemetry locations. Differential use of areas near water was then determined using chi-square test with expected values based on area in and outside buffered water sources.

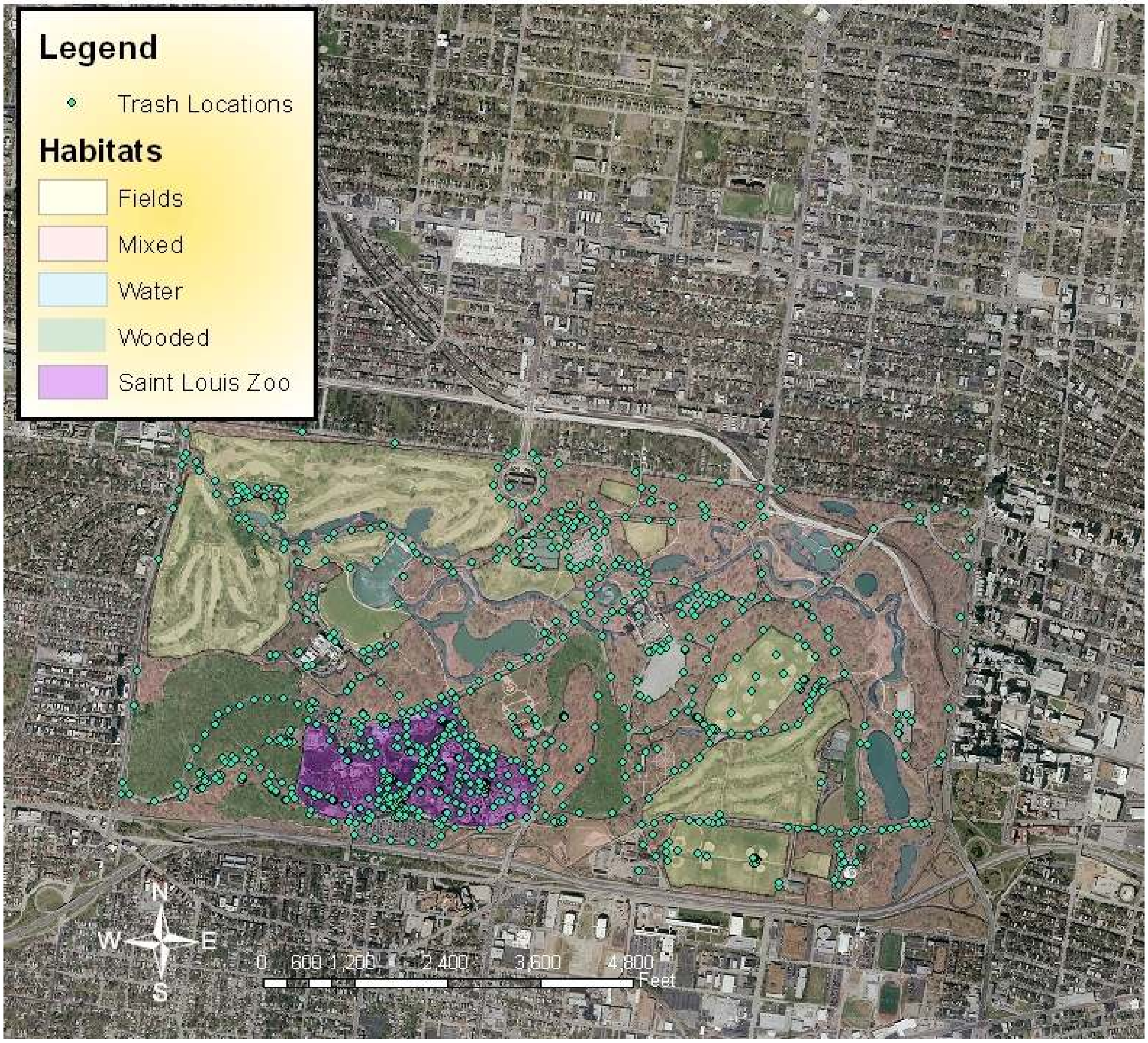

Figure 2 – Habitat types and locations of all types of trash/food resources within Forest Park

Results

Trapping and Radio telemetry

Seventeen raccoons were captured during the initial grid trapping between 16 May and 3 June 2006, six of which were females (one sub-adult and five middle-aged). During subsequent trapping from 7 June 2006 - 3 July 2007, 29 females (eight juveniles, five sub-adults, 11 middle aged adults, and five of unknown age) and 38 males were captured.

Ten sub-adult or adult females trapped between 23 May and 23 Nov 2006 met the criteria we set for radio collaring based on body weight, age class and our goal to have the females studied originate from different habitat types and areas in the Park. One additional female was collared on 1 May 2007 and added to the study to replace a female killed by a car. A total of 2142 locations that resulted from triangulation with 2 or more bearings were collected during diurnal sampling, while 1287 locations with 2 or more bearings were collected during monthly nocturnal data collection (Table 1). Data on one (#862) of the eleven females, however, was dropped from the analysis because of too few locations.

Home range

Fixed-kernel home ranges (KHR) were calculated separately for diurnal and nocturnal data using the Animal Movement Extension for 10 females (Table 1). Although we found considerable variation in home range size among females, home range sizes were similar on average between diurnal and nocturnal data sets (Table 1). Mean diurnal home range size was 110.4 ± 74.45 ha and 17.30 ± 18.37 ha for 95% and 50% respectively, and mean nocturnal home range size was 132.21 ± 107.26 ha and 17.72 ± 12.76 ha for 95% and 50%, respectively.

Home range data examined by season did show variation in home range size for the diurnal, but not for the nocturnal data (Table 2). For the diurnal data, raccoons in summer had the smallest mean home range sizes (50 ha for 95% and 8 ha for 50%), followed by fall (95 ha for 95% and 18 ha for 50%), spring (111 ha for 95% and 18 ha for 50%) and winter (120 ha for 95% and 19 ha for 50%) (Table 2). The nocturnal data yielded slightly different results with the smallest mean home range occurring in the fall (105 ha for 95% and 22 ha for 50%), followed by spring (130 ha for 95% and 25 ha for 50%), summer (137 ha for 95% and 23 ha for 50%) and winter (154 ha for 95% and 38 ha for 50%). No shift was seen in location for either the diurnal (Figures 5a-d) or nocturnal data (Figures 6a-6d).

