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Home Range Size and Habitat Use : Analysis on the State Endangered Bobcat (Lynx rufus) in Northwestern New Jersey

Rita Isabel Matos

ABSTRACT

Knowledge of an animal's home range provides insights into their ranging patterns and the habitats they exploit. Carnivores serve a fundamental role in ecosystems due to their trophic significance. They require large areas to roam and when these areas are protected many other species benefit. In this study, thirteen bobcats *(Lynx rufus)* in northwestern New Jersey were captured between 2002-2016 and fitted with GPS telemetry collars to assess their home range sizes and habitat utilization. We determined that female bobcats utilized forested landscapes more so than males, and that males utilized agricultural landscapes more so than females. We did not detect home range size differences amongst the sexes. Our results shed light on the habitat use of New Jersey's state endangered bobcat and provide important information for management and direction for future research related to spatial requirements, habitat selection, and population dynamics of this elusive cat.

MONTCLAIR STATE UNIVERSITY

HOME RANGE AND HABITAT USE: ANALYSIS ON THE STATE ENDANGERED BOBCAT (*Lynx rufus*) IN NORTHWESTERN NEW JERSEY

by

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The concept of home range and territory in regards to utilization of space by mammals has been thoroughly studied by researchers studying mammalian populations (Burt 1943; Koehler and Hornocker 1989; Chamberlain et al. 2003; Litvaitis et al. 1986; Lovallo and Anderson 1996). A home range is defined as an area where an animal settles during its lifetime and utilizes the resources in that given area (Burt 1943). A territory is a subset of the home range that is actively defended by the animal via intraspecific competition whether for mating, rearing young, securing shelter, or food and is usually characterized as a smaller defined area within the home range (Burt 1943). It is important to study an animal's home range in order to understand the kinds of habitats it exploits and to facilitate decisions made for conservation and management of the species.

Carnivores are a conservation concern due to their life history strategies. They possess low reproductive rates, occur at low population densities, and are elusive making them a difficult group to study (Ruediger 1998). Sampling techniques for carnivore research are mostly direct and intensive, with capturing and global positioning system (GPS) telemetry utilized regularly (Broman 2012; Litvaitis et al. 1986; Martin et al. 2009; Powell 1987; Riley 2006; Young et al. 2019; Fuller et al. 1985). However, radio-telemetry receivers and transmitters are expensive, so a variety of other techniques are often utilized including camera traps, scat surveys, scent station monitoring, incident sightings, and snow tracking (Broman 2012). Although inexpensive, some of these methods are climate and seasonally dependent (Broman 2012). GPS radio collars facilitate the collection of spatial and temporal data by providing many locations in a relatively short period of time (Martin et al. 2009). With the use of this technology, valuable location information on animals that occur in low densities and occupy inaccessible habitats can be collected (Martin et al. 2009). However, due to its cost and satellite signal interference due to vegetation and terrain bias (Frair et al. 2004), researchers may be limited to sampling fewer individuals (Broman 2012).

Carnivores are known to occupy large home ranges due to cyclic prey densities and abundances (Bailey 1974; Litvaitis et al. 1986). They are crucial for ecosystem stability in controlling lagomorph, rodent, and ungulate populations (Litvaitis et al. 1986). When protected, their habitats can serve as barriers to urbanization while providing conservation areas for many species. Additionally, by protecting these large areas, the ecosystem remains intact and provides unlimited ecosystem services to all the animals, including humans, that reside in the area. Habitat fragmentation is a major threat to large carnivores and will continue to increase as humans continue to expand outside urbanized areas making these protected lands a place of 'last hope' for many species.

The state of New Jersey is 47th in size with Connecticut, Delaware, and Rhode Island being smaller. However, it has the densest population of any state in the country with approximately 1,200 persons/mi^2 (3,108persons/km^2) and a population of almost 9 million people (Census Bureau 2020). Most of the population resides within urban areas near New York City, Philadelphia, and along the coast, with the northwest and south being less dense; however, all 21 counties are considered urban. Given these facts, wildlife in the state are presented with numerous challenges such as habitat fragmentation, roadway barriers, and human disturbance. The New Jersey Department of Environmental Protection (NJDEP) recognizes the issue and has reserved over 750,000 acres of protected open-spaced land for wildlife and public access for recreational activities; an area the size of Rhode Island (NJDEP 2020). Additionally, the NJDEP has worked alongside universities and nonprofit organizations to conduct research and assist in appropriate management techniques to facilitate wildlife crossings of roadways.

European colonization of North America resulted in deforestation for lumber, charcoal, and agriculture, and contributed to the degradation of habitat for bobcats *(Lynx rufus)*. In addition, bobcats were harvested for their pelts. This led to the extirpation of bobcats from New Jersey by the early 1970s (NJDEP 2019). In efforts to bring this elusive predator back to New Jersey, 24 bobcats were captured in Maine and released into northwestern New Jersey between 1978-1982 (NJDEP 2019). The bobcat was listed as endangered in New Jersey in June of 1991 and has continued in that status to this day. Since its reintroduction, the population has gradually increased and is concentrated in the northwestern counties of the state: Morris, Sussex, Warren, and Passaic, although reports of bobcat sightings in Mercer and Bergen county have increased (NJDEP 2019). Unfortunately, eastern, central, and southern counties remain uninhabited due to agriculture and heavy urbanization. The population has been continuously monitored by NJDEP biologists since the early 2000's via live trapping, scat collecting, mortality tissue collection, radio-telemetry, and camera traps. Recent estimates show there are approximately 250 unique individuals residing in the state (Fowles 2019). Although sporadic monitoring has continued, a comprehensive home range analysis has not been performed to date, and consequently we do not know what kinds of habitat the endangered bobcat prefers in New Jersey.

The bobcat *(Lynx rufus)* is a medium-sized wild felid that is widespread across the United States with limited range in the great lakes region, Canada, and Mexico and is absent in the mid-western regions of the United States due to extensive deforestation for agriculture (McCord and Cardoza 1982). Bobcats exhibit the usual sexual dimorphism exhibited by a polygynous mammal with males being larger in size (12kg) than females (9kg); however, fluctuations exist depending on region (Lovallo and Anderson 1996; Crowe 1975; McCord and Cardoza 1982). Their diet consists of various species of lagomorphs, rodents, aves, and ungulates with occasional consumption of reptiles (Litvaitis et al. 1984; Young 1978). Bobcats inhabit various habitats such as riparian, wetland, deciduous, coniferous, mixed-deciduous/coniferous, savanna, chapparal, and coastal sedge scrubs (Lyren 2001; Lovallo and Anderson 1996; McCord and Cardoza 1982; Young 1978). Research has found that male home ranges are larger than females, however, average home range sizes vary considerably with latitude due to prey and habitat availability (Lovallo and Anderson 1996; McCord and Cardoza 1982; Hansen 2007; Riley et al. 2003; Kitchings and Story 1984). Typical of polygynous mammalian species, male home ranges overlap several female home ranges to increase breeding opportunities (Bailey 1974). They maintain these home ranges via scent marking with feces, urine, or anal gland secretions on various objects such as rocks, trees, shrubs, or fallen logs and occasional conflicts with rival male neighbors will occur (Bailey 1974).

Bobcats are solitary and territorial with mating, rearing/nursing of young, and territorial disputes being the only forms of interaction within the species (Bailey 1974; Young 1978). Their mating system is defined as polygynous with males mating with multiple females (McCord and Cardoza 1982; Young 1978; Sleater-Squires 2016; Janečka et al. 2006). The breeding season varies with latitude but is generally between December-July (Young 1978; McCord and Cardoza 1982; Bailey 1974; Litvaitis et al.

1987; Crowe 1975). Female bobcats are seasonally polyestrous in that they may breed later on in the season if breeding was unsuccessful or if a litter was lost early on in the season (Crowe 1975); however, most females only have one litter per year (McCord and Cardoza 1982). Males reach sexual maturity during their second year while females reach maturity at 9-12 months; however, females rarely breed before their second year (Crowe 1975; McCord and Cardoza 1982). Gestation is between 60-70 days with an average litter size of 1-4 kittens (Young 1978; McCord and Cardoza 1982). Kittens are born blind and emerge from the den after 30-40 days. The young will stay in the accompaniment of their mother for 9 months to a year, some as long as a year and a half (McCord and Cardoza 1982). Mothers are territorial as a method of protecting their young and will not tolerate the presence of any male until the kittens are older or the next breeding season begins (McCord and Cardoza 1982). Once the young reach independence, they are known as transients and may disperse far distances from their mothers territory in search of their own location (McCord and Cardoza 1982; Bailey 1974).

Various studies have been conducted across the United States on bobcat home ranges and habitat use; however, such an analysis has not been done for New Jersey (Bailey 1974; Lovallo and Anderson 1996; Fuller et al. 1985; Litvaitis et al. 1986; Donovan et al. 2011; Koehler and Hornocker 1989; Chamberlain et al. 2003). In this study, the investigator will shed some light on how bobcats utilize the habitat in New Jersey by examining and analyzing GPS telemetry collar data from thirteen bobcats between 2002 and 2016, provided by the NJDEP. With this data, we seek to answer several questions on New Jersey bobcats such as: (1) Are male home ranges larger than females in NJ? (2) What type of habitats are they utilizing? (3) are there seasonal differences in habitat use? and (4) is there a sex difference in habitat use?

METHODS

Study Area

The bobcats in this investigation were captured in an area of approximately 1,614 km^2 (Figure 1.1) encompassing three northwestern counties (Sussex, Warren, Morris) in the state of New Jersey where the bobcat population resides exclusively (NJDEP 2019). Topography of the area is rugged with elevations reaching 550m above sea level at High Point State Park in Sussex County, and the lowest elevations reaching approximately 90m above sea level in the eastern corner of Morris County. The climate is variable due to the Kittatinny Ridge which stretches across Warren and Sussex counties where average annual temperatures fall between -3C in January and 22C in July and average annual snowfall accumulations are between 102 and 127cm (ONJSC, Rutgers Climate Data 2019). The forest community is classified as an oak-hickory climax forest with various species of oak *(Quercus spp.)*, Shagbark hickory *(Carya ovata),* Sugar Maple *(Acer saccharum),* various species of pine *(Pinus spp.),* American Beech *(Fagus grandifolia),* Black Birch *(Betula lenta)*, White Ash *(Fraxinus americana)*, American Elm *(Ulmus americana)*, Sweetgum *(Liquidambar Styraciflua)*, Tulip Poplar *(Liriodendron tulipifera)*, and Eastern Hemlock *(Tsuga canadensis)*. Average human population density across all three counties is approximately 1,628persons/km^2 with Sussex county being the least dense at 745persons/km^2.

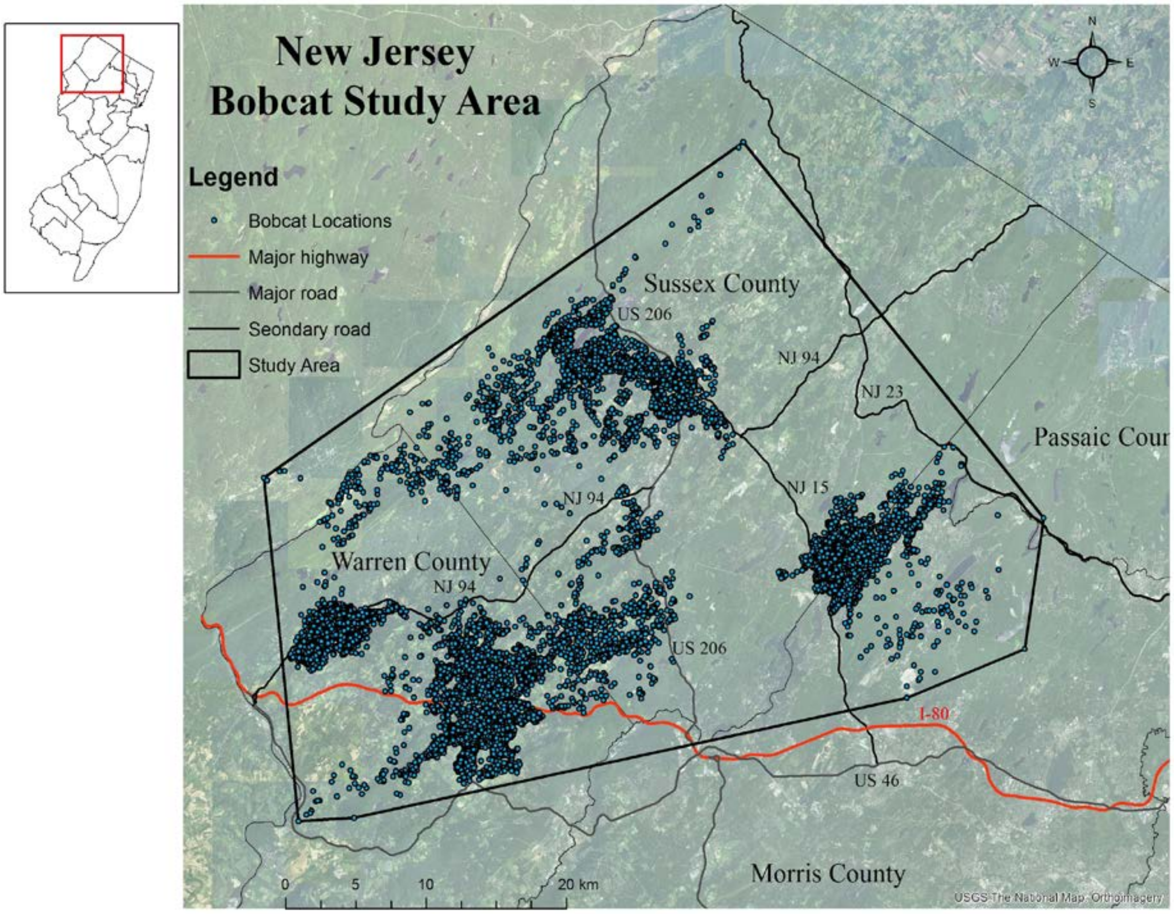

Figure 1.1 New Jersey bobcat study area (Minimum Convex Polygon) (1,614 km²) of thirteen (6F, 7M) radio-collared bobcat locations in New Jersey's northwestern counties; Sussex, Morris, and Warren between 2002-2016. Highways and major roadways have been added to show home range overlaps with roadways.

Capturing and Monitoring

Bobcats were captured by NJDEP, Division of Fish and Wildlife biologists utilizing 19"x19"x48" wire mesh Tomahawk traps (Tomahawk Live Trap, Hazelhurst, WI) baited with beaver carcasses between the winters of 2002-2005 and then again in 2008-2016. Bobcats were sedated inside of the traps utilizing a Dan-Inject automatic jabstick of Ketamine HCl and Xylazine HCl (5:1; 10mg/kg:2mg/kg) following the protocols of Dr. Keith D. Amass and Dr. Mark Andrews of Safe Capture International, Inc. Gender and age was determined for each individual based on weight and tooth condition and if conditions permitted, an ear tag was given. Bobcats weighing less than 4kg with little tooth wear were considered juvenile and released. Tooth extraction to determine exact age was taken via cementem analysis (Crowe 1975). Adult bobcats captured between the 2002-2005 seasons were equipped with a Televilt GPS-Porsec™ Model 200 (295g, Televilt/TVP Positioning AB, Lindesberg, Sweden). The collars were programmed to attempt 2 GPS positions at 05:00 and 22:00EST three times per week (Mon., Wed. and Fri.). The collar emitted a VHF signal four times each week (Mon., Wed., Thurs. and Fri.) from 10:00 to 14:00 EST. Estimated battery life was 418 days (as programmed). The collars possessed an activity and mortality sensor and a dropoff mechanism that would activate by a low battery. Once the collar drops off the animal it emitted a double pulse at 48 ppm for 45 days, allowing recovery of the collar. The radio collared bobcats were tracked using VHF radio telemetry every month to locate the animal and ensure the collars were still functioning.

Bobcats that were captured during the 2008-2016 season were fitted with ATS G2110B (Advanced Telemetry Systems, Isanti MN) collars. Trapping procedures utilized from previous years were implemented. The collars were programmed to capture GPS locations every hour for 24hrs. The collars contained a time release mechanism which was programmed to release and send out a retrieval signal after 365 days of usage. Once the collar was secured to the animal and the samples taken, the bobcats were monitored until sedation receded and the cat was released at the point of capture within 24 hours of capture. The radio collared bobcats were tracked using VHF radio telemetry approximately every 2 weeks to locate the animals and ensure that the collars were still functioning properly. When the collars sent out a retrieval signal, ground telemetry was utilized to retrieve the collar.

Home Range Estimation and Habitat Use

GPS telemetry data on bobcat locations were provided by the NJDEP based on prior tracking activities. Bobcat home range sizes were calculated using the ArcMet (Movement Ecology Tools) (Wall 2019) extension for ArcGIS 10.5 (Environmental Systems Research Institute, Redlands, CA, USA). A minimum convex polygon (MCP) and a fixed kernel density method (FKD) using *h_ref* estimation for bandwidth selection was used in the home range estimation analysis (Hayne 1948; Worton 1989; Seaman and Powell 1996). Current extension does not have least-cross squares validation (LCSV) developed and software utilized by previous studies has been outdated for the current versions of ArcGIS (Broman 2012; Lyren 2001; Abouelezz et al. 2018). MCP estimator was used because it provides an overview of the area used utilizing the x-y coordinates, however, it assumes the animal utilized the entire area equally and does not differentiate between areas the animal has used or not (Powell 2000; Gregory 2017). Kernel density estimators utilize a statistical based estimator in giving the probability that an animal was found in the given area and are unbiased over the grid size or placement (Gregory 2017). Each estimator calculates their estimates differently and possesses positive and negative attributes such as overestimation of an area (Powell 2000); however, both methods were used to increase robustness between home range estimates and show if both methods produced any differences in estimation. Furthermore, these two methods for estimating home range size have been used extensively across the literature solidifying the selection for the estimation technique (Powell 2000; Lyren 2001; Donovan et al. 2011; Riley et al. 2003; Young et al. 2019). Home ranges had a minimum of 30 locations (Seaman and Powell 1996) and 95% utilization distribution and core areas (50% UD) were calculated to illustrate the animal's use of space across the home range area (Silverman 1986).

To assess seasonal differences among bobcat habitat use, bobcat GPS data was divided into two seasons: Jan1-May31 (breeding) and June1-Dec31 (non-breeding). The decision was based on the literature which indicated northern latitude bobcats bred later in the season than southern latitude bobcats (Bailey 1974; Crowe 1975; Litvaitis et al. 1987; McCord and Cardoza 1982; Clare et al. 2015; Janecka et al. 2006). ArcGIS version 10.5 (Environmental Systems Research Institute, Redlands, CA, USA) along with NJDEP LULC 2002, 2007, 2012 and roads layers were used to extract habitat use data from GPS-collar locations utilizing the MCP home range estimation method. Land use and land cover layers were reclassified for simplification (Table 3.1) for the habitat use analysis.