The majority of female home ranges were within Forest Park during the day (Figure 3a), whereas several females extended their area of activity beyond Forest Park and into adjacent neighborhoods at night (Figure4a). All core home ranges (i.e., 50% kernel) during the day were contained within Forest Park except for 1 female (Figure 3b), while 95 % home ranges showed extensive overlap among females. However, with the exception of two females that had very large home ranges, females tended to cluster in the southwest corner of the Park (three females) and in the north-central/north-east corner of the Park (four females). At night, several females used the Park and adjacent neighborhoods (Figure 4a). There was lower overlap among females in the use of space at night and, thus, less of a tendency for females to cluster in certain areas of the Park as they did during the day.

Home ranges were clustered at the 95% level for both the diurnal and nocturnal data at scales of 0.25ha, 1ha and 6.25ha (Table 3). At the 25ha scale the pattern only slightly differed from a random distribution, with the diurnal data being slightly clustered (Moran's Index = 0.2), whereas the raccoons were found to be distributed at random at this scale at night (Table 3). When the distribution of raccoons were examined based on core home ranges (i.e., 50% kernel), raccoons was found to be distributed at random at night, whereas they were found to be dispersed or randomly distributed during the day at scales from 0.25 to 6.25 ha. (Table 3); distribution at 25 ha scale was not measured due to low sample size.

a.

Nocturnal

Collar ID	Total Location	Months Located	95% KHR	50% KHR
34	105	All	116.32	22.78
64	203	All	115.56	13.82
124	184	All, but Nov	373.18	27.96
155	121	All, but Nov & Dec	267.73	44.03
362	96	Feb - May	45.77	7.16
423	13	Feb only	21.91	7.4
504	55	Feb - May	23.63	3.67
562	161	May - Jan	85.41	13.31
663	181	All	158.25	31.82
784	161	All, but Oct	74.33	5.29
862	7	May only	n/a	n/a
Total	1287	n/a	n/a	n/a
Mean	n/a	n/a	132.21	17.72

b.

Diurnal

Collar ID	Total Location	Months Located	95% KHR	50% KHR
34	4	May only	n/a	n/a
64	420	All	261.01	60.08
124	350		190.56	12.9
155	79		145.4	39.56
362	266	All, but Sep - Dec	30.98	3.62
423	40	Feb - June	78.71	9.35
504	194	Feb - Apr	38.92	4.42
562	125	Feb - June	60.97	6.98
663	320	May - Jan; no Dec	138.41	13.91
784	334	All	48.56	4.86
862	10	May	n/a	n/a
Total	2142	n/a	n/a	n/a
Mean	n/a	n/a	110.39	17.3

Table 1 – Data on number of telemetry locations, months located, and kernel home range calculations in hectares by individual for nocturnal (a) and diurnal (b) data.

a.

	Nocturnal							
	Fall		Spring		Summer		Winter	
Collar ID	**95% KHR**	**50% KHR**	**95% KHR**	**50% KHR**	**95% KHR**	**50% KHR**	**95% KHR**	**50% KHR**
34	7	2			98	32	114	25
64	75	11	127	19	106	21		
124	206	51	470	111	317	35	215	37
155			218	42	122	19	166	52
362			25	3				
423								
504			22	5				
562	93	16	14	5	87	21		
663	169	32	124	15	172	26	233	62
784	80	18	43	4	54	8	40	11
Mean	105	22	130	25	137	23	154	38

b.

	Diurnal							
	Fall		Spring		Summer		Winter	
Collar ID	**95% KHR**	**50% KHR**	**95% KHR**	**50% KHR**	**95% KHR**	**50% KHR**	**95% KHR**	**50% KHR**
34								
64	110	23	215	28	98	16	147	25
124	169	27	255	36	91	9	121	14
155			114	29	19	5		
362			30	4	14	3	106	36
423			66	13			96	11
504			49	7	8	2	113	17
562	38	8			72	13		
663	123	24	92	14	68	13	204	21
784	30	8	63	14	29	3	57	10
Mean	105	22	130	25	137	23	154	38

Table 2 – Nocturnal (a) and diurnal (b) kernel home range calculations by season in hectares for each individual. Home ranges only reported for seasons where an individual was regularly located (see table 1).

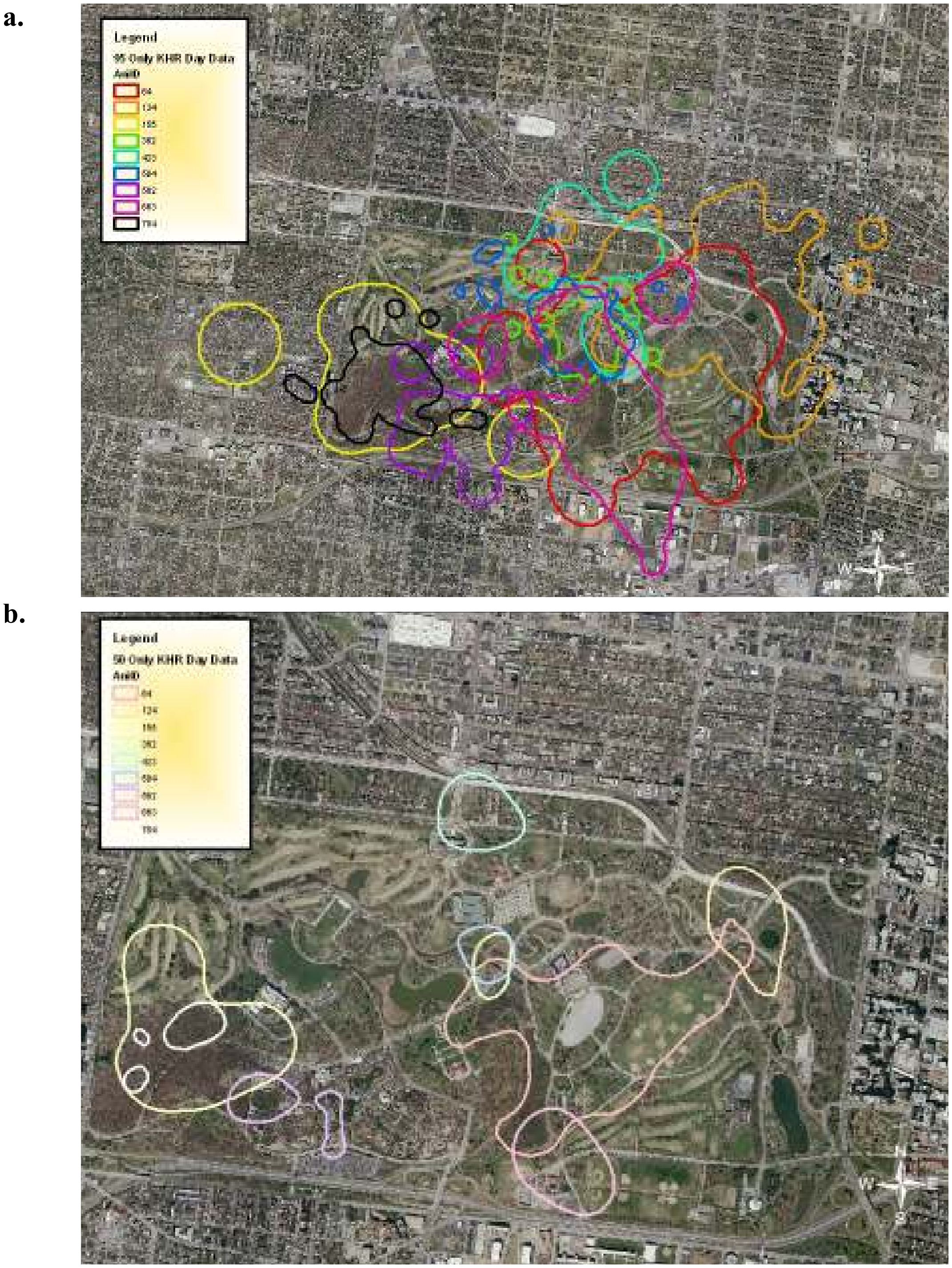

Figure 3 – 95% (a) and 50% (b) kernel utilization distributions for the raccoon diurnal data set with each individual represented by a separate color.

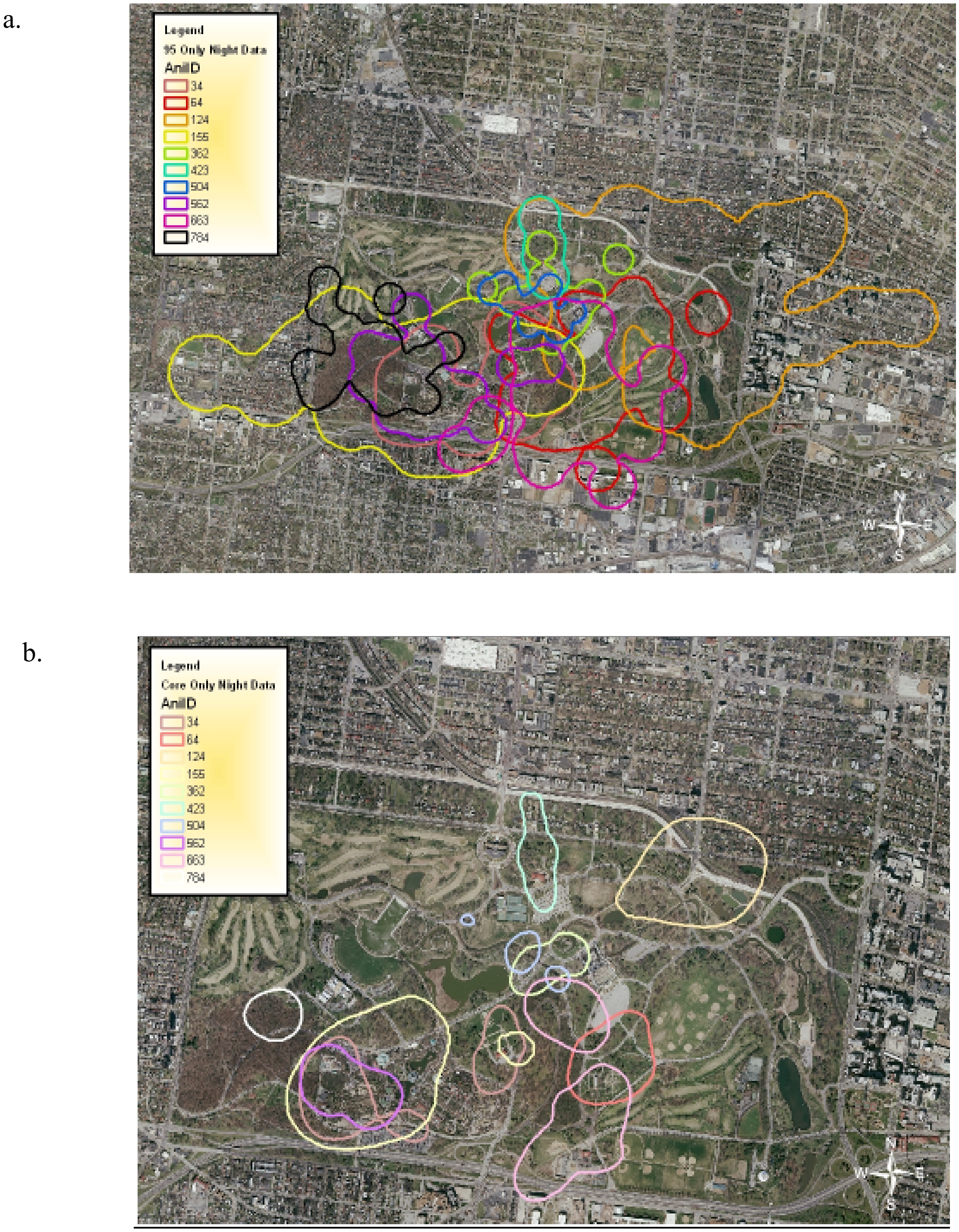

Figure 4 – 95% (a) and 50% (b) kernel utilization distributions for the raccoon nocturnal data set with each individual represented by a separate color.