Statistical Analysis

The statistical software packages used for assessing the relationships between home range sizes, sex, season, and habitat type amongst home ranges was JMPPRO version 14.2 and SAS On Demand (SAS Institute Inc., SAS Campus Drive, Cary, NC, USA). Normality of the data was tested utilizing the UNIVARIATE procedure in SAS where it produced a Shapiro-Wilk test and there was no evidence the data was not normal. A Bartlett's test using the GLM procedure on SAS was used to test whether the data contained equal variances, ensuring homoscedasticity in the data. A Welch's t-test was used to test if there were any differences between sex and home range size for each home range estimator method. To test whether there were any differences in home range means across the sexes between the two estimation methods, a MANOVA was performed using the Fit Model function in JMP. To test the relationships between sex and season and sex and habitat, an ANOVA was performed against land use. A Tukey-HSD all pairwise comparisons report was run with the effect model to compare any differences across the sexes and habitat type. Finally, to test the relationship between sex, season, and habitat use, a Kruskal-Wallis ANOVA on ranks was performed to test for differences amongst sex, season, and habitat use using a Wilcoxon test. The significance level for all statistical tests was set at α=0.05.

RESULTS

Home Ranges

Twelve adult bobcats (6F, 6M) and one juvenile (1M) were fitted with GPS collars (Table 1.1).

Bobcat Cat ID	Sex	Age	Date Collared/end	Mortality Date	Age at Death (yrs)	Cause of Death
3	F	Adult	3/5/2003-7/2003	-	-	-
622	F	Adult	3/16/2005-6/2006	3/2015	12	Trap
742	F	Adult	2/12/2009-1/2010	-	-	-
351	F	Adult	2/15/2011-12/11	12/2011	2	Trap
370	F	Adult	1/2014-1/2015	-	-	-
800	F	Adult	3/23/2015-3/2016	-	-	-
2	M	Adult	3/6/2002-10/2002	-	-	-
620	M	Adult	3/8/2004-7/2005	1/2006	-	Territorial Fight
621	M	Juvenile	3/16/2005-7/2005	12/2005	1	Vehicle
912	M	Adult	2/25/2010-3/2011	2/2013	2	Trap
382	M	Adult	3/8/2012-1/2013	1/2014	5	Trap
760	M	Adult	2/25/2014-2/2015	-	-	-
350	M	Adult	3/18/2014-1/2015	1/2015	3	Trap

Table 1.1 Trapping time and mortality data for thirteen (6F, 7M) bobcats in New Jersey between 2002-2016. Most bobcats were killed via inadvertent trapping by licensed trappers.

The spatial data from twelve bobcats (5F, 7M) with ≥ 30 locations was used to create home ranges (Seaman and Powell 1996). The MCP estimation method showed mean composite home ranges and core areas for males were 70.5±11.8SE km² and 20±3.7SE km² whereas for females they were 87.7±30.4SE km² and 39±20SE km² (Figure 1.2).

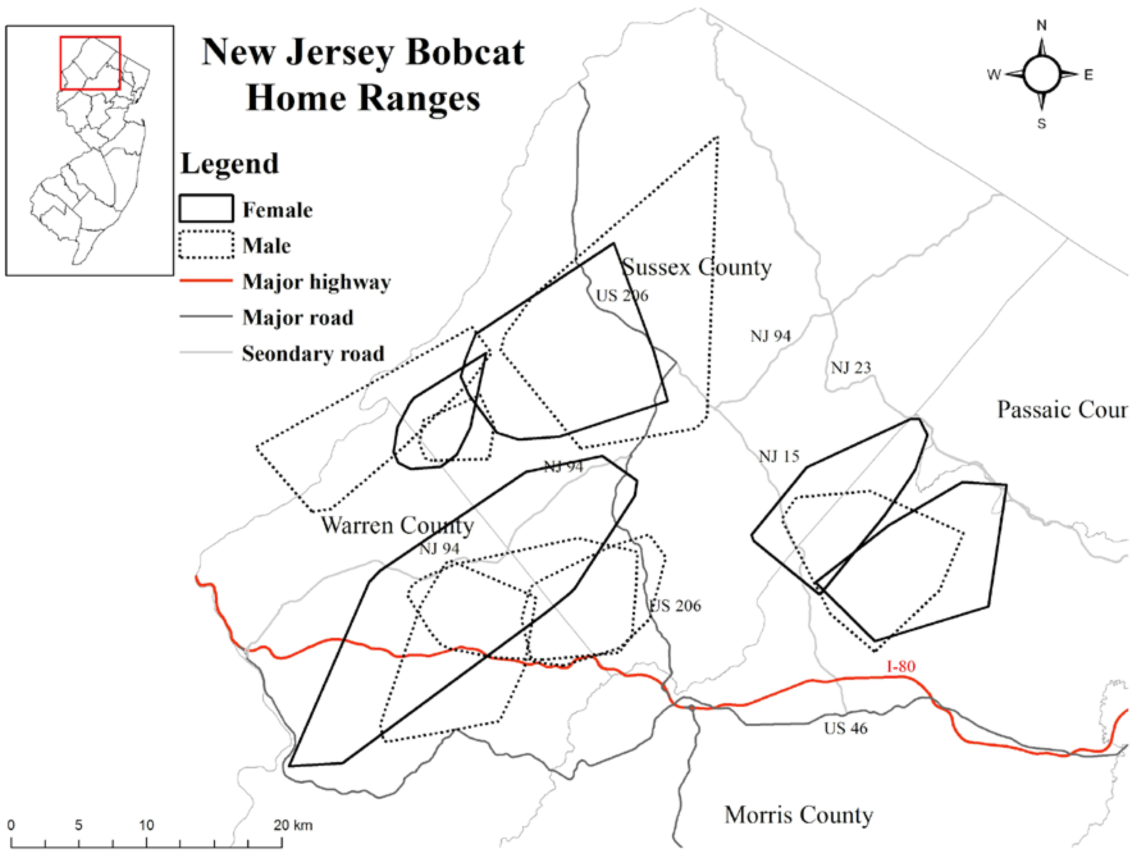

Figure 1.2 Composite home ranges of twelve (5F, 7M) bobcats (95% multiple convex polygons) between 2002-2016. Highways and major roadways shown to portray overlap between home ranges and roadways.

The fixed kernel density estimation method showed mean composite home ranges and core areas for males were 58.4±9.7SE km² and 21.8±6.1SE km² whereas for females they were 89.8±35.1SE km² and 33.1±19.2SE km² (Table 2.1). There were no differences between the two estimation methods for estimating home range sizes within the sexes (*F=0.111, p=0.315)* nor for core areas (*F=0.0875, p=0.371)*. There were no differences in home range sizes between males and females for both MCP *(F=0.276, p=0.6202)* and KDE *(F=0.7492, p=0.429)* estimation methods (Table 2.1).

Bobcat ID	Sex	95% MCP (km²)	50% MCP (km²)	95% KDE (km²)	50% KDE (km²)
3	F	60.92	10.4	79	16.4
622	F	19.82	4.96	22.9	7.2
742	F	103.41	58.63	109	21.2
351	F	197.14	109.3	214	109.3
800	F	57.22	11.94	24.5	11.2
2	M	83.39	30.43	99.6	54.6
620	M	62.47	10.7	53	12.2
621	M	13.72	4.04	18.8	7.1
912	M	106.7	30.12	79.3	29
382	M	57.89	19.78	56	21.1
760	M	65.94	23.99	57.5	17.1
350	M	103.45	21.39	44.3	11.5

Table 2.1 Composite home ranges for twelve (5F, 7M) bobcats utilizing the two estimation techniques, MCP and KDE. 95% UD signifies home range and 50% UD signifies core areas.

Male seasonal home ranges for the breeding season were 57.5±17.4SE km² *(range: 7.22-94.31 km²)* and non-breeding were 57.9±17.4SE km² *(range: 1.79-94.71 km²*) (Table 2.2). Female breeding season home ranges were 63.5±20.6SE km² *(range: 14.68-189.25 km²*) and non-breeding were 65.2±20.6SE km² *(range: 16.67-138.04 km²)* (Table 2.2).

Bobcat ID	Sex	UD	Composite	Breeding	Non-breeding
			Area (km²)	Area (km²)	Area (km²)
3	F	95	60.92	42.63	22.8
		50	10.4	-	-
622	F	95	19.82	14.68	16.67
		50	4.96	-	-
742	F	95	103.41	55.66	98.07
		50	58.63	-	-
351	F	95	197.14	189.25	138.04
		50	109.3	-	-
800	F	95	57.22	15.54	50.76
		50	11.94	-	-
2	M	95	83.39	50.12	79.25
		50	30.43	-	-
620	M	95	62.47	60.98	31.17
		50	10.7	-	-
621	M	95	13.72	7.22	1.79
		50	4.04	-	-
912	M	95	106.7	94.31	94.71
		50	30.12	-	-
382	M	95	57.89	46.67	54.92
		50	19.78	-	-
760	M	95	65.94	60.1	66.11
		50	23.99	-	-
350	M	95	103.45	83.49	77.8
		50	21.39	-	-

Table 2.2 Composite home ranges (95%UD) and core areas (50%UD) for twelve bobcats along with breeding and nonbreeding home ranges.

There were no differences seasonally in home range sizes between the sexes *(F=0.0012, p=0.973)* nor were there any differences seasonally within the sexes *(Females: F=0.0019, p=0.966; Males: F=.0006, p=.9802).* There was no overlap in home ranges between males and females contrary to what figure 1.2 shows due to dataset being from 2002-2016.

Habitat Use

To examine bobcat habitat use, the NJDEP LULC layers were downloaded onto an ArcGIS map and reclassified according to habitat type (Table 3.1).

NJDEP LULC Layers	Reclassified
Pastureland Cropland Orchards/Vineyard	Agriculture
Deciduous Coniferous Mixed forest Deciduous Shrubland	Forest
High-low Density Rural Industrial Commercial	Urban
Saline Marsh Freshwater Tidal Marshes Deciduous woodland wetland Coniferous woodland wetland	Wetland
Bare exposed rock Mining Altered Lands	Barren Land

Table 3.1 Reclassification for land use types utilized for the habitat use analysis based on NJDEP LULC data layer.

The 95%UD MCP home range polygons were used to examine seasonal and home range habitat use on twelve bobcats (5F, 7M). New Jersey bobcats utilized agriculture, forested, urban, wetland, and barren landscapes in varying degrees throughout their home range (Table 3.2).

Sex	n	95% MCP home range area (km²) mean ± SD	Agriculture (%)	Barren Land (%)	Forest (%)	Wetland (%)	Urban (%)
Female	5	87.7 ± 69.96	5.99	0.72	66.43 *	10.96	11.94
Male	7	70.5 ± 31.7	12.92 *	0.33	57.96	14.93	10.61
All	12	77.67 ± 48.02	9.75	0.49	61.49	13.24	11.16

Table 3.2 Proportion of habitat use by sex with respect to home range size for twelve bobcats in New Jersey. * denotes significant differences between habitat use and sexes

Male bobcats used agricultural *(t=-5.60, p<0.0051)* landscapes significantly more than females. However, females used forested landscapes significantly more than males *(t=5.19, p<0.0089).* There were no differences between male and female use of urban *(t=0.40, p=1.00)*, barren land *(t=0.14, p=1.00)*, and wetland *(t=-2.62, p=0.317)* habitats. There were no significant seasonal differences in habitat use between the sexes across all habitat types *(Breeding: H=7.74, df=4, p=0.101; non-breeding: H=6.98, df=4, p=0.136)* (Figure 1.3).

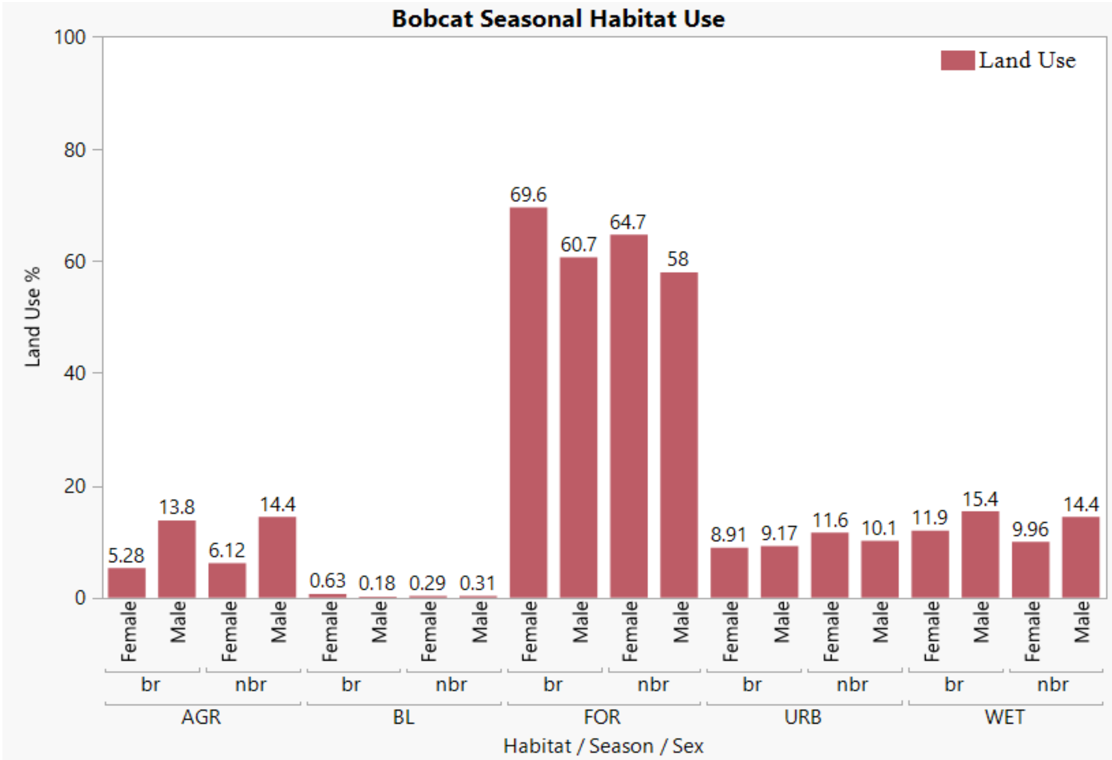

Figure 1.3 Graph of proportion of land use by habitat, season, and sex for New Jersey bobcats. AGR=agriculture, BL=barren land, FOR=forest, URB=urban, WET=wetland. Br=breeding and nbr=nonbreeding.

DISCUSSION

Home Range Estimation

Every animal possesses a home range that is specific to their trophic level and quantifying that home range provides valuable insight on the animal's habits, social structure, and lifestyle. Currently, there are no standard methods in quantifying an animal's home range; however, many different methods have been deployed by researchers to quantify such valuable pieces of information (Powell 2000). Examples of methods used to calculate home range sizes include minimum convex polygons (MCP) (Hayne 1948), kernel density estimators (KDE) (Worton 1989), low convex hull (LoCOH) (Getz et al. 2007) and recently, time-geographic density estimators (TGDE)

(Quinton 2016). Each estimator contains different measuring parameters which influence the results and appearance of the home ranges created.

Across the literature, MCP and KDE estimators are used extensively to estimate home range sizes of various animals, specifically for mammals (Powell 2000; Lyren 2001; Donovan et al. 2011; Riley et al. 2003; Young et al. 2019; Cain et al. 2003; Lovallo and Anderson 1996; Fuller et al. 1985; Litvaitis et al. 1986; Quinton 2016; Cochrane et al. 2008). Being consistent with the majority of mammalian studies of home range size, this study employed both the minimum convex polygon (MCP) and fixed kernel density estimator (FKDE). When the results of these two estimators were compared, they showed no difference in their effectiveness to produce consistent home range sizes for the state endangered New Jersey bobcat (Table 2.1). Although both estimators possess flaws, such as overestimation (Powell 2000), both provided similar results. Caution must be advised when discussing the use of these estimators, for they are not claiming where an animal has lived, rather they are predicting where an animal was likely to travel within a set of points in a given area resulting in an estimation of where the animal lived (Quinton 2016).

Home Range Sizes

Across the literature, male bobcats possess larger home ranges than females due, among other variables, to their polygynous mating system (Bailey 1974; Burt 1943; McCord and Cordoza 1982). Males maximize their fitness by mating with multiple females while females maximize their fitness by providing adequate resources for their kittens resulting in smaller home ranges (Bailey 1974; Burt 1943; McCord and Cordoza 1982; Riley et al. 2003; Chamberlain et al. 2003; Cochrane et al. 2008; Fuller et al. 1984;

Kitchings and Story 1984; Litvaitis et al. 1986; Lovallo and Anderson 1996; Young et al. 2019). In the northern regions of the United States, bobcats have been found to possess larger home ranges than their southern counterparts due to prey availability and climatic changes (Broman 2012; Litvaitis et al. 1986; Young et al. 2019; Lovallo and Anderson 1996). In this study, our sample of bobcats did not show any significant differences in home range sizes between the sexes and there were no seasonal differences in their home range sizes. However, the small sample size undoubtedly had an effect on the results.

Female bobcats have been shown to contract and expand their home range according to the energetic demands related to lactation and prey abundance (Lovallo and Anderson 1996; Bailey 1974; Litvaitis et al. 1986). According to the literature, northern ranging bobcats avoid higher altitudes during severe winters due to snowfall (Lovallo and Anderson 1996); expanding during the summer-fall months when prey diversity is high and contracting during the winter-spring due to rearing of young and snowfall (Koehler and Hornocker 1989; Bailey 1974; Fuller et al. 1985; Litvaitis et al. 1987). This suggests females alter their habitat usage seasonally in response to climatic conditions, prey diversity, and reproductive status (Litvaitis et al. 1987).