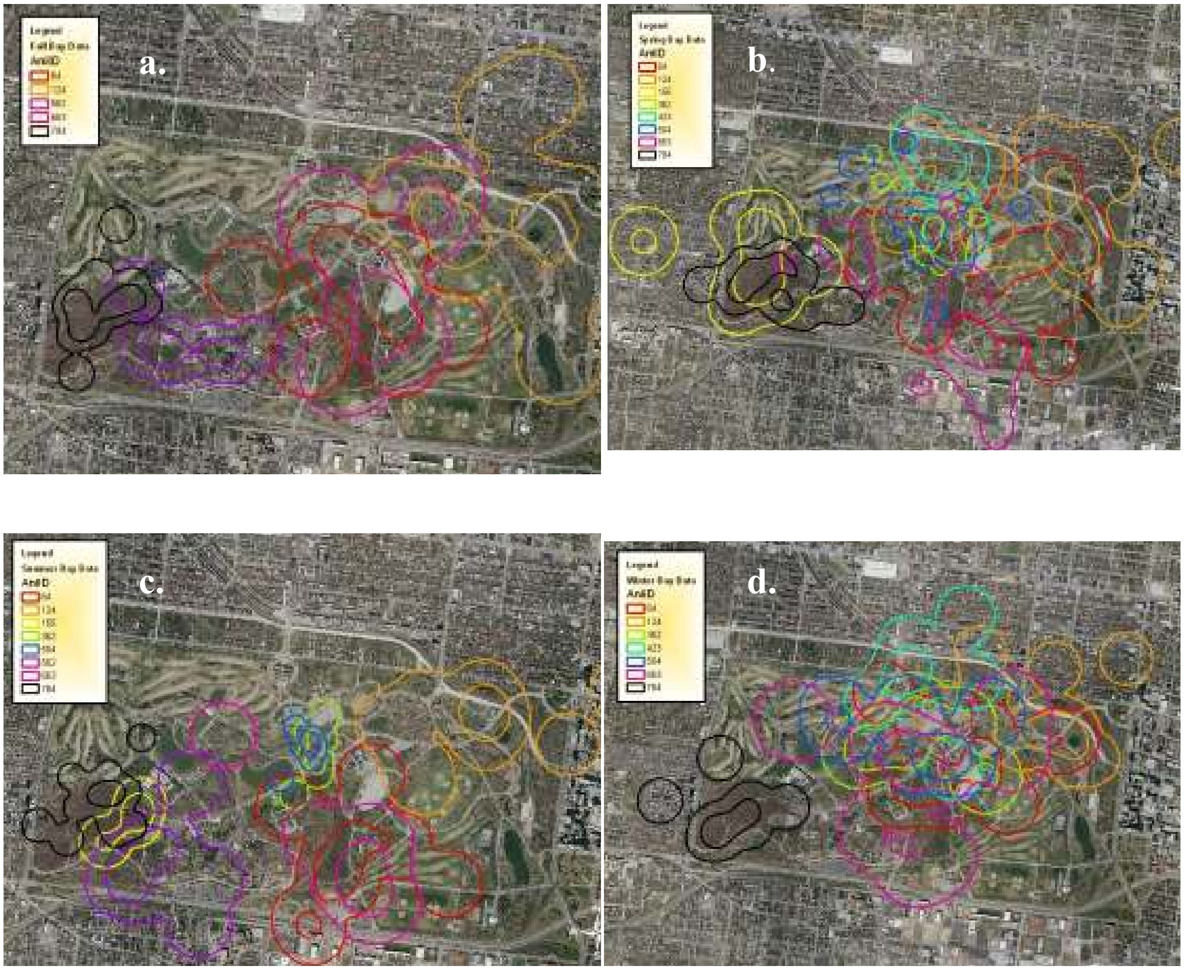

Figure 5 – Diurnal 95% utilization distributions by season, fall (a), spring (b), summer (c) and winter (d). Home ranges only reported for seasons where an individual was regularly located (see table 1).

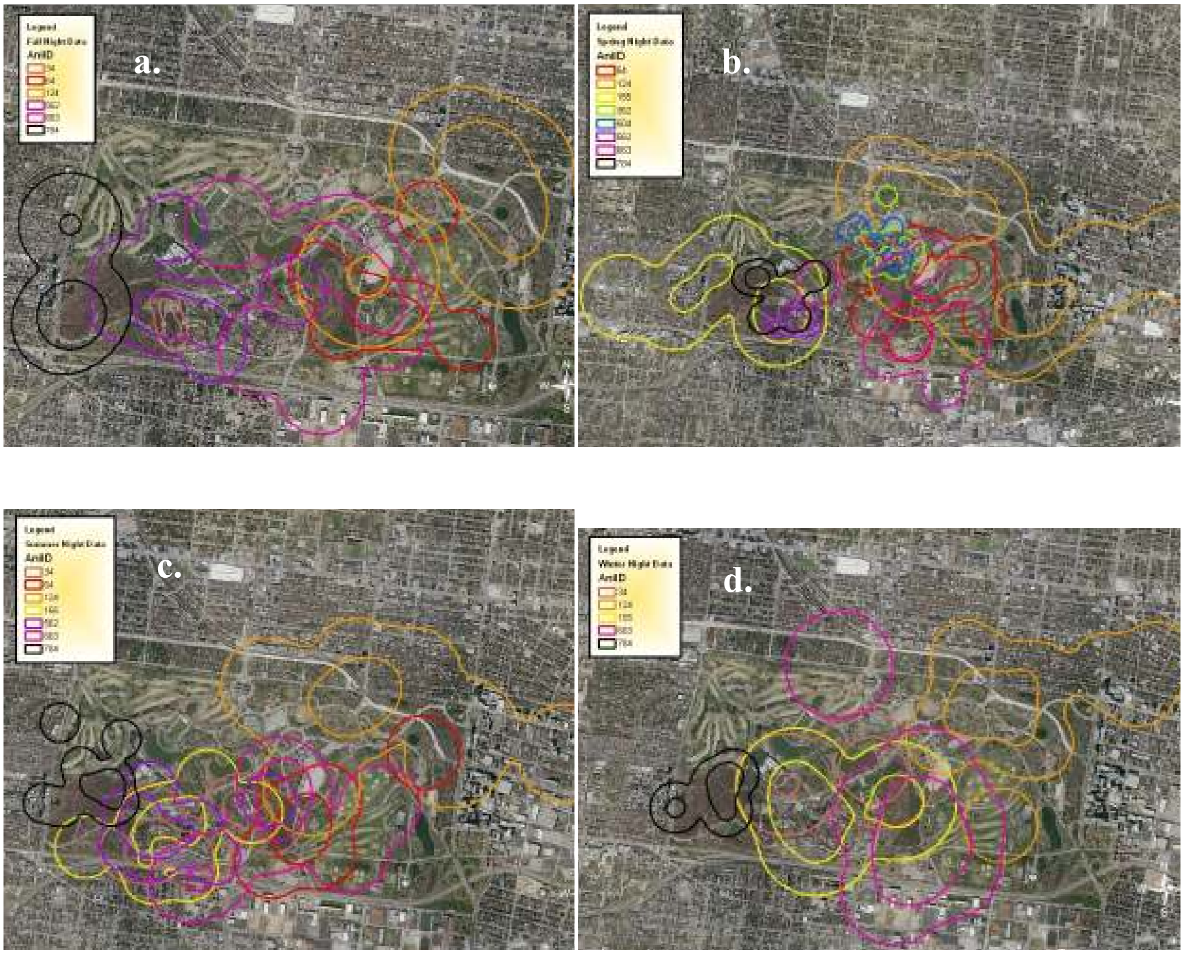

Figure 6 – Nocturnal 95% utilization distributions by season, fall (a), spring (b), summer (c) and winter (d). Home ranges only reported for seasons where an individual was regularly located (see table 1).

Table 3 – Results from Moran's Index quantifying the amount of home range overlap for each grid cell size to evaluate if home ranges are aggregated or not at different scales.

a.

Night	**.25ha**		**1ha**		**6.25ha**		**25ha**	
	50%	95%	50%	95%	50%	95%	50%	95%
Moran's Index	0.022	0.546	-0.0316	0.378	0.026	0.364	n/a	0.0874
Z score	0.760	20.252	0.140	13.048	0.572	5.837	n/a	1.076
P value	0.447	0.000	0.889	0.000	0.567	0.000	n/a	0.282
Pattern	R	C	R	C	R	C	n/a	Slightly R

b.

Day	**.25ha**		**1ha**		**6.25ha**		**25ha**	
	50%	95%	50%	95%	50%	95%	50%	95%
Moran's Index	-0.221	0.448	-0.301	0.394	-0.736	0.339	n/a	0.207
Z score	-0.919	10.633	-1.037	12.471	-3.361	0.0117	n/a	0.019
P value	0.358	0.000	0.300	0.000	0.001	0.001	n/a	0.055
Pattern	R	C	Slightly D	C	D	C	n/a	Partly C

Relationship between food resources and raccoon distribution

The geographically weighted regression (GWR) was a better fit than the ordinary least squares regression for all food resource models, which included all food resources alone, in combination, and in total. The GWR had lower AIC values and higher r-squared values in every model tested when compared to ordinary least squares regression (Table 4). Better performance of GWR models likely results because these models include a distance weighted component of resources available in the area surrounding the focal point. Consequently, GWR accounts for locally available resources by incorporating spatial information into the regression analysis while ordinary least squares regression does not include spatial information. The low ranking of the dumpster only model in explaining female raccoon distribution was not expected. Given the importance of this food resource, we expected an association of raccoons with dumpster distribution, especially at the 50% nocturnal home range data set (raccoons are nocturnal foragers). Individual trash can distribution appeared to be driving the raccoon activity; this model accounted for over 70% of the variation for both the diurnal and nocturnal at the 95% kernel, and over 50% of the variation for the 50% kernel (Table 4). Other models that were equally supported to predicted raccoon distribution (i.e., delta AICc < 3) included: cans-caddies, cans-picnic, caddies-picnic, all-food types, and cans-dumpsters (see Table 4).

Table 4 –Results from the comparison between ordinary least squares and geographically weighted regression showing the best fit determined by the top three delta AICc for predicting raccoon abundance. 95% (a) and 50% (b) nocturnal utilization distributions as well as 95% (c) and 50% (d) diurnal utilization distributions.

a

Raccoon 95% Night	Model ID	AICc	Delta AICc	Akiake weight	R Squared
GWR Cans-Caddies	5	1804.2	0	0.0000	0.7930
GWR Cans Only	1	1806.3	2.1	0.0001	0.7960
GWR Cans-Picnic	7	1807.0	2.8	0.0002	0.7960

b

Raccoon 50% Night	Model ID	AICc	Delta AICc	Akiake weight	R Squared
GWR Cans Only	1	750.0	0	0.0000	0.5370
GWR Cans-Caddies	5	754.8	4.8	0.0006	0.5390
GWR Cans-Picnic	7	755.4	5.4	0.0006	0.5380

c

Raccoon 95% Day	Model ID	AICc	Delta AICc	Akiake weight	R squared
GWR Cans-Picnic	7	1626.4	0	0.0000	0.7450
GWR Cans Only	1	1629.4	3	0.0002	0.7450
GWR Caddies-Picnic	9	1629.5	3.1	0.0002	0.5050

d

Raccoon 50% Day	Model ID	AICc	Delta AICc	Akiake weight	R Squared
GWR All Food Resources	11	394.4	0	0	0.5230
GWR Cans-Dumpsters	6	395.6	1.2	0.000137621	0.5200
GWR Cans-Caddies	5	400.4	6	0.000688105	0.5200

Non-food resources

Results indicate that relative use by raccoons differed as a function of the total by habitat type. When based on 95% kernel home ranges, raccoons were found more often than expected in mixed habitat, followed by fields, wooded, Zoo and water (Table 5); this habitat-use pattern was the same for both diurnal and nocturnal data. When based on 50% home ranges, raccoons were found most often in the mixed habitat again. However, in the core home ranges raccoons were found secondarily in the wooded, then the fields, the Zoo and lastly the water during the day. At night, raccoons at the 50% home range level were most often in the mixed habitats, followed by the zoo, wooded, field and water. However this may change if we had accounted for area as these data were not adjusted by total habitat area.