Habitat Use

New Jersey's northwestern part of the state consists of extensive forested habitats, cliff sides and rocky outcrops, wetlands, agriculture lands, and low to moderate densities of urbanized areas. It is because of these characteristics, the bobcat population has been able to establish itself in this region of the state. Across the United States, bobcats have inhabited similar landscapes showing some variation due to latitudinal and longitudinal differences (McCord and Cordoza 1982). Bobcats in New Jersey inhabited all habitat types (Table 3.2); however, males inhabited agricultural landscapes and wetlands more so than females. Previous studies have shown that male bobcats tolerate open areas better than female bobcats which could account for the agricultural and wetland selection (Riley et al. 2003; Tigas et al. 2002; Rockhill et al. 2013; Broman et al. 2014). Agricultural and wetland habitats provide understory cover for lagomorph and rodent species such as the Eastern Cottontail *(S. floridanus)* and the White-footed mouse *(Peromyscus leucopus)* which are prey items for bobcats (Litvaitis 2001). Females were found to inhabit forested areas more so than males. Forested landscapes provide a diversity of prey items, abundant possibilities for natal dens, and adequate cover from human disturbances (Riley et al. 2003; Koehler and Hornocker 1989; Chamberlain et al. 2003). Although in this study, there were no significant differences amongst habitat selection seasonally, in other studies, females have been shown to preferentially choose forests and riparian landscapes where enough cover is provided and prey availability is adequate (Litvaitis et al. 1986; Bailey 1974). In addition, these habitats are likely to possess lower densities of roadways which is a factor females consider when choosing den locations (Lovallo and Anderson 1996).

This investigation has provided a comprehensive analysis of the ranging patterns and habitat use of the state’s endangered bobcats, providing critical information necessary for the conservation of this population. Unlike other studies that reported seasonal home range shifts, we cannot account for this as there were no sex differences in home range sizes and no variations between seasonal home range sizes amongst females or males (Table 2.2) in our study (Koehler and Hornocker 1989; Bailey 1974; Lovallo and Anderson 1996; Litvaitis et al. 1986; Litvaitis et al. 1987). Previous studies found bobcats that inhabit higher latitudes (New England states and Great lakes region) tend to possess larger home ranges than lower latitude bobcats (Southern States). Home range sizes in this study align with previous research done at various latitudes (Litvaitis et al. 1986; Lovallo and Anderson 1996; Cochrane et al. 2008; Koehler and Hornocker 1989; Chamberlain et al. 2003; Young et al. 2019; Riley et al. 2003). We found that female bobcats had a greater association to forested landscapes than any other land use type as opposed to males who inhabited wetlands and agricultural regions in addition to forests (Table 3.2); however, it should be noted that forested landscapes were the dominant land use type in the study area.

This investigation provides insights in New Jersey's endangered bobcat population; however, due to small sample size and a sampling period of 14 years, the findings of this research can only provide a glimpse into the natural history of New Jersey's bobcat population. During the time when bobcats were monitored with radio-collars, they had a 42% survival rate. Most of our cats were inadvertently killed by licensed trappers who were legally trapping other fur-bearing game species. Even though the trappers check their traps regularly, most of the time, a bobcat capture results in mortality.

Although not accounted for in this study, roads are a major barrier to animal movement (Tigas et al. 2002; Lyren 2001; Riley et al. 2003; Riley 2006; Forman et al. 1998; Litvaitis et al. 2015). Roadways fragment habitats and limit physical movement and gene flow (Forman et al. 1998; Riley 2006; Litvaitis et al. 1987). In Riley et al. 2003, two of the four bobcats in their study were killed by vehicle collisions due to their home ranges overlapping with roadways. Other studies have shown that by providing adequate safe crossing opportunities in the form of crossing culverts, animal movements are enhanced and result in a reduction of mortality events (Tigas et al. 2002; Lyren 2001). Among the mortality events that could be documented in the current study, vehicle collisions accounted for one death.

Future Recommendations

Future research into the ranging patterns and habitat use of New Jersey bobcats should consider a larger sample size of radio-collared cats, concentrated in a specific region of the state. This kind of study would provide a robust dataset of current bobcat population dynamics in a region of the state where the highest population resides - the northwestern corner of New Jersey. Definitive home range sizes, seasonal distributions, current habitat use, and interactions between individuals could be analyzed from such a dataset.

Collecting blood samples for the purpose of looking at genetic markers for individuals could provide important insights into the genetic structure of New Jersey's bobcat population. New Jersey's bobcat population is descended from 24 bobcats in Maine; however, the neighboring populations of New York and Pennsylvania along with the appropriate habitat in northwestern New Jersey provides opportunity for genetic diversity. These data would help to evaluate the genetic health of the population by calculating genetic diversity. Genetic diversity is positively correlated with fitness, survivorship, and population growth.

In addition, a comprehensive habitat selection model could be developed to assess preferred habitats as population expansion occurs. The current research did not account for snowfall and snow depth over the time of the investigation, something a habitat suitability model could address (Reed et al. 2017). In other studies of bobcats in northern regions, where snowfall and snow depth are additional variables, bobcats have been found to utilize areas where snowfall and elevations are low (Reed et al. 2017; Litvaitis et al. 1986; Broman 2012; Bailey 1974). Furthermore, accountability of roadway density would provide valuable data on road mortalities and habitat fragmentation. In order to ensure the survival of our state bobcats, additional research needs to be conducted for proper conservation practices to be implemented.

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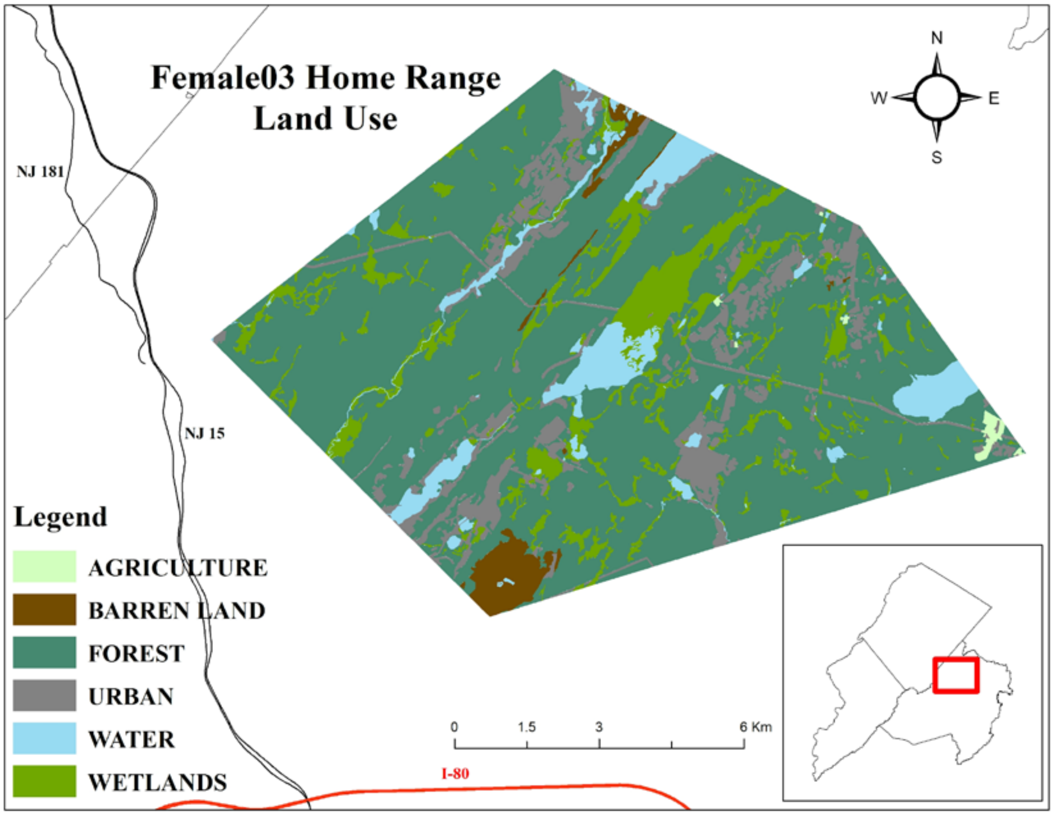
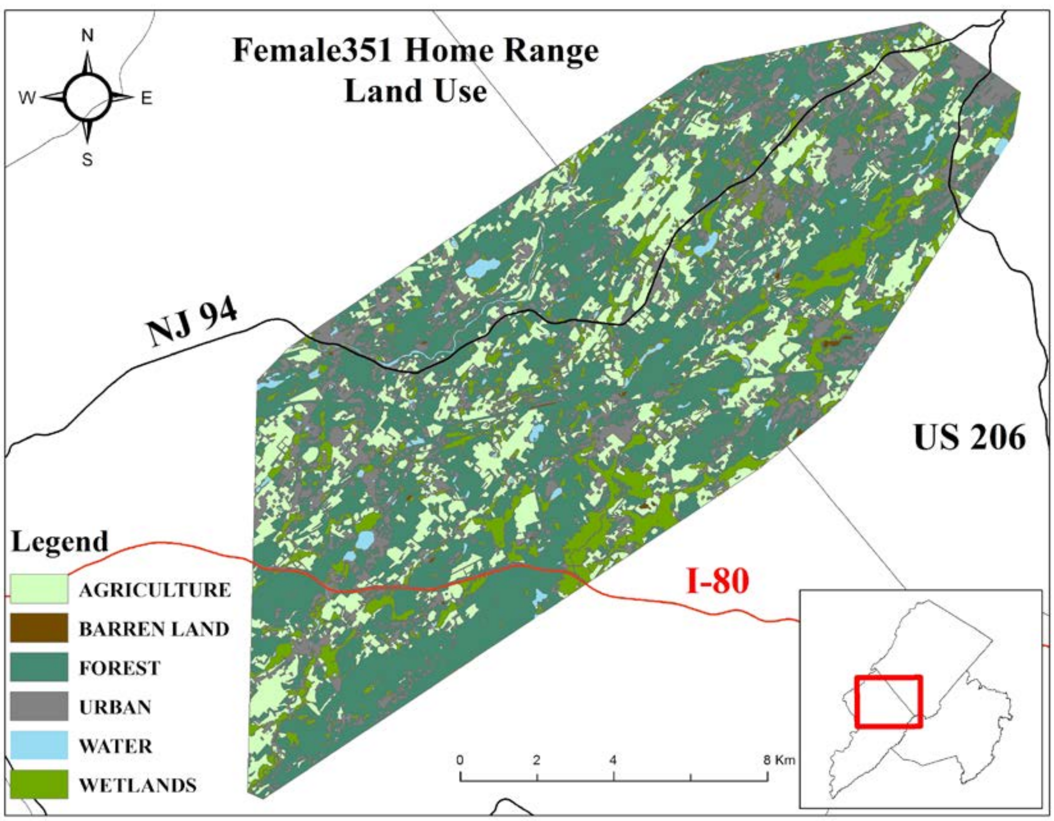
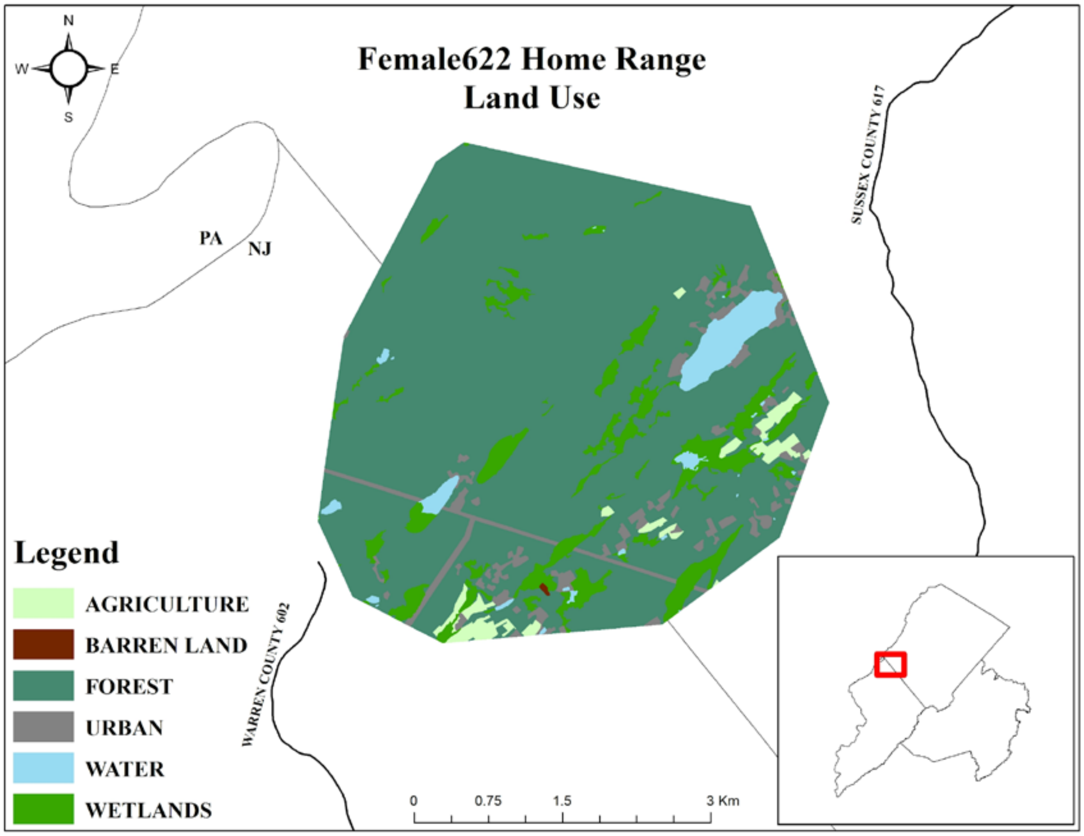
APPENDIX A: Female Bobcats Composite Home Ranges and Land Use






Female622 Home Range
Land Use
N
W
E
S
PA
NJ
SUSSEX COUNTY 617
WARREN COUNTY 602
Legend
AGRICULTURE
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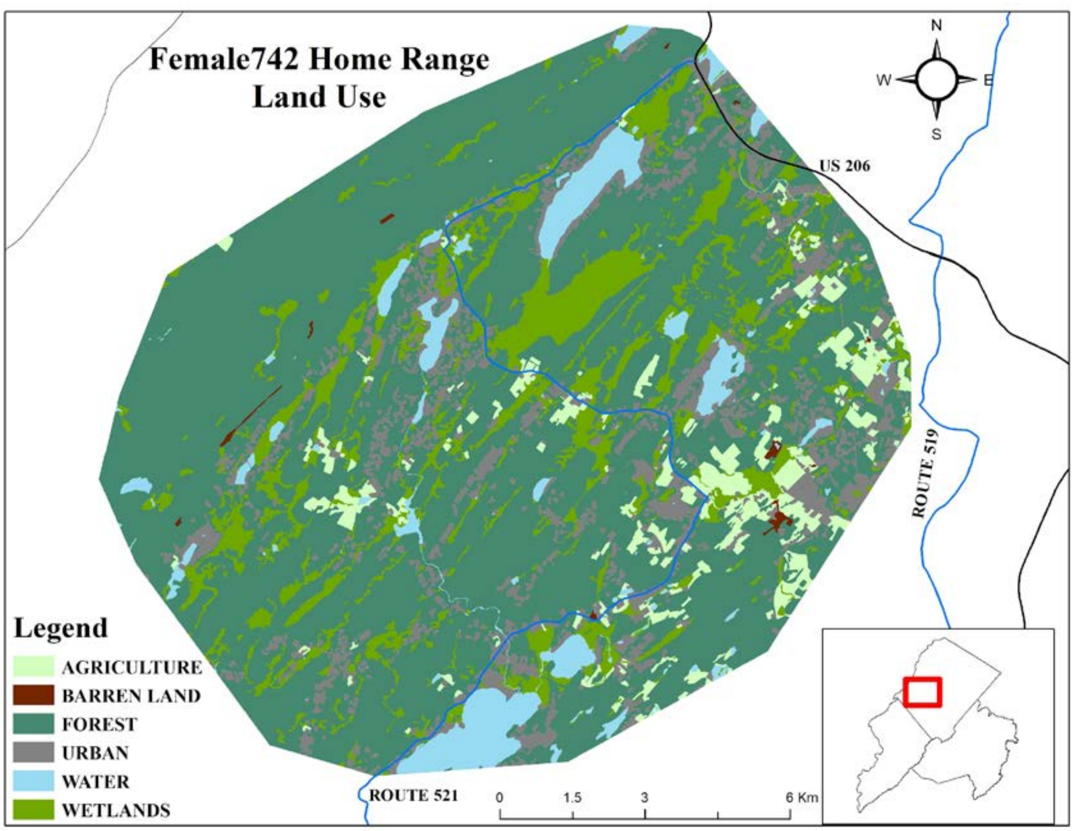
FOREST
URBAN
WATER
WETLANDS
0
0.75
1.5
3 Km


Female742 Home Range
Land Use
N
W
E
S
US 206
ROUTE 519
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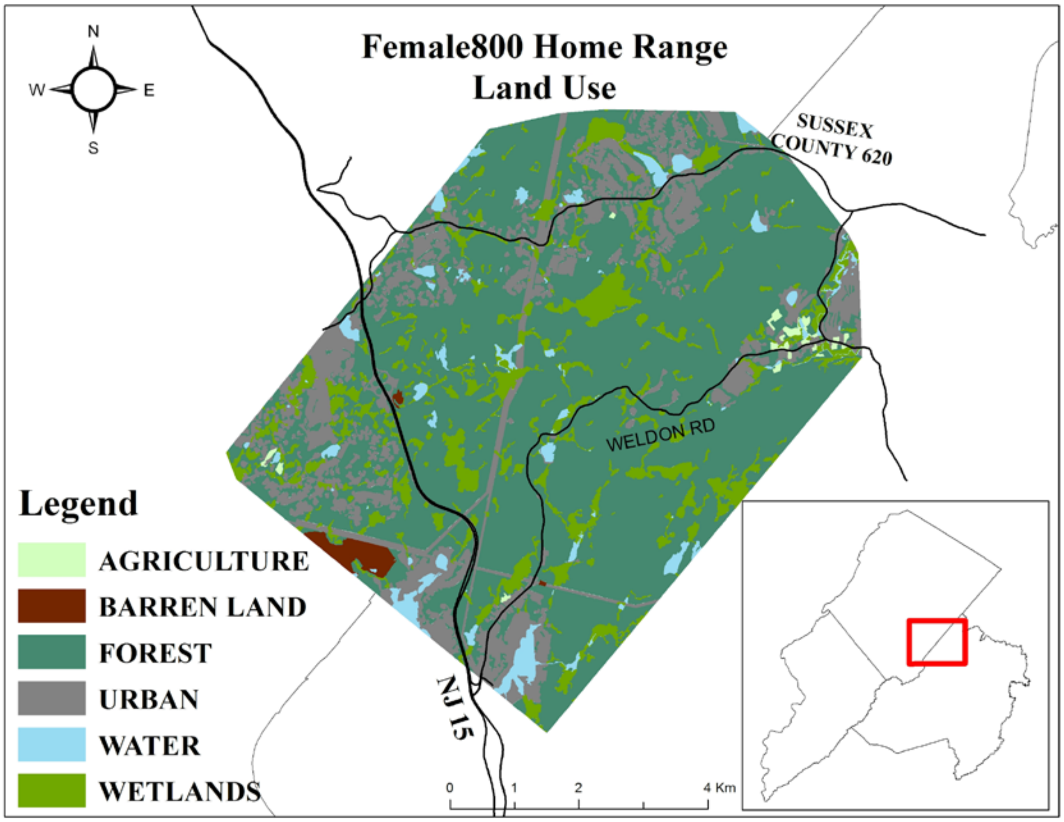
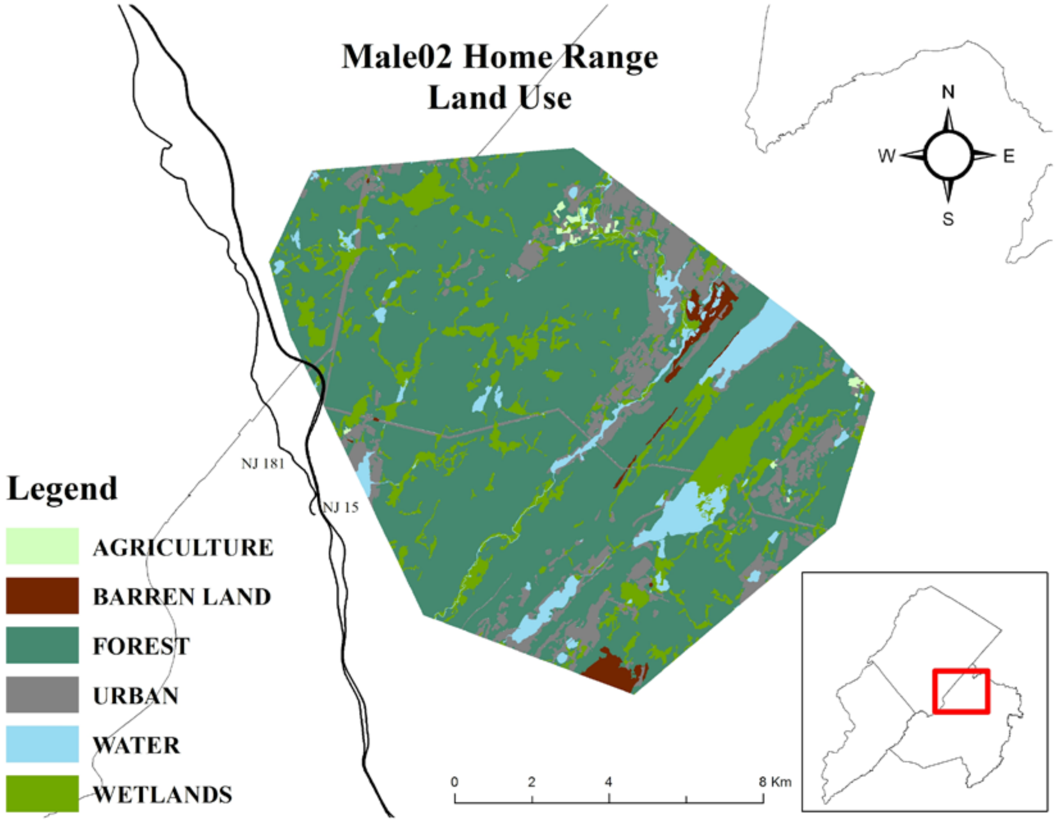
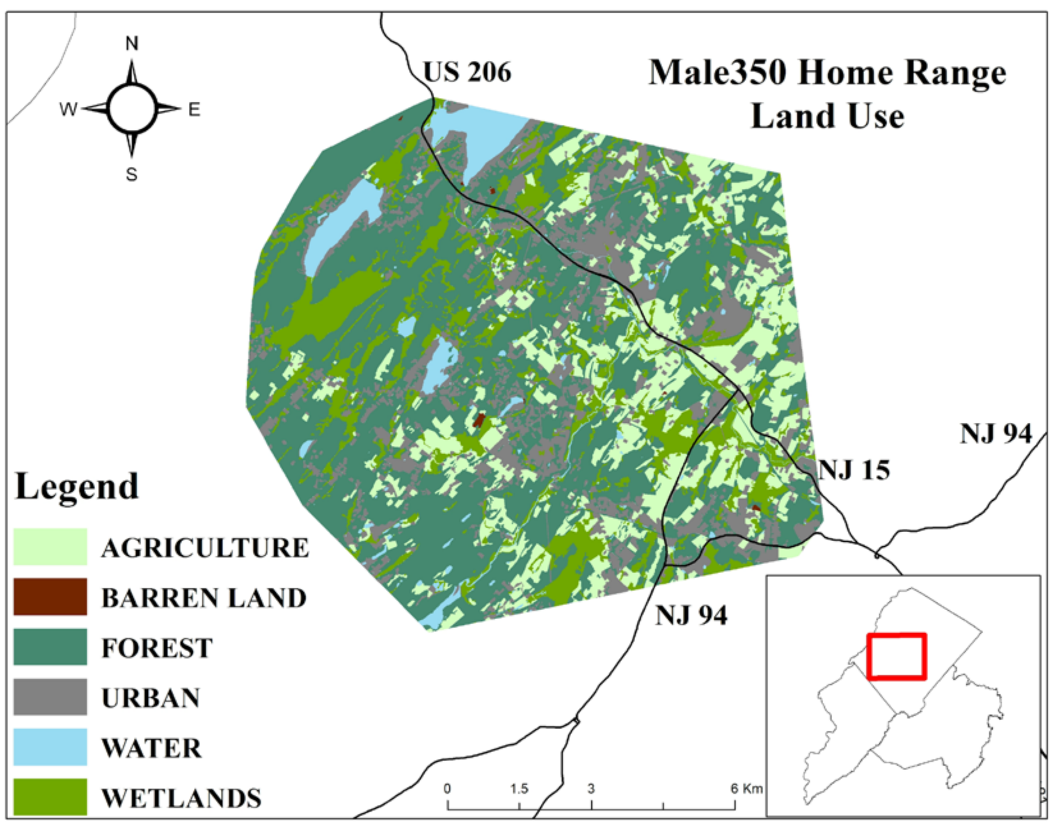
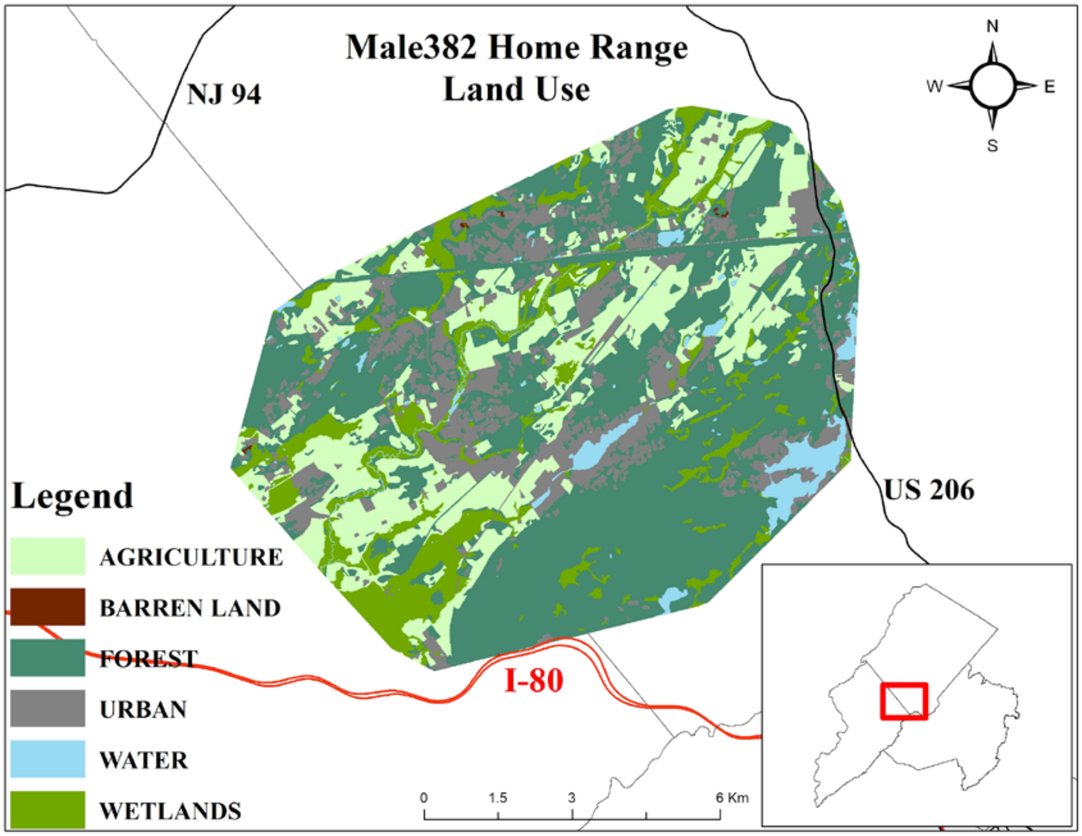
URBAN
WATER
WETLANDS
0
1.5
3
6 Km


Female800 Home Range
Land Use
N
W
E
S
SUSSEX
COUNTY 620
WELDON RD
NJ 15
Legend
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
0
1
2
4 Km

APPENDIX B: Male Bobcats Composite Home Ranges and Land Use






Male382 Home Range
Land Use
NJ 94
N
W
E
S
US 206
I-80
Legend
AGRICULTURE
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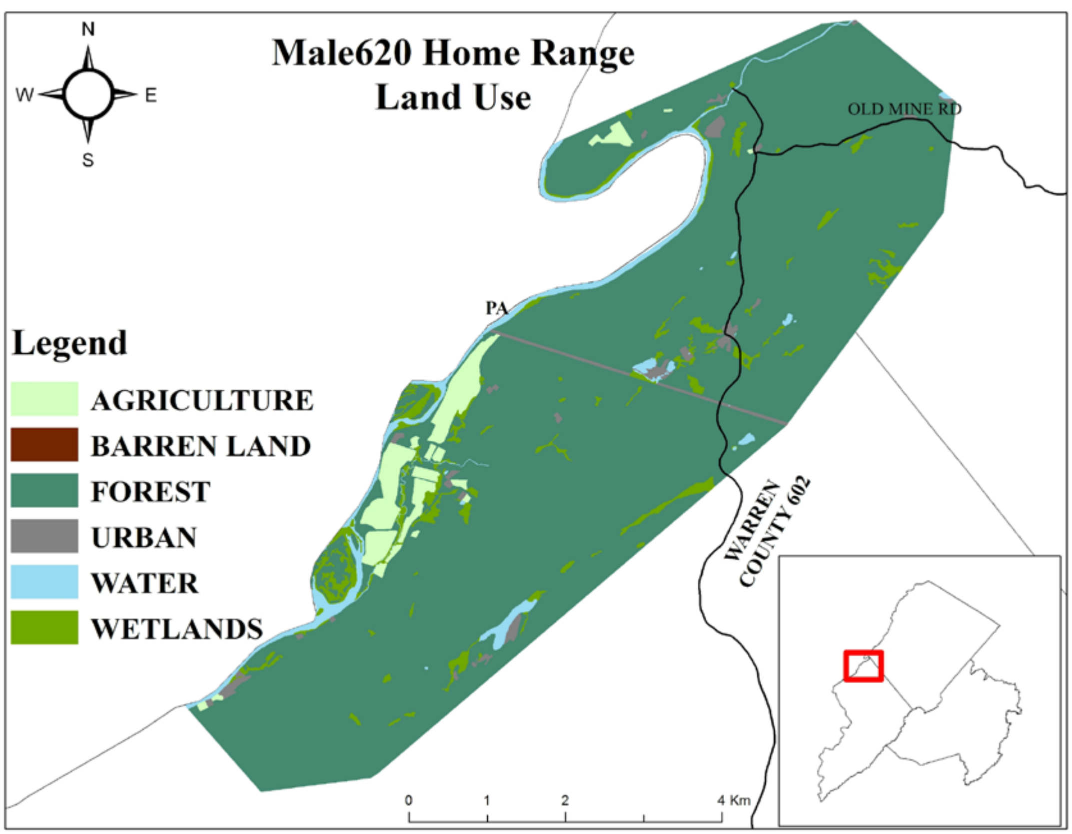
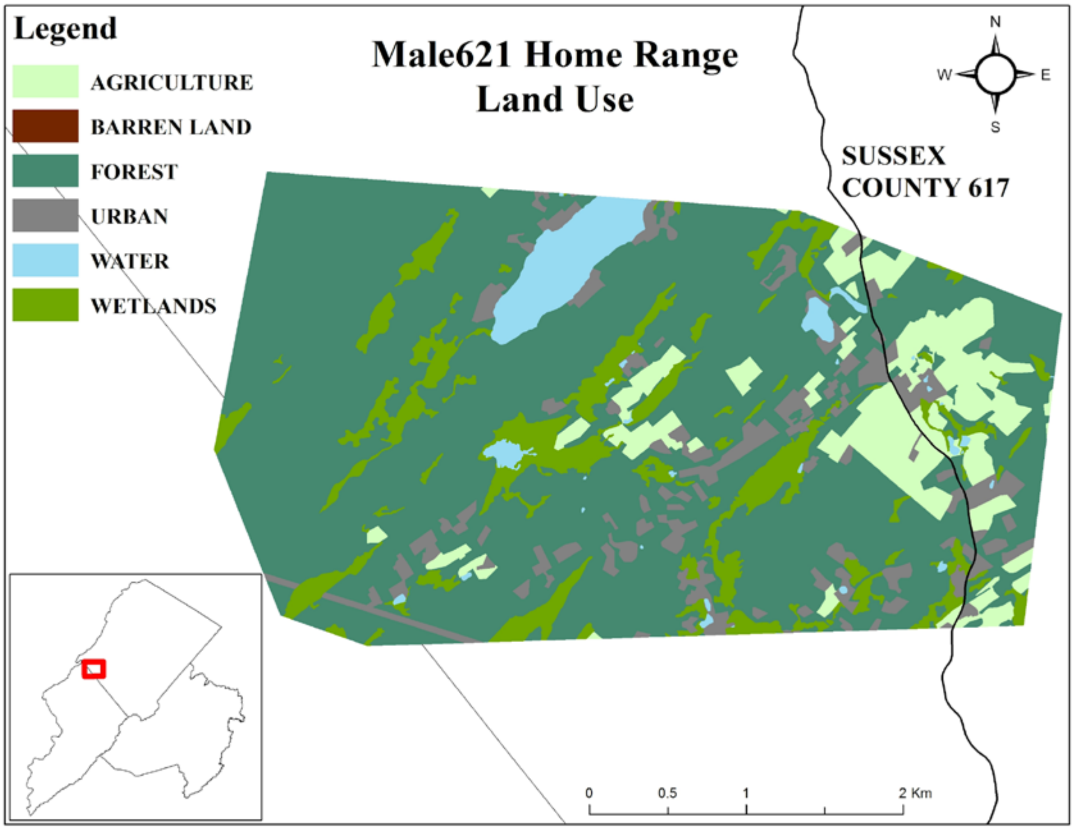
FOREST
URBAN
WATER
WETLANDS
0
1.5
3
6 Km


Male620 Home Range
Land Use
N
W
E
S
OLD MINE RD
PA
WARREN
COUNTY 602
Legend
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
0
1
2
4 Km


Legend
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
Male621 Home Range
Land Use
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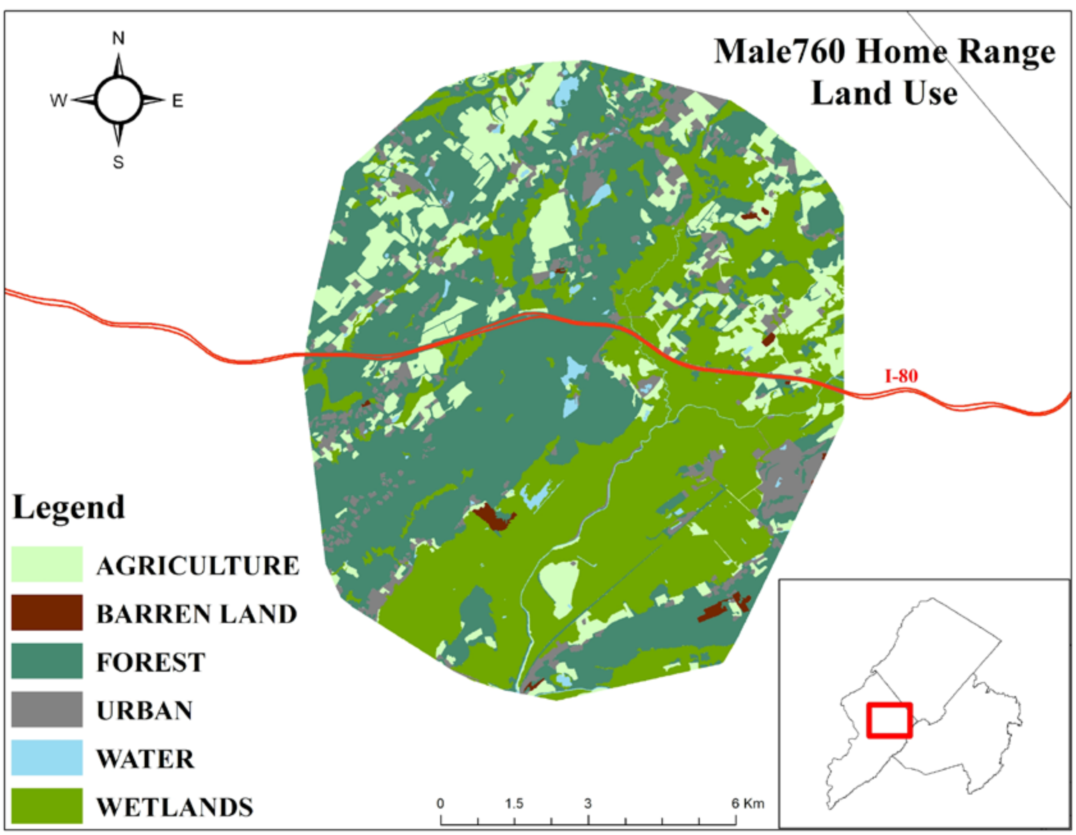
W
E
S
SUSSEX
COUNTY 617
0
0.5
1
2 Km