Of the 456 diurnal locations of raccoons, 52 locations were in the water or completely within the 10m buffer surrounding the water's edge. Similarly, for the nocturnal data only 15 of the 261 raccoon locations were in the water or contained within the buffer for the nocturnal data. These were significant findings with more raccoons found away from water sources than would be expected by chance (chi-square 204.5, DF=1, $p < 0.0001$ diurnal and chi-square 279.8, DF=1, $p < 0.0001$ nocturnal) which was unexpected as most other studies have shown association for water.

Table 5 – Relative habitat use by raccoons as measured by the area (in hectares) included in the 95% or 50% utilization home ranges for nocturnal and diurnal data sets. Note these data have not been adjusted for total habitat area.

Nocturnal		Diurnal	
95%	50%	95%	50%
Mixed	Mixed	Mixed	Mixed
Fields	Wooded	Fields	Zoo
Wooded	Fields	Wooded	Wooded
Zoo	Zoo	Zoo	Fields
Water	Water	Water	Water

Discussion

Trapping -

Female raccoons are documented to be more difficult than males to trap (Gehrt, 2003) which may explain why only 36% of the raccoons initially trapped were female. During the time grid trapping was conducted in this study, female raccoons were giving birth or nursing so they were not likely moving far from dens. In later trapping, 43% of the animals trapped were females. Our trapping results, although male-biased, generally included proportionately more females than other studies. A possible explanation for our trapping results is that raccoon density is extremely high at the site and, thus, our traps were more likely to encounter females. Three different attempts to estimate density of the raccoon population were made between 2003-2005 using mark/recapture techniques by setting traps for 10 to14 consecutive nights on. During these periods we trapped 62 raccoons, but because recapture rates were so low (15 individuals or 24.2%), density estimates could not be made. Nonetheless, the number of new, unmarked raccoons captured during these censuses suggests a high density of raccoons in the Park (K. Bauman, unpublished data). Mean raccoon densities in urban areas vary from 4 to 238 individuals/km^2 (Hadidian, 2010). In Rock Creek Park in Washington DC the average density was 125 individuals/ km^2, but densities were as high as 333 (Riley, 1998) during that same study. If similar densities occurred in Forest Park (i.e., approx. 250 individuals/ km^2) there would be approximately 1250 raccoons.

Radio telemetry

Our initial goals were to conduct radio-telemetry studies on a larger sample of adult females. Despite catching a relatively large proportion of females, more adult females could not be collared given our decision to radio-collar females from different portions of the Park, not only certain areas and, thus, did not put collars on females captured at the same trap site or in sites near where other females had already been collared. As females were not distributed randomly throughout the Park, many were captured at sites where females occur at higher densities (i.e., Zoo and a large wooded area) were not radio-collared. We also did not want to put radio-collars on juveniles or small sub-adults because we did not want to put these animals at risk since their neck sizes were likely to increase as they grew.

Given the effort expended during both diurnal and nocturnal radio tracking, it is notable that some females (34, 155 & 862) had so few locations during radio-tracking.

As receiving locations were distributed throughout the park, it was unlikely to be a problem with some raccoons being too far from these locations, especially since these females were located in the north-east corner of the Park where there were multiple receiving stations. Limited data on these females were more likely to be related to the problems with the antennas on the radio collars. Five of the 11 radio collars used were recovered when the females were re-trapped; in all cases the antennas were severely damaged. Four of the antennas were completely missing with only the portion that emerges from the collar remaining (about 2.5cm). A missing antenna drastically reduces the transmitter signal range, therefore, if other collars were damaged in a similar manner, that would explain the low number of locations for some individuals when they were further from the van locations. Another possible explanation is that several of the raccoons appeared to have daytime dens that were underground, either in abandoned sewer pipes or in other man-made structures. Given the historical and current uses of the Park, there are many non-natural den sites available beyond those typically found in a urban setting. For example, on three occasions raccoon 34 was tracked by foot to a planter area within the wall of the Zoo's sunken lion enclosure. This wall is made of sprayed concrete upon a rebar frame so that it is hollow inside. Our previous work with raccoons and opossums on the Zoo grounds has demonstrated that similar walls are popular den sites for both species (Wilson, 2004; K. Bauman, unpublished). Raccoons denning underground during the day would explain why, despite the amount of effort, the number of night locations was higher. At night raccoons are active and moving above ground, thus making it easier to detect them from a distance.

Home range

Mean home range sizes of 110.39 ha and 132.21 ha for the diurnal and nocturnal data, respectively, are above the reported range of means in urban settings (Gehrt, 2004). However, approximately half the animals in our study had smaller home ranges than those previously reported for urban areas, with these smaller ranges located in wooded habitats such as are found in the southwest corner of the Park. Given that Forest Park is highly fragmented, it is likely that raccoons have to relocate more frequently due to human disturbance. Raccoons may also move frequently to find food since there are only a few locations in the Park that have a high concentration of trash cans. Likewise wooded or human-use areas where ideal dens may be located are spread out. Some locations in the Park may only have one key resource (dens, food and water), so raccoons must make trade-offs as predicted. The extensive 95% home range overlap was similar to other reports in urban settings (Riley, 1998; Prange 2004; Hadidan, 2010). None of these studies quantified the aggregation of females as we did using Moran's Index. It would be helpful if future studies in other areas would evaluate overlap in female use of space as indicated by aggregation indices such as Moran's Index. Additionally, with the exception of a study by Chamberlain (2003) in an agricultural area in Mississippi, none of the other authors have examined the effect of scale as we did.

Although there were some changes in home range size by season, there was very little shifting of location by season. This likely is due to the high abundance of resources within the Park, so a marked seasonal shift of home range location is dampened under these conditions. Prange (2004) found that some female raccoons at her study site in Chicago had large seasonal shifts moving out of the forest preserves and into the surrounding urban matrix. A similar situation may have occurred with female 862 because all of her locations were on the edge of the Park. However this cannot be confirmed, since it was not possible to take the telemetry vehicle far into surrounding neighborhoods due to the traffic, and the number of low tree branches and power cables which would potentially collide with the van's extended antenna.