Male760 Home Range
Land Use
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W
E
S
I-80
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URBAN
WATER
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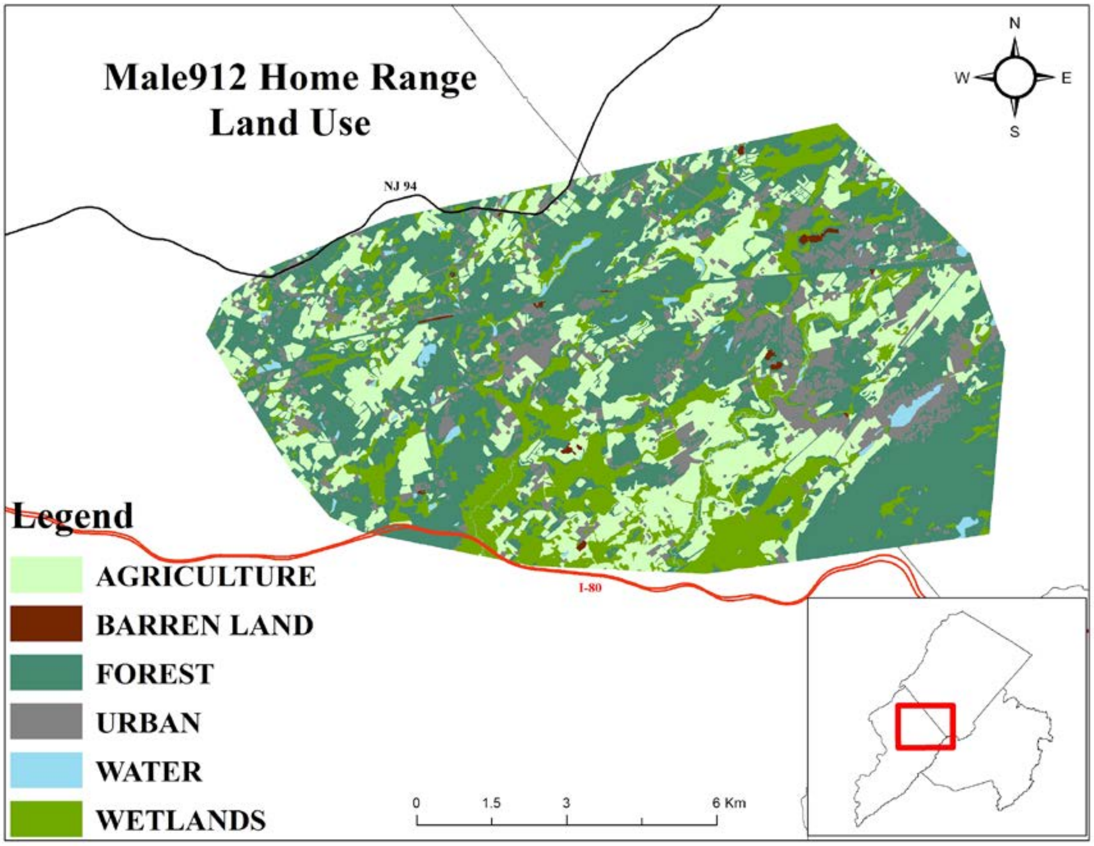
1.5
3
6 Km



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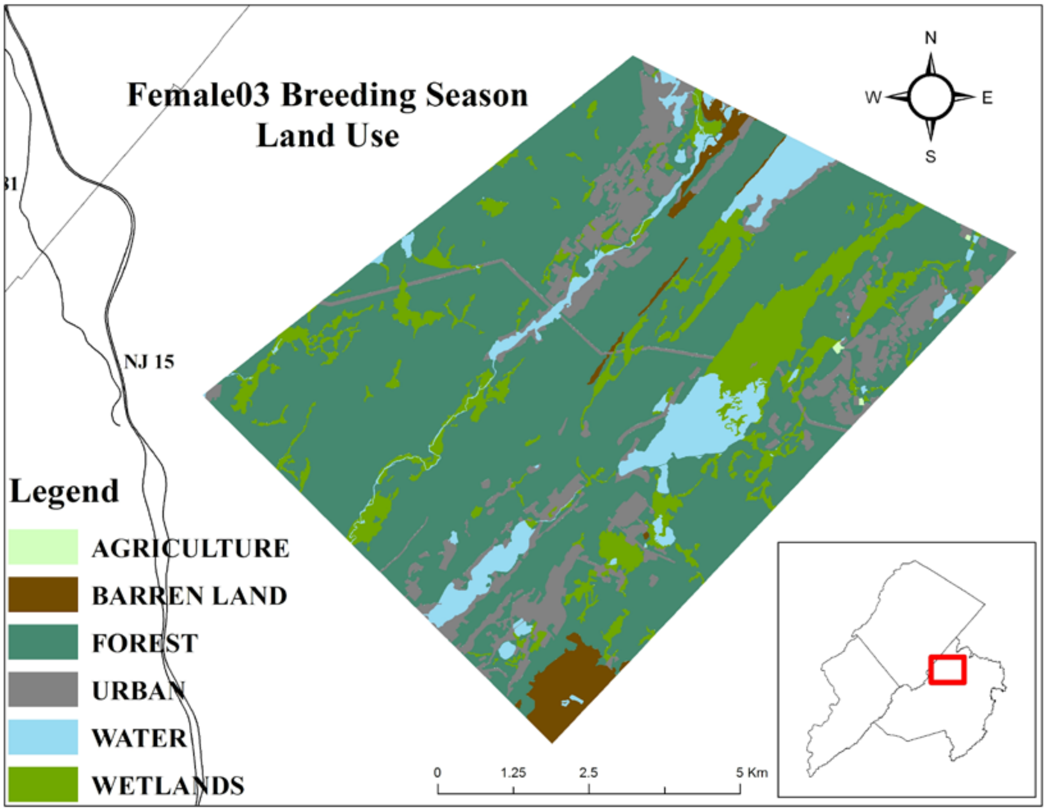
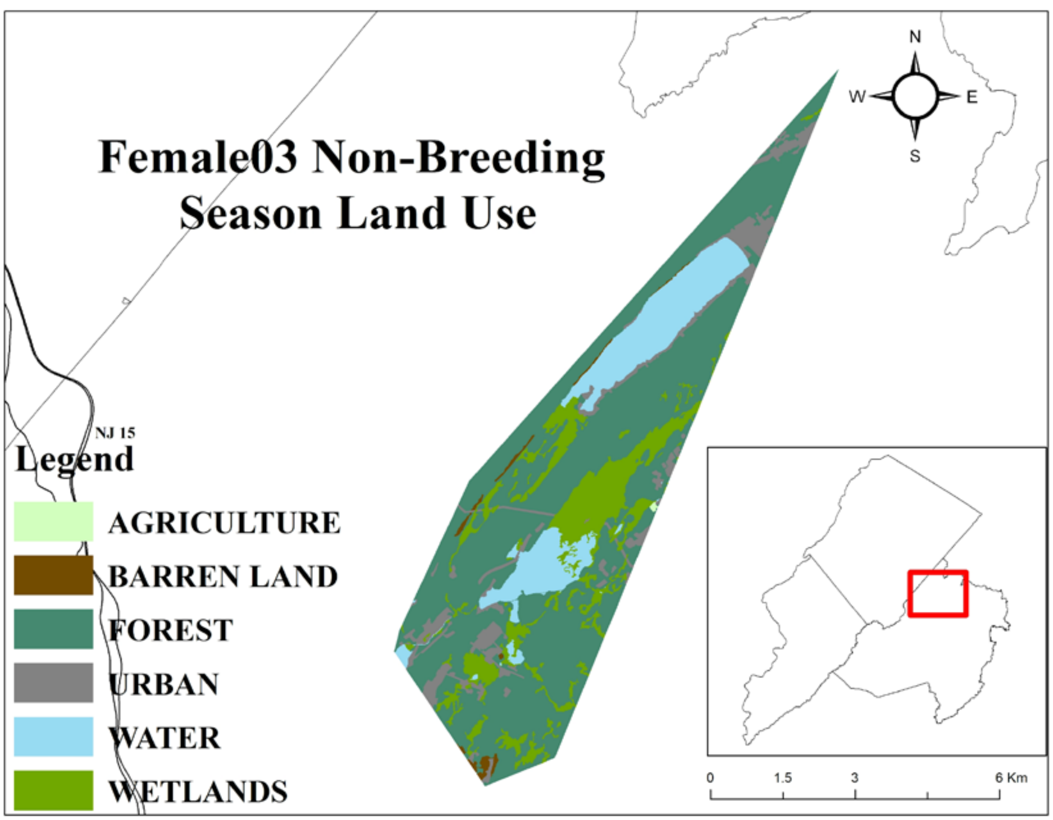
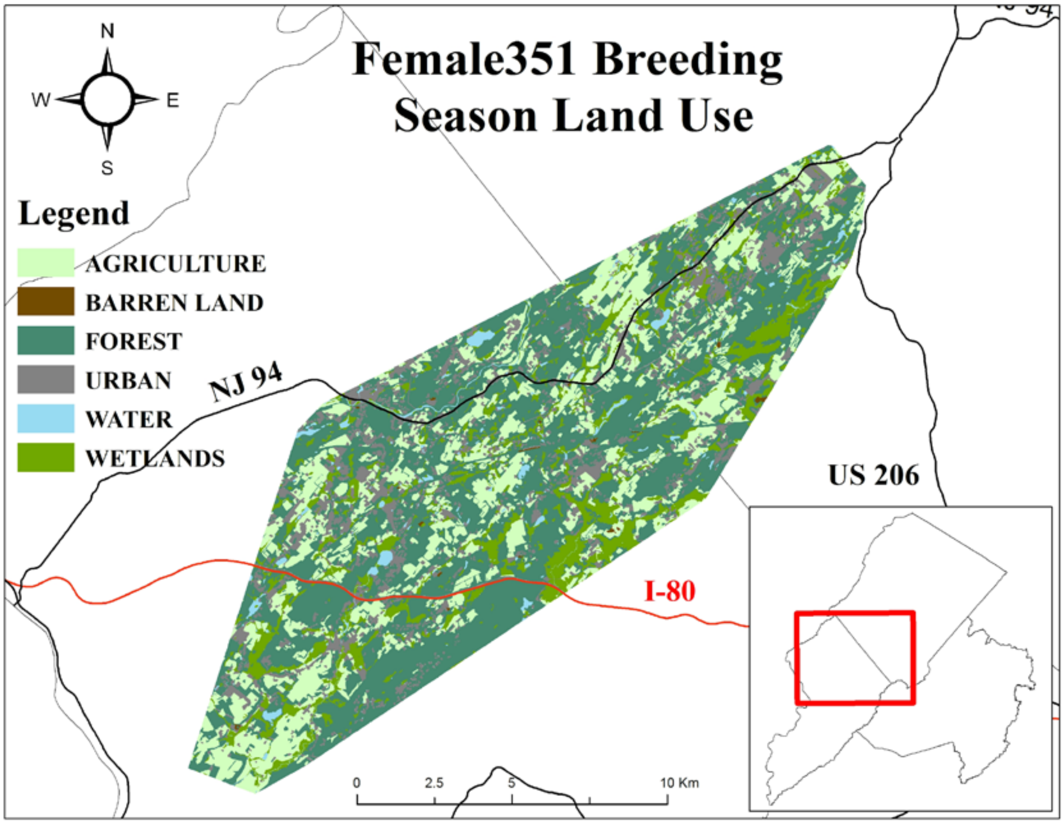
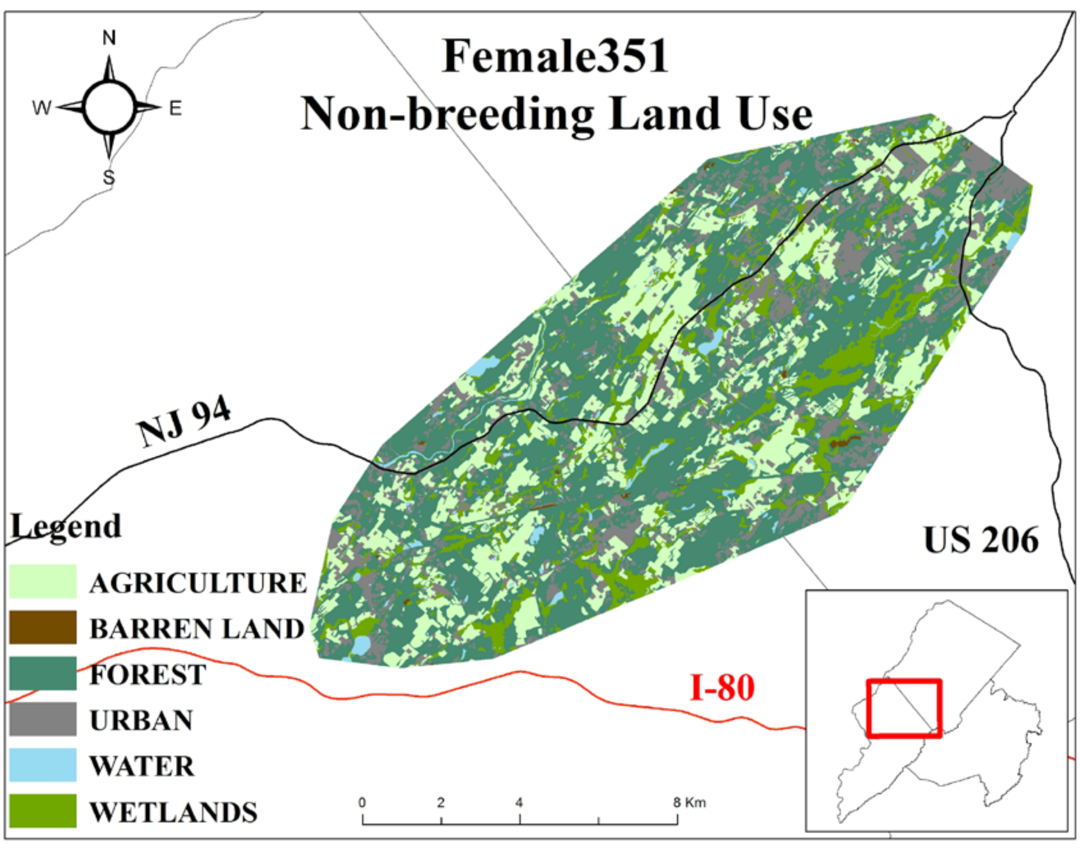
W
E
S
NJ 94
I-80
Legend
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
0
1.5
3
6 Km

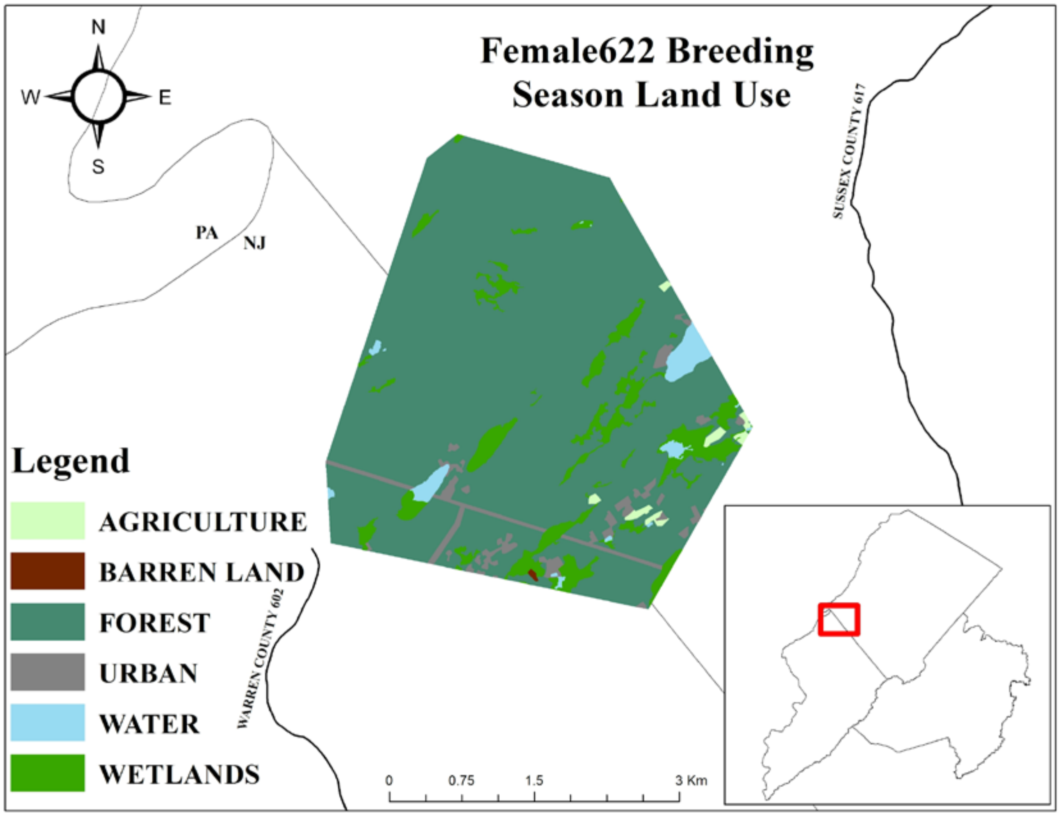
APPENDIX C: Female Bobcats Breeding and Nonbreeding Home Ranges and Land Use

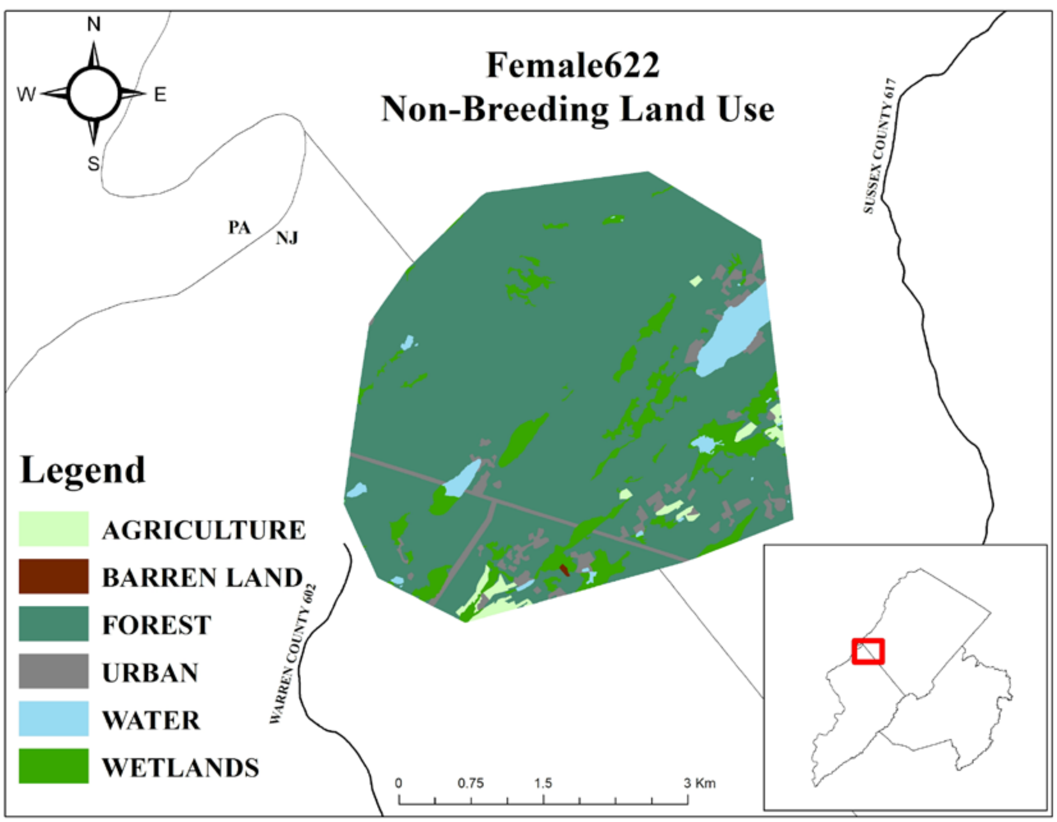


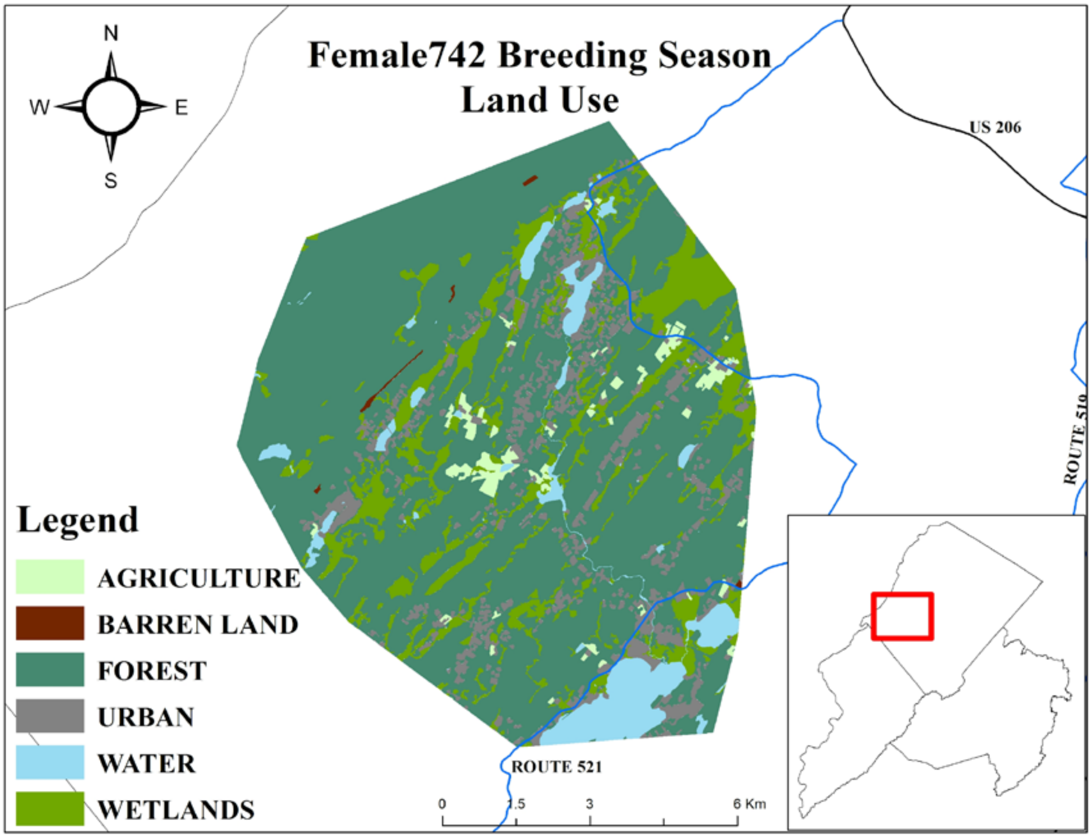


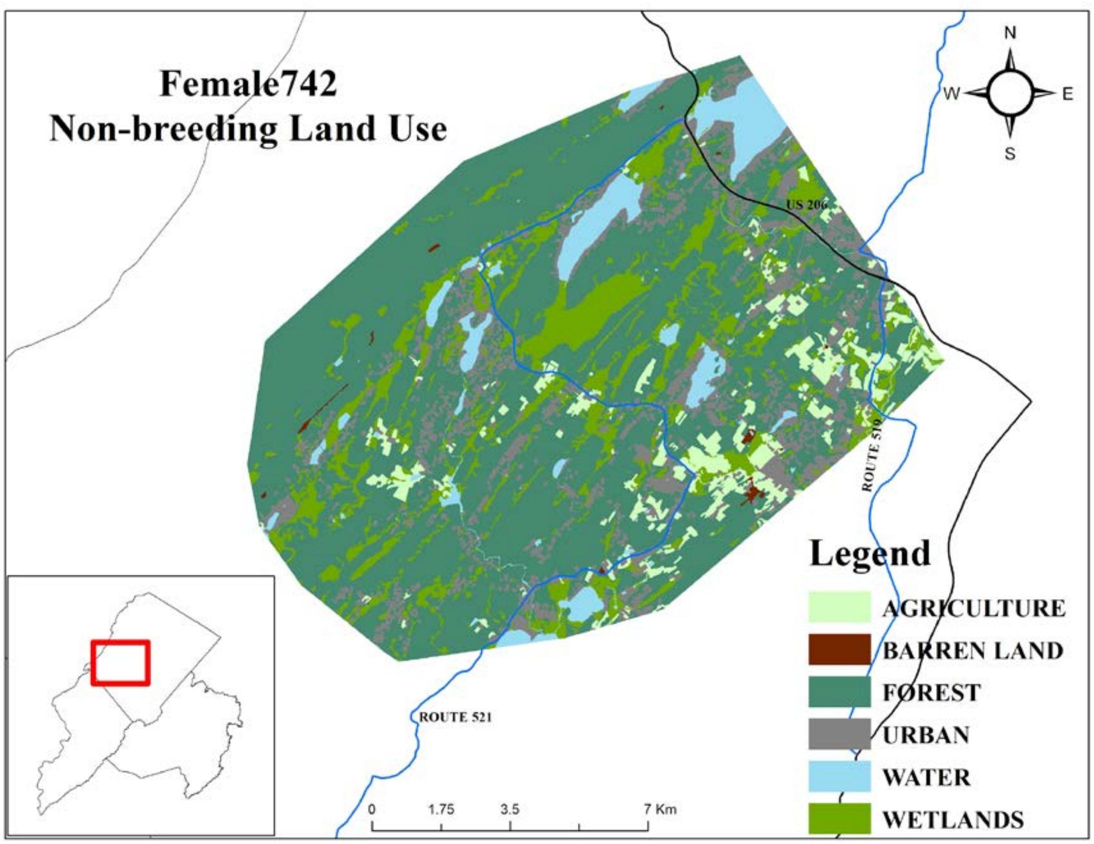

Female351 Breeding
Season Land Use
N
W
E
S
Legend
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
NJ 94
US 206
I-80
0
2.5
5
10 Km


Female351
Non-breeding Land Use
N
W
E
S
NJ 94
US 206
Legend
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
I-80
0
2
4
8 Km


Female622 Breeding
Season Land Use
N
W
E
S
PA
NJ
SUSSEX COUNTY 617
WARREN COUNTY 602
Legend
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
0
0.75
1.5
3 Km


Female622
Non-Breeding Land Use
N
W
E
S
PA
NJ
SUSSEX COUNTY 617
WARREN COUNTY 602
Legend
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
0
0.75
1.5
3 Km


Female742 Breeding Season
Land Use
N
W
E
S
US 206
ROUTE 510
ROUTE 521
Legend
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
0
1.5
3
6 Km


Female742
Non-breeding Land Use
N
W
E
S
US 206
ROUTE 510
ROUTE 521
Legend
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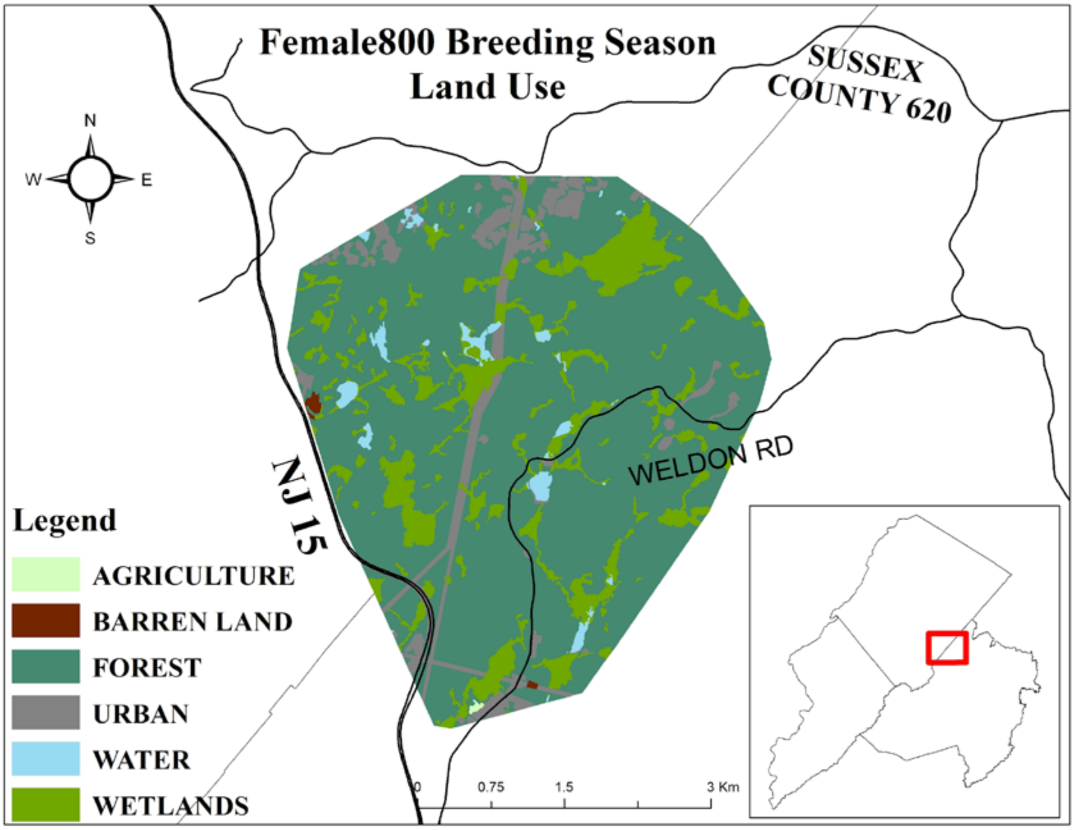
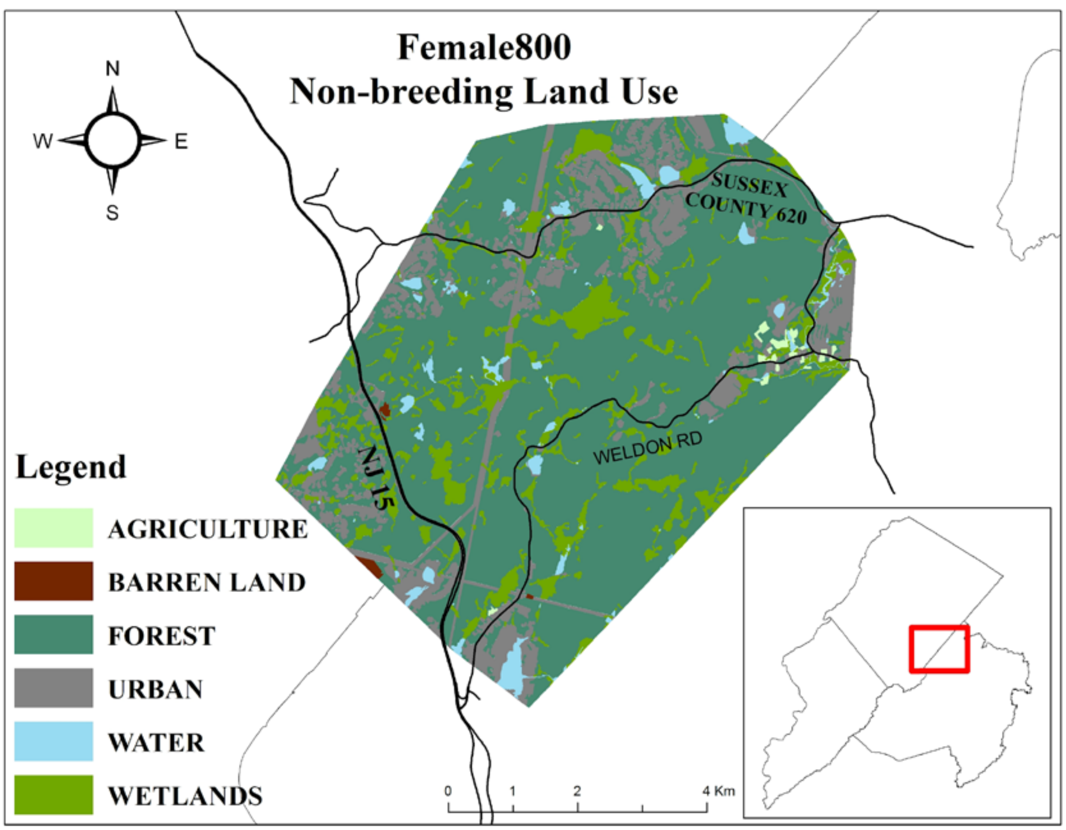
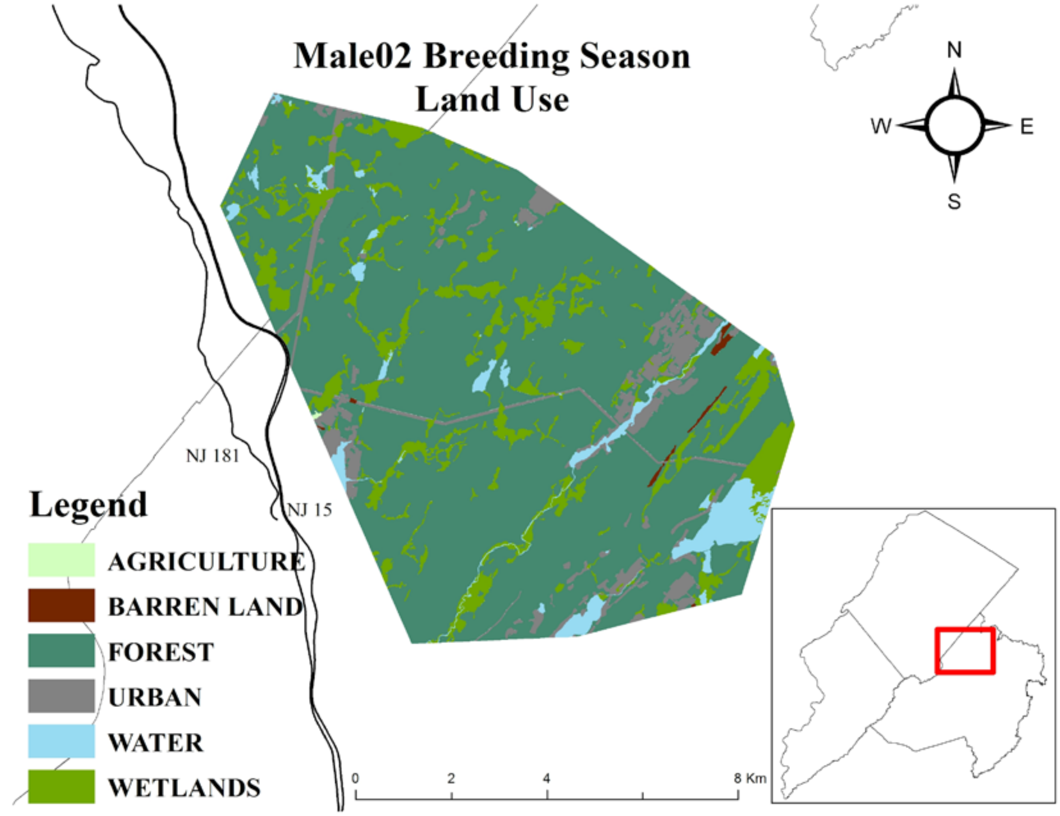
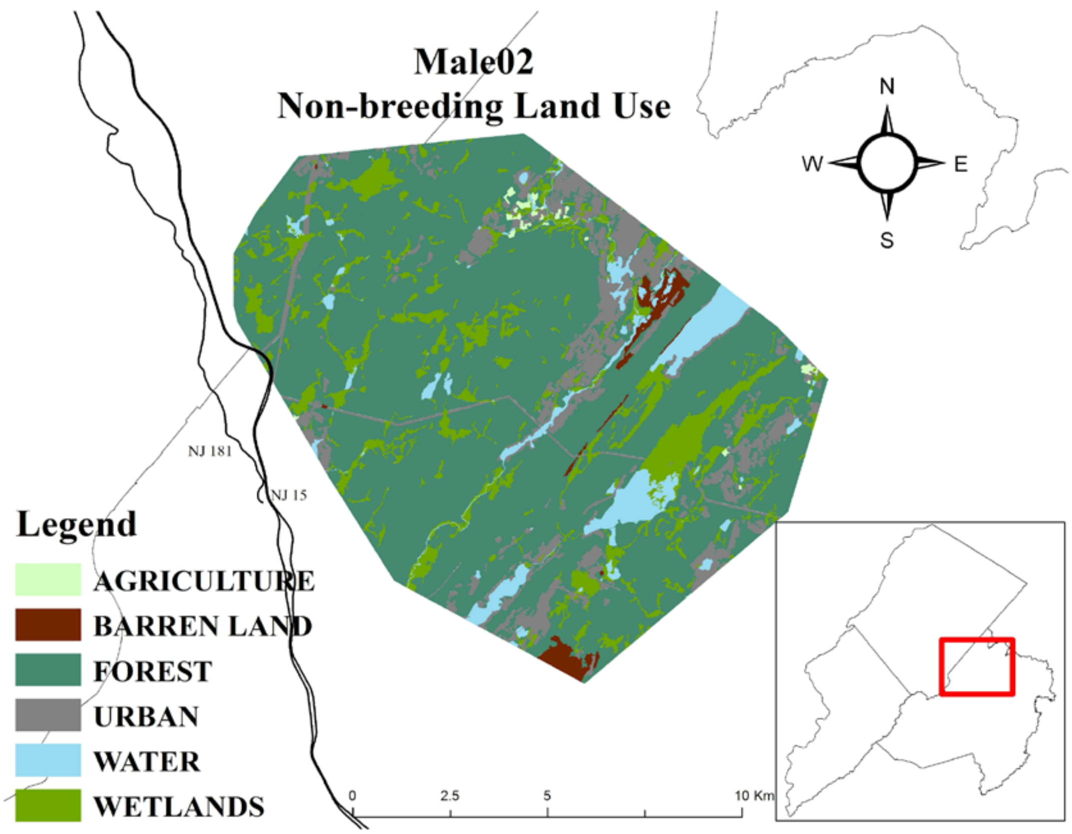
1.75
3.5
7 Km