Food resources

Anthropogenic food from trash cans, caddies and dumpsters appear to have stronger influence on home range placement than water or habitat type. All home ranges contained dumpsters except female 784's diurnal home range in which a dumpster was located near to, but not inside the home range. Nonetheless, dumpsters only accounted for a small amount (20% core and <50% home range scale) of the variance in raccoon locations. On the other hand, trash-can location accounted for more than 70% of the variance in home range placement. This suggests a very strong effect of trash cans which was surprising given the size difference and variability in the food resources between trash cans and dumpsters. However, trash cans are the most numerous food resource and, as such, are highly available so this may be a factor. Bozak (2007) also found that food resources dictated home range placement during the summer season, but she did not analyze trash cans separately from other food resources, such as picnic areas. Rather the constraints at her study site caused her to combine food resource types, so that only our all food resource model would comparable. Similar to her study, raccons were found to be significantly associated with all food resources as indicated by GWR models.

Non-food resources

Results indicate that raccoons appear to focus their activities in the mixed habitat for both diurnal and nocturnal 95% and the 50% home range kernels. This is not surprising given that almost 50% of the Park is of the mixed habitat type and raccoons have a very plastic ecology. The mixed habitat includes lots of edge areas, a mixture of mature trees and grass areas and also has the most trash cans located in this habitat. It was unanticipated that fields was the next highest ranked habitat at the home range level because this is atypical raccoon habitat and we were unable to trap a raccoon in the fields habitat despite considerable effort. However in the diurnal dataset, wooded habitats ranked higher than fields at the core home range level. This result likely reflects the availability and, potentially, even a difference in den quantity and quality since raccoons are known to prefer to den in trees (Hadidan, 1997, Henner, 2004, Prange, 2004). Most surprising was that the Zoo habitat ranked fourth for both 95% and 50% home ranges since we had predicted it would be preferred given the amount of food available year round. This lower than expected ranking may reflect the fact that the Zoo comprises only 7% of the total Park area so if we had adjusted our results based on total area available, the Zoo may have ranked higher.

Proximity to water sources did not appear to be a primary determinant of home range location for the females we radio collared. Most of the raccoon locations were not within 10m of the water's edge, and only a few home ranges were located near water. Similarly, none of the core home ranges were located near water, including the largest bodies of water within the Park. This is a bit surprising as other studies have found that water is a key resource. This result may simply reflect limitations of our data set (i.e., GIS water layer was not detailed enough and did not reflect the spatial availability of water for raccoons). We digitized all the habitat types, including water, from a orthoquad that was very detailed, but we know from working in the Park that not all of the minor streams were included, especially in the wooded habitats where canopy cover obscured water courses. Additionally, we could not account for other minor sources of water such as ephemeral streams, small decorative drinking fountains and water that may pool on surfaces in the hardscape (e.g. parking lots, building roofs, etc.) after a rain. Lastly, and potentially, most significant is that we were unable to map underground sewer pipes and openings and we do not have any knowledge of water available underground in areas raccoons may frequent. Availability of underground water is quite likely given the historic uses in the Park. Prior to the 1904 World's Fair, the River Des Peres, which ran through the Park, was re-routed underground; there are many abandoned old sewer lines in the Park as well. If historic maps could be located, this might change our interpretation of our results. It is also possible, although unlikely that the relationship with water was not as strong in Forest Park as it is in some other areas in the country (Gehrt, 1999).

Concluding remarks

Ecologists only have a rudimentary knowledge of the mechanisms that drive the changes in human dominated landscapes (Miller, 2001). Until recently scientists have focused their efforts on documenting species loss, homogenization and landscape changes along the urban gradient. While studying the negative aspects of urbanization is important, scientists should also focus on understanding the ecology of urban adaptor species. If predictions hold, by the year 2050, three-fourths of the world's population will live in suburbs and cities (Cohn, 2005). Studies of urban adaptive species like raccoons can lend insight into how the biodiversity of the urban landscape can be conserved.

In the last decade several researchers have studied urban raccoon populations, which have contributed to our understanding of the ecology of urban raccoons. Our study adds additional empirical data from a new study site. We concentrated our study on how the abundance and distribution affected the home ranges of female raccoons in Forest Park, a site that appears to have the heaviest human use and be the most fragmented of those studied to date. We found that mean home range sizes were similar for the diurnal and nocturnal datasets, but were above the reported range of mean home range sizes in urban settings. Home ranges did not appear to shift by season although more data are needed to demonstrate this conclusively at this site. The Moran's index verified that home range overlap or clustering is occurring, but not at the core home range level. We found that the mixed habitat appeared to be used the most by raccoons, and that proximity to water did not appear to determine home range placement in this study. In contrast, the location of anthropogenic food resources did appear to be determine raccoon location.

Urban ecology is a rapidly growing new discipline and therefore it is likely the next decade of studies will fill in the gaps in our understanding of the ecology of urban raccoons. While studies focusing on comparing urban to non-urban populations are important and insightful, new evidence suggests that there is more variability among urban areas than previously thought. Therefore more rigorous comparisons between urban populations and study sites are also important to elucidate variation in behavior and ecology of raccoons.

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Appendix A – All results for both ordinary least squares and geographically weighted regression models.

a

Raccoon 95% Night	Model ID	AICc	Delta AICc	Akiake weight	R Squared
GWR Cans-Caddies	5	1804.2	0	0.0000	0.7930
GWR Cans Only	1	1806.3	2.1	0.0001	0.7960
GWR Cans-Picnic	7	1807.0	2.8	0.0002	0.7960
GWR All Food Resources	11	1811.4	7.2	0.0004	0.7950
GWR CansDumpsters	6	1813.4	9.2	0.0005	0.7950
GWR DumpstersPicnic	10	2152.9	348.7	0.0190	0.6880
GWR CaddiesDumpsters	8	2412.0	607.8	0.0331	0.5780
GWR Dumpsters Only	3	2427.4	623.2	0.0339	0.5710
GWR Caddies Picnic	9	2488.4	684.2	0.0372	0.5380
GWR Picnic Only	4	2505.5	701.3	0.0381	0.5300
GWR Caddy Only	2	2874.7	1070.5	0.0582	0.2920
OLS All Food Resources	22	3035.1	1230.9	0.0669	0.1520
OLS CansCaddies	16	3045.0	1240.8	0.0675	0.1429
OLS CansDumpsters	17	3050.8	1246.6	0.0678	0.1376
OLS CansPicnic	18	3055.6	1251.4	0.0681	0.1332
OLE Cans Only	12	3055.7	1251.5	0.0681	0.1331
OLS CaddiesDumpsters	19	3140.0	1335.8	0.0726	0.0514
OLS Caddies Picnic	20	3146.0	1341.8	0.0730	0.0574
OLS DumpstersPicnic	21	3151.9	1347.7	0.0733	0.0392
OLE CaddyOnly	13	3155.1	1350.9	0.0735	0.0359
OLE Picnic Only	15	3169.7	1365.5	0.0743	0.0208
OLE Dumpsters Only	14	3171.2	1367.0	0.0743	0.0193