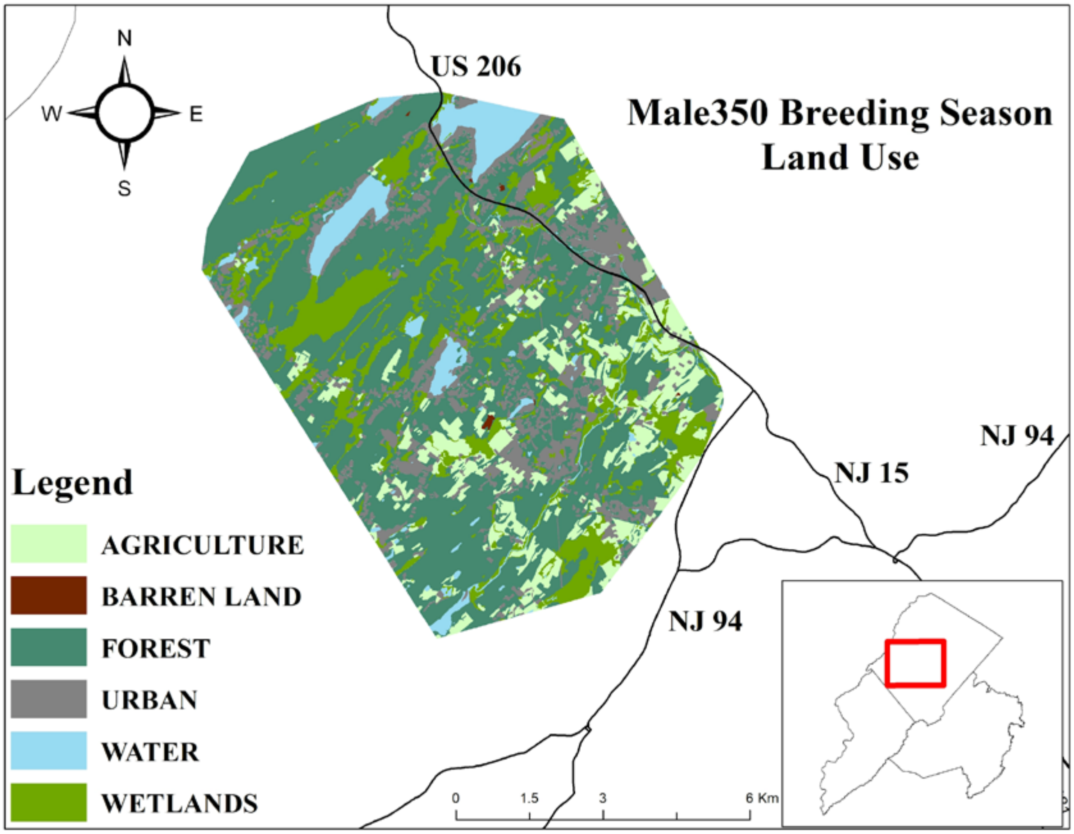

Female800 Breeding Season
Land Use
SUSSEX
COUNTY 620
N
W
E
S
NJ 15
WELDON RD
Legend
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
0
0.75
1.5
3 Km


Female800
Non-breeding Land Use
N
W
E
S
SUSSEX
COUNTY 620
NJ 15
WELDON RD
Legend
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
0
1
2
4 Km

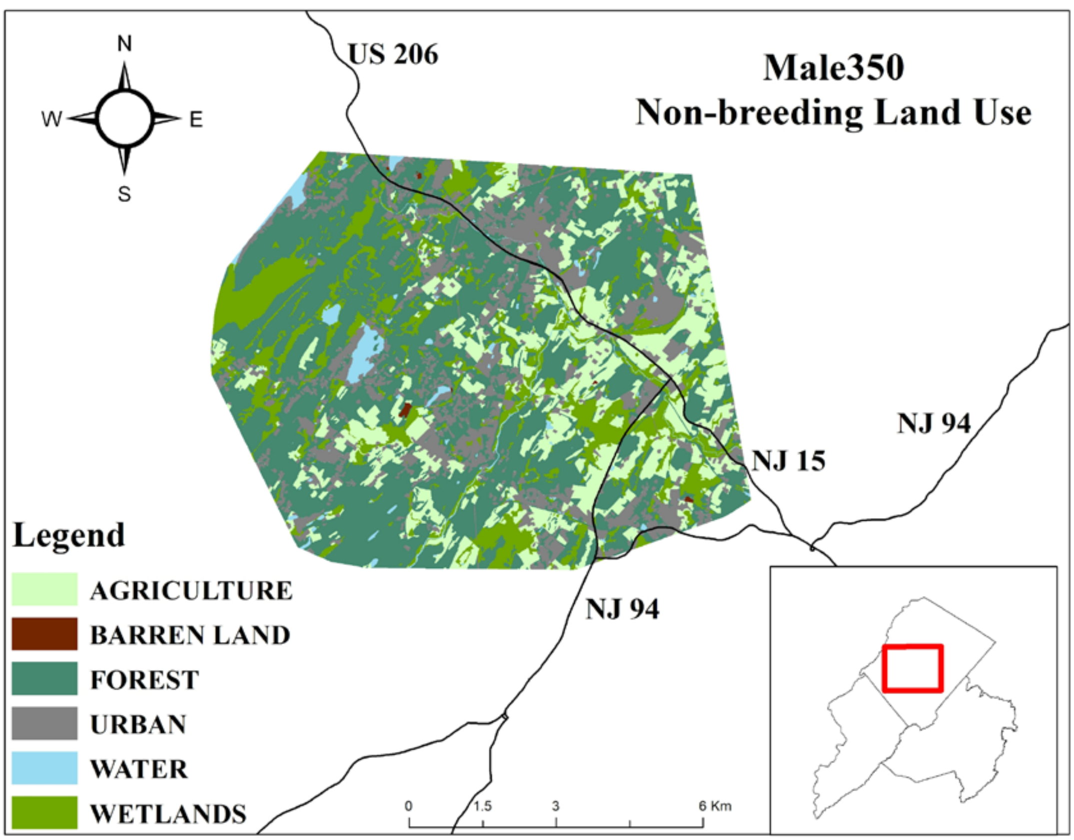
APPENDIX D: Male Bobcats Breeding and Nonbreeding Home Ranges and Land Use



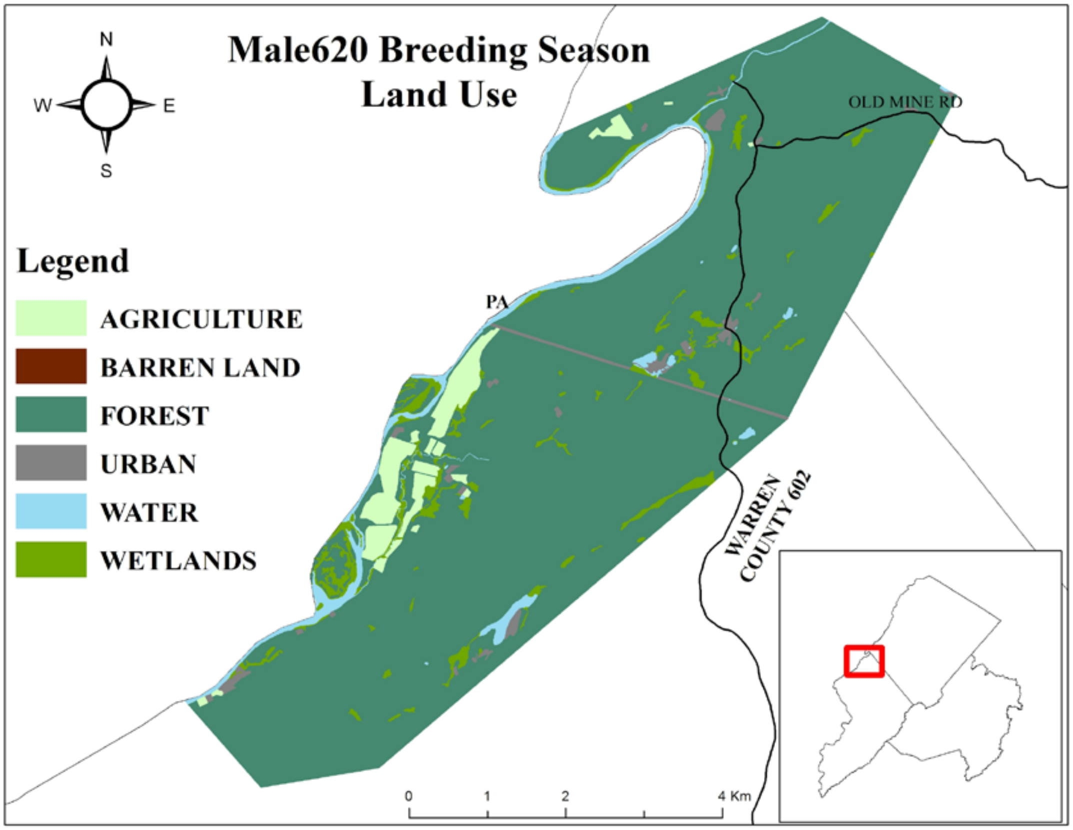


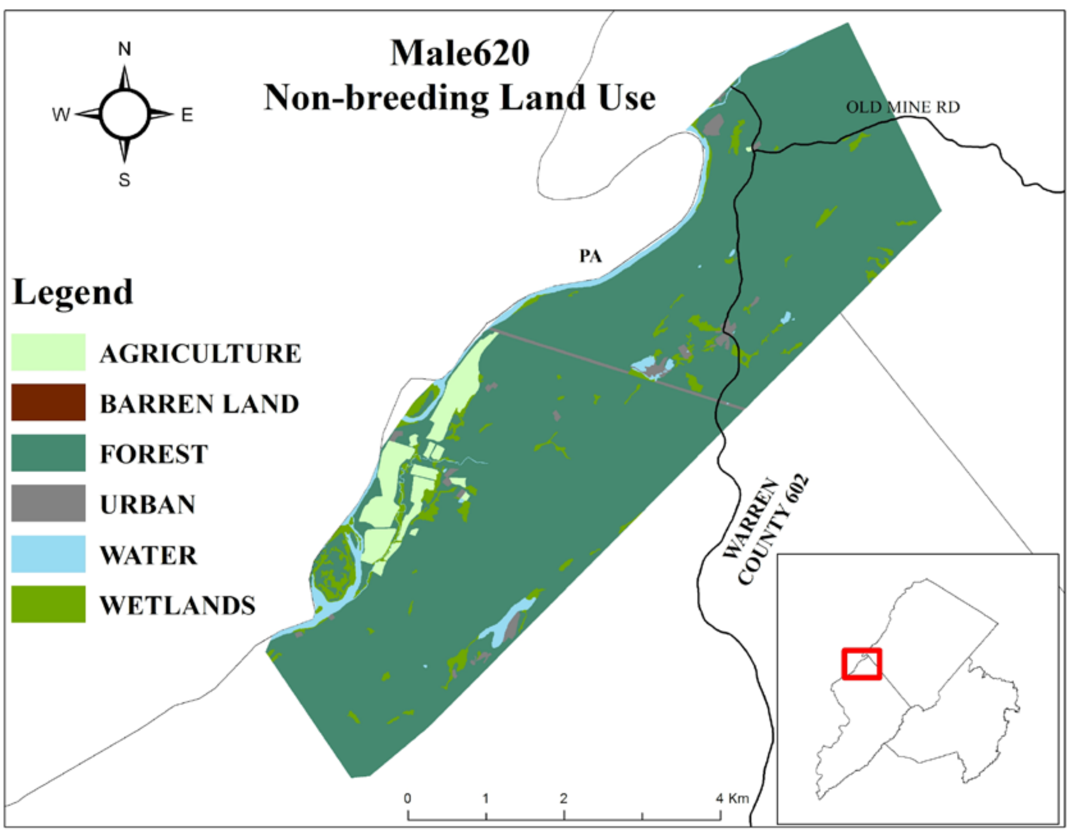


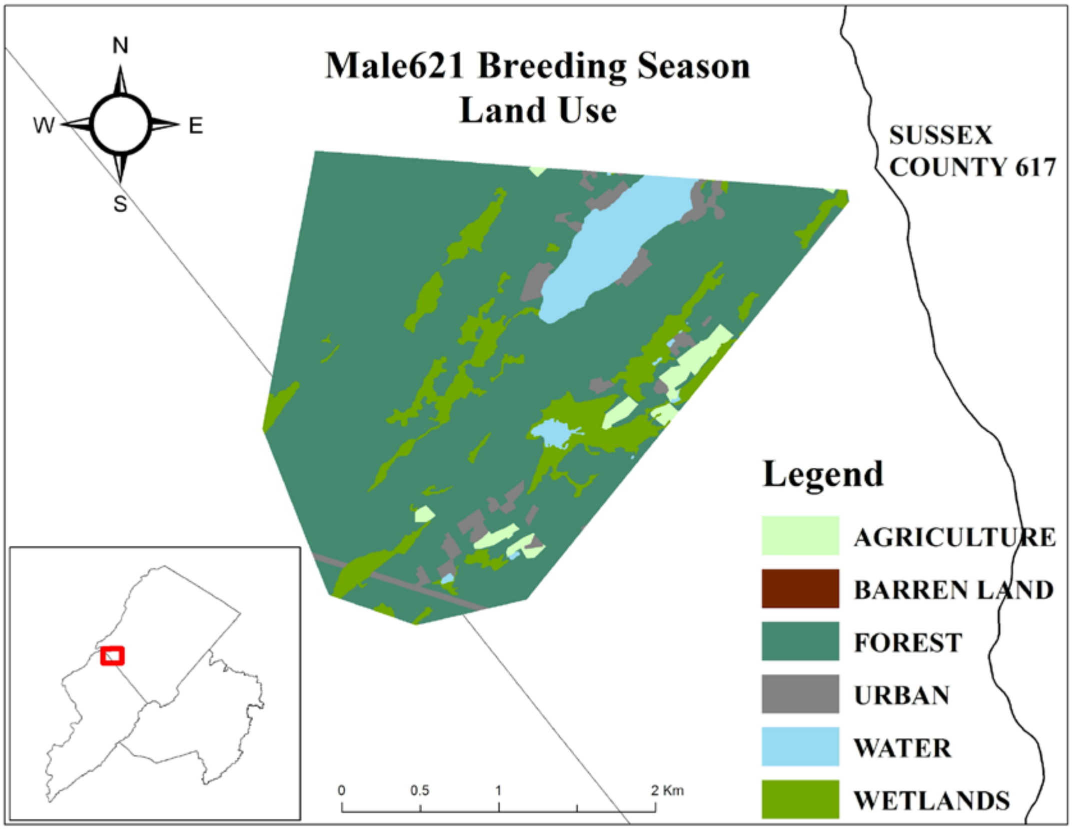
Male350 Breeding Season Land Use
N
W
E
S
US 206
NJ 15
NJ 94
NJ 94
Legend
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
0
1.5
3
6 Km

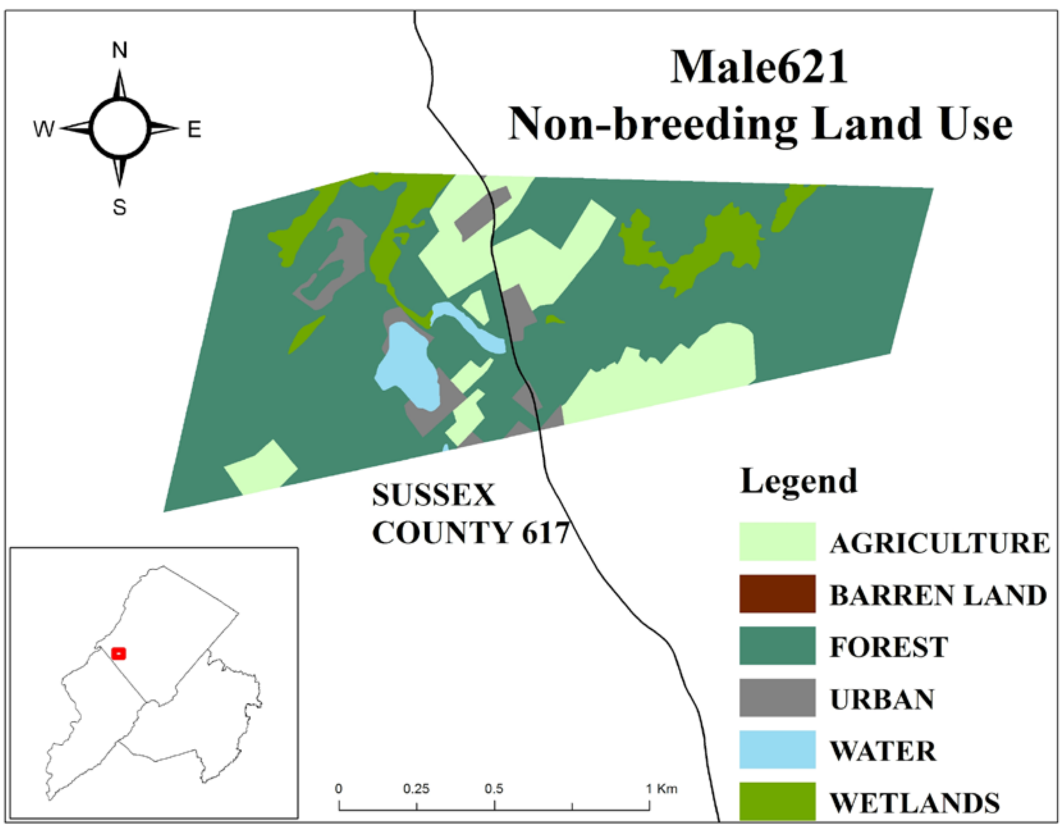


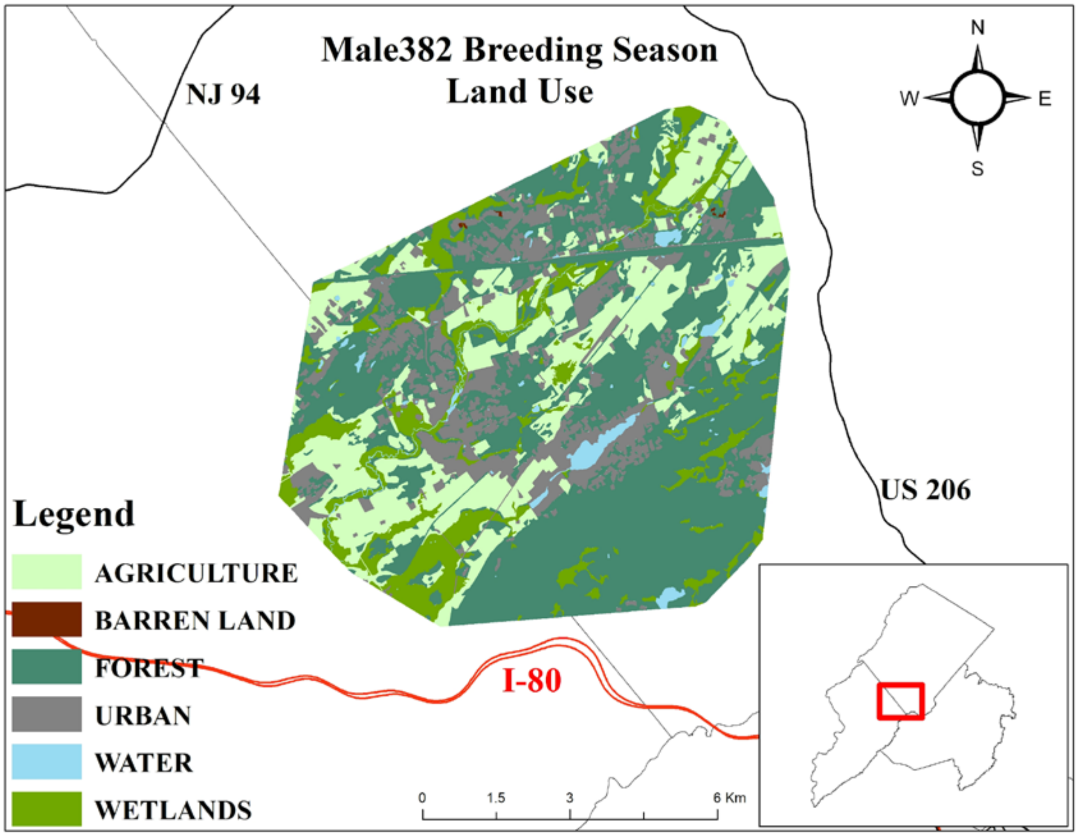
Male350 Non-breeding Land Use
N
W
E
S
US 206
NJ 15
NJ 94
NJ 94
Legend
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
0
1.5
3
6 Km

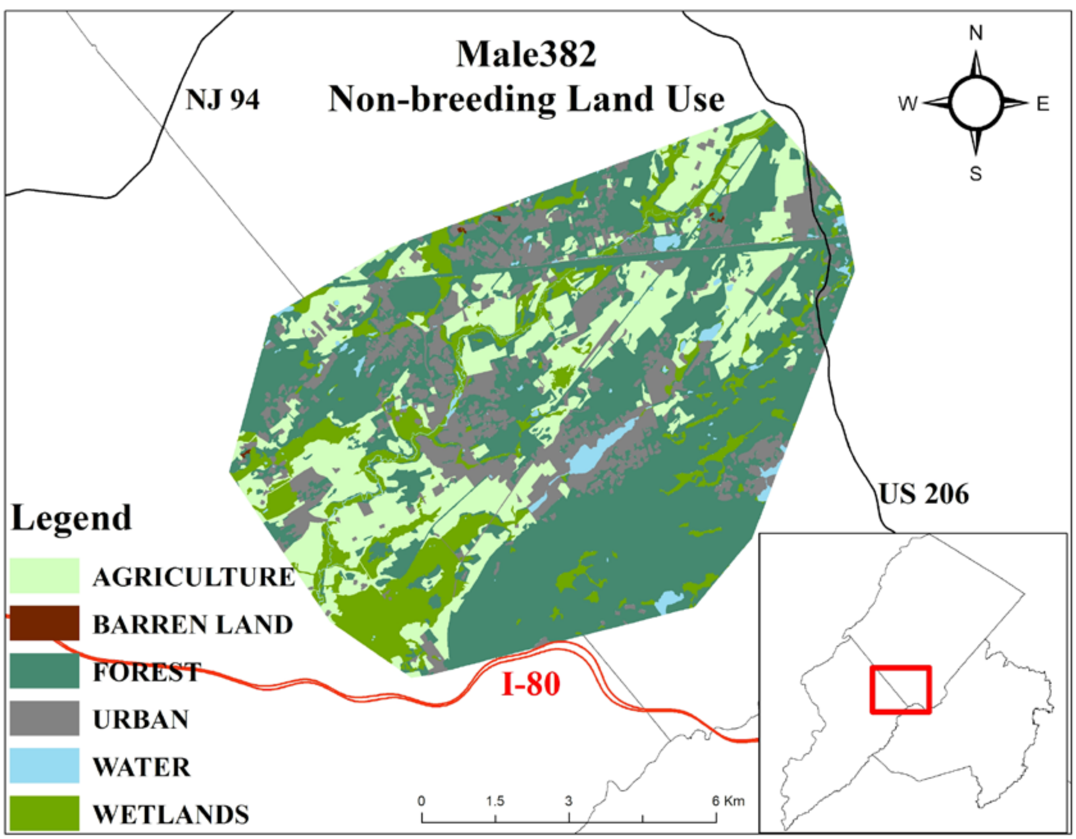

Male620 Breeding Season
Land Use
N
W
E
S
Legend
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
PA
OLD MINE RD
WARREN
COUNTY 602
0
1
2
4 Km

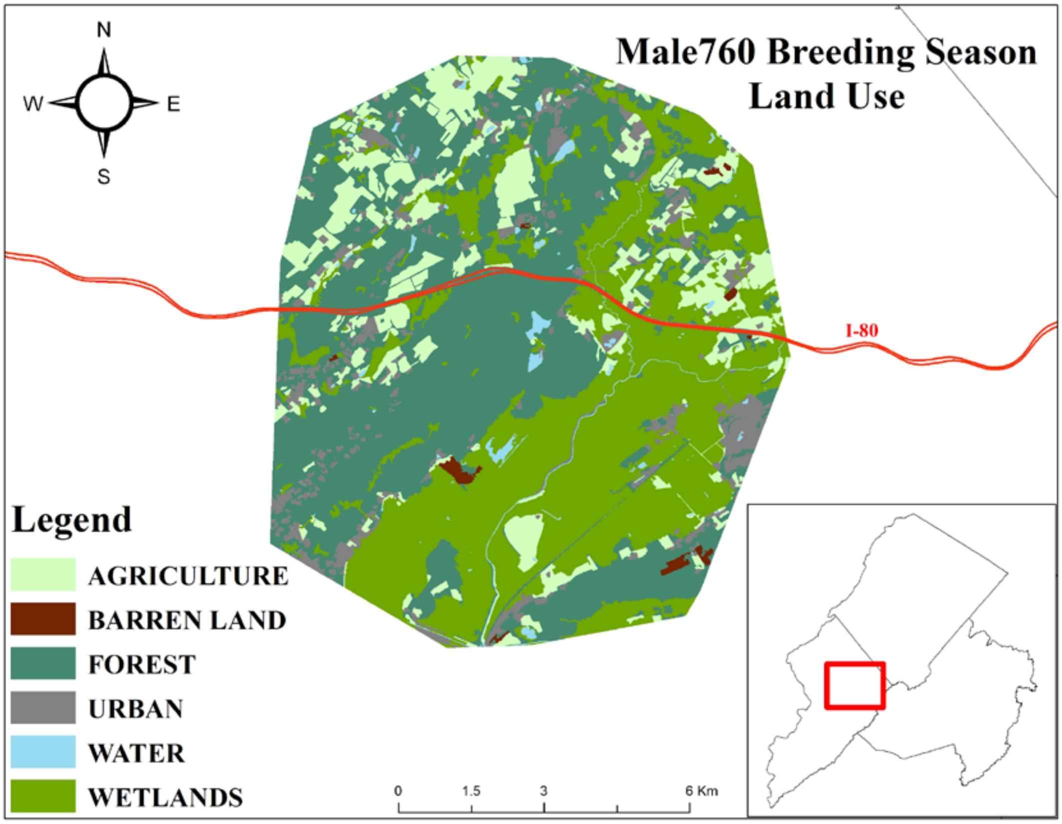

Male620
Non-breeding Land Use
N
W
E
S
Legend
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
PA
OLD MINE RD
WARREN
COUNTY 602
0
1
2
4 Km

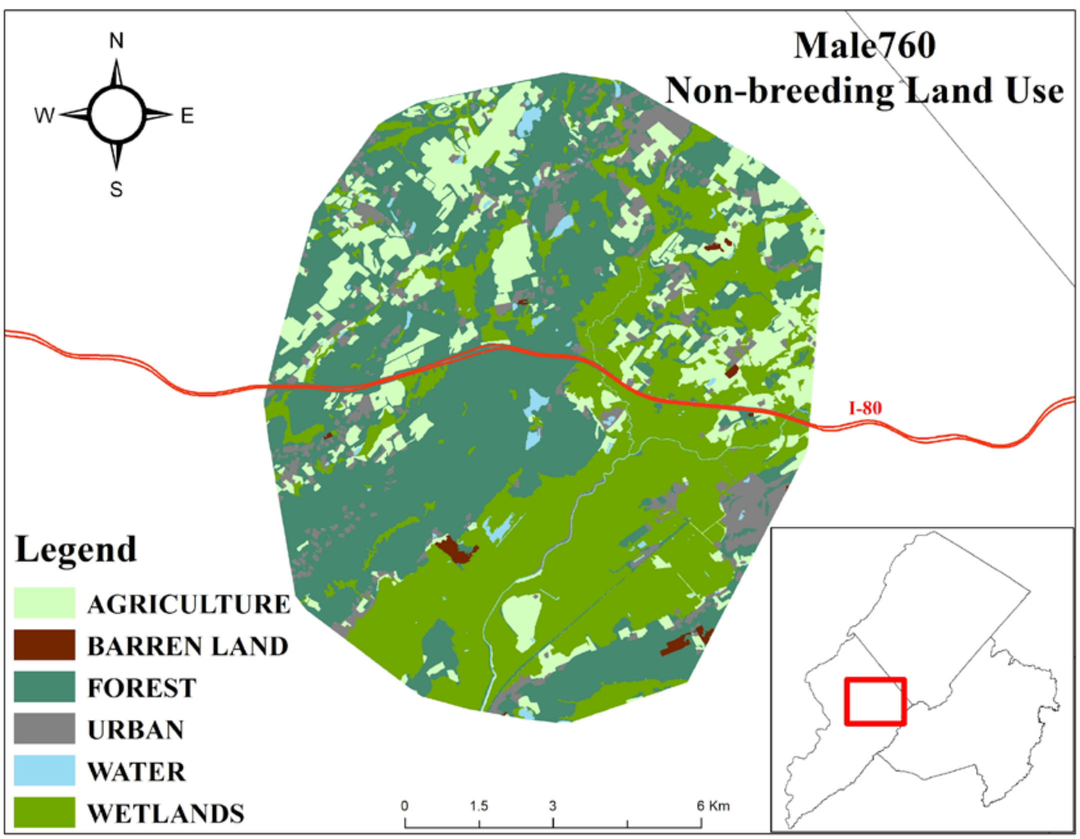

Male621 Breeding Season
Land Use
N
W
E
S
SUSSEX
COUNTY 617
Legend
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
0
0.5
1
2 Km

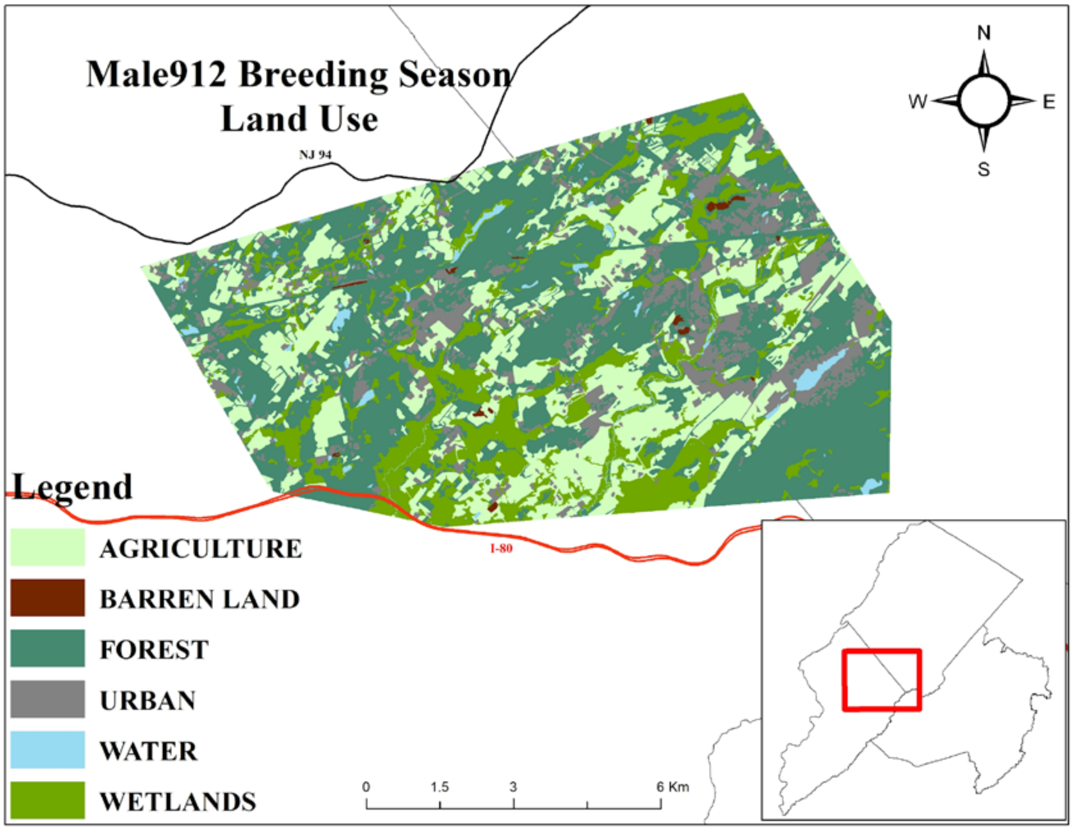

Male621
Non-breeding Land Use
N
W
E
S
SUSSEX
COUNTY 617
Legend
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
0
0.25
0.5
1 Km

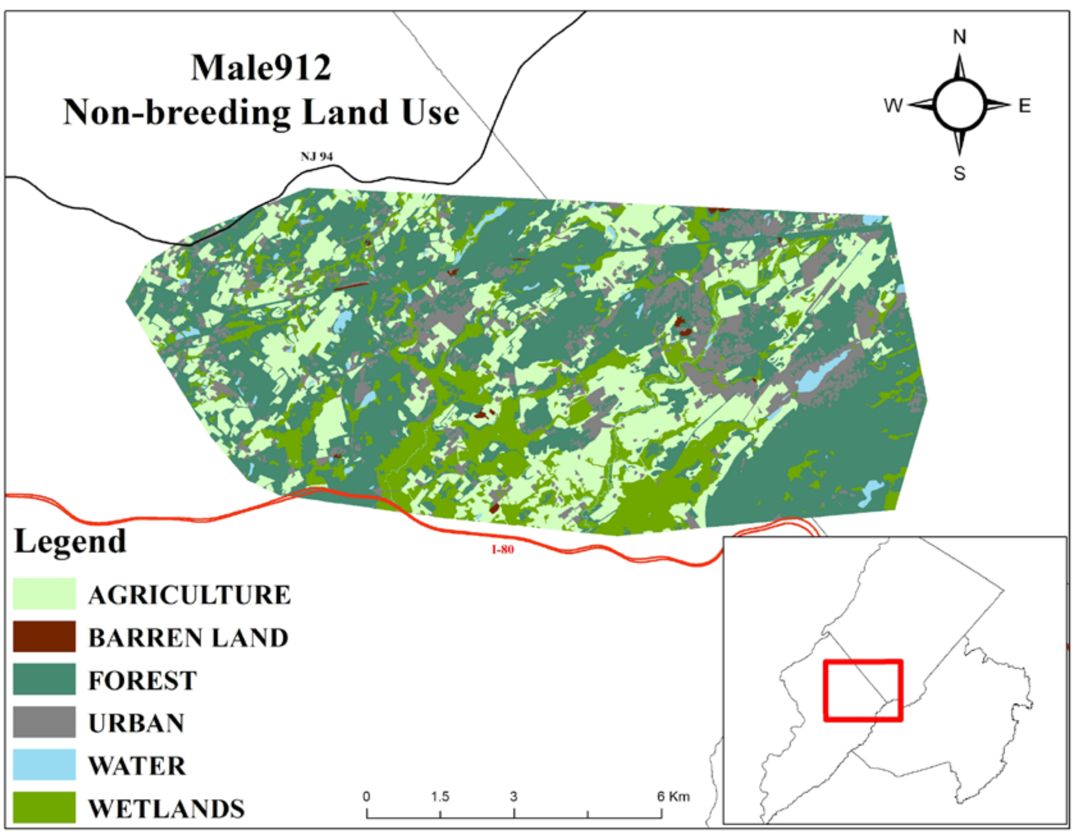

Male382 Breeding Season
Land Use
NJ 94
US 206
I-80
N
W
E
S
Legend
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
0
1.5
3
6 Km


Male382
Non-breeding Land Use
NJ 94
US 206
I-80
N
W
E
S
Legend
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
0
1.5
3
6 Km


Male760 Breeding Season
Land Use
N
W
E
S
I-80
Legend
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
0
1.5
3
6 Km


Male760
Non-breeding Land Use
N
W
E
S
I-80
Legend
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
0
1.5
3
6 Km


Male912 Breeding Season
Land Use
NJ 94
N
W
E
S
Legend
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
I-80
0
1.5
3
6 Km


Male912
Non-breeding Land Use
NJ 94
N
W
E
S
Legend
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
I-80
0
1.5
3
6 Km