b

Raccoon 50% Night	**Model ID**	**AICc**	**Delta AICc**	**Akiake weight**	**R Squared**
GWR Cans Only	1	750.0	0	0.0000	0.5370
GWR CansCaddies	5	754.8	4.8	0.0006	0.5390
GWR CansPicnic	7	755.4	5.4	0.0006	0.5380
GWR All Food Resources	11	759.9	9.9	0.0012	0.5360
GWR CansDumpsters	6	764.7	14.7	0.0017	0.5340
GWR DumpstersPicnic	10	1019.8	269.8	0.0316	0.3520
GWR CaddiesDumpsters	8	1104.7	354.7	0.0416	0.2730
GWR Dumpsters Only	3	1138.9	388.9	0.0456	0.2470
GWR Caddies Picnic	9	1148.7	398.7	0.0467	0.2730
GWR Picnic Only	4	1173.4	423.4	0.0496	0.2130
GWR Caddy Only	2	1236.0	486	0.0570	0.1450
OLS CansCaddies	16	1254.8	504.8	0.0592	0.1198
OLS All Food Resources	22	1260.2	510.2	0.0598	0.1147
OLS CansDumpsters	17	1266.6	516.6	0.0606	0.1086
OLE Cans Only	12	1271.2	521.2	0.0611	0.1042
OLS CansPicnic	18	1284.4	534.4	0.0627	0.0915
OLS CaddiesDumpsters	19	1322.8	572.8	0.0672	0.0534
OLE CaddyOnly	13	1331.4	581.4	0.0682	0.0447
OLS Caddies Picnic	20	1340.9	590.9	0.0693	0.0534
OLS DumpstersPicnic	21	1358.9	608.9	0.0714	0.0162
OLE Dumpsters Only	14	1359.0	609	0.0714	0.0161
OLE Picnic Only	15	1372.8	622.8	0.0730	0.0015

c

Raccoon 95% Day	**Model ID**	**AICc**	**Delta AICc**	**Akiake weight**	**R squared**
GWR CansPicnic	7	1626.4	0	0.0000	0.7450
GWR Cans Only	1	1629.4	3	0.0002	0.7450
GWR Caddies Picnic	9	1629.5	3.1	0.0002	0.5050
GWR All Food Resources	11	1634.9	8.5	0.0006	0.7440
GWR CaddiesDumpsters	8	1636.3	9.9	0.0007	0.5430
GWR DumpstersPicnic	10	1886.4	260	0.0190	0.6460
GWR CansCaddies	5	2102.6	476.2	0.0348	0.7460
GWR Dumpsters Only	3	2107.9	481.5	0.0351	0.5400
GWR CansDumpsters	6	2168.9	542.5	0.0396	0.7440
GWR Picnic Only	4	2179.8	553.4	0.0404	0.4990
OLS All Food Resources	22	2732.0	1105.6	0.0807	0.0753
OLS CansDumpsters	17	2732.2	1105.8	0.0807	0.0752
OLE Cans Only	12	2734.3	1107.9	0.0809	0.0730
OLS CansCaddies	16	2735.5	1109.1	0.0809	0.0719
OLS CansPicnic	18	2736.5	1110.1	0.0810	0.0709
OLS CaddiesDumpsters	19	2787.3	1160.9	0.0847	0.0191
OLS DumpstersPicnic	21	2788.2	1161.8	0.0848	0.0181
OLS Caddies Picnic	20	2789.1	1162.7	0.0849	0.0172
OLE Dumpsters Only	14	2795.7	1169.3	0.0853	0.0100
OLE Picnic Only	15	2797.9	1171.5	0.0855	0.0079
GWR Caddy Only	2	error		0.0000	error
OLE CaddyOnly	13	error		0.0000	error

d

Raccoon 50% Day	Model ID	AICc	Delta AICc	Akiake weight	R Squared
GWR All Food Resources	11	394.4	0	0	0.5230
GWR CansDumpsters	6	395.6	1.2	0.000137621	0.5200
GWR CansCaddies	5	400.4	6	0.000688105	0.5200
GWR CansPicnic	7	401.6	7.2	0.000825726	0.5200
GWR Cans Only	1	402.2	7.8	0.000894536	0.5200
GWR DumpstersPicnic	10	622.5	228.1	0.026159457	0.3570
GWR CaddiesDumpsters	8	757.2	362.8	0.041607413	0.2390
GWR Dumpsters Only	3	757.5	363.1	0.041641818	0.2380
GWR Caddies Picnic	9	776.5	382.1	0.043820817	0.2170
GWR Picnic Only	4	782.5	388.1	0.044508922	0.2120
GWR Caddy Only	2	914.4	520	0.059635763	0.0790
OLS CansDumpsters	17	978.9	584.5	0.067032891	0.0048
OLE Cans Only	12	979.6	585.2	0.06711317	0.0035
OLS CansPicnic	18	979.6	585.2	0.06711317	0.0035
OLS All Food Resources	22	980.5	586.1	0.067216386	0.0026
OLS DumpstersPicnic	21	981.0	586.6	0.067273728	0.0020
OLE CaddyOnly	13	981.2	586.8	0.067296665	0.0019
OLS CansCaddies	16	981.3	586.9	0.067308133	0.0018
OLE Dumpsters Only	14	981.5	587.1	0.06733107	0.0015
OLE Picnic Only	15	982.5	588.1	0.067445754	0.0005
OLS Caddies Picnic	20	982.6	588.2	0.067457223	0.0003
OLS CaddiesDumpsters	19	982.9	588.5	0.067491628	0.0000