The Influence of Roads on the Florida Panther

by

Autumn C. Schwab

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Arts
Department of Geography
College of Arts and Sciences
University of South Florida

Major Professor: Paul Zandbergen, Ph.D.
Steven Reader, Ph.D.
Melissa Grigione, Ph.D.

Date of Approval:
April 3, 2006

Keywords: crossing behavior, gis, vehicular mortality, wildlife underpasses, spatial ecology

Dedication

This thesis is dedicated to several people who have provided support in very valuable ways. Firstly, I would like to thank Dr. Paul Zandbergen for all the support and friendship that has been essential in my fascination of all things spatial. You have also given me the academic encouragement and confidence necessary for me to complete this project and finish my graduate degree. Thanks Paul.

I would also like to thank Kevin Kerrigan for loving and supporting me no matter how much I procrastinated or how little sleep I got. You seem to have infinite patience for my shenanigans, and have the uncanny ability to make me laugh on the darkest of days. You are my best friend, and I love you.

Finally, I would like to thank Mom, Dad, and Spence for always letting me be the “navigator” on family road trips and encouraging me to do whatever it is that makes me happy, no matter what. I love you all so very much.

Table of Contents

List of Tables

List of Figures

The Influence of Roads on the Florida Panther

Autumn C. Schwab

ABSTRACT

The Florida panther (*Puma concolor coryi*) is a relatively well studied species, but some aspects of its habitat requirements remain poorly understood. While it has been well established that the most important threat to panthers include limited habitat area and continued habitat loss and fragmentation, the importance of roads in this context has not been determined. The goal of this research is to determine the influence of roads on the movement patterns of the Florida panther. Panther telemetry data from 1981 until 2003 was used, as well as detailed road networks and vegetation maps. The influence of roads on individual panthers was determined through an analysis of: 1) vehicular mortality; 2) road crossing behavior; 3) road barrier effects; and 4) effectiveness of preventative measures. Results indicate that vehicle collisions continue to be a major threat to the Florida panther population, specifically adult males. Major roads form more of a barrier to movement than minor roads, but females are affected more than males. The combination of wildlife underpasses and high right-of-way fencing on I-75 has been extremely effective at vehicular mortality prevention, but the roadway remains a major barrier, particularly for female panthers. This has essentially segregated the movement of the sexes and has

fragmented not only the limited habitat of the Florida panther, but also segments of the adult population critical to the propagation of the species.

Chapter One

Introduction

1.1 Problem Statement

One of over 20 subspecies of cougar (*Puma concolor*), the Florida panther's (*Puma concolor coryi*) range once extended throughout most of the southeastern United States, including Louisiana, north to Tennessee, and east to the Atlantic as well as the entire state of Florida (FFWCC, 1999). Currently one of the most publicized endangered animals in the United States, there are an estimated 70 to 100 adult Florida panthers in their last remaining population in southwest Florida (FFWCC,1999).

Despite over 25 years of research, several aspects of the relationship between Florida panthers and habitat characteristics remain controversial and poorly understood. Although some inferences on panther dependence on forest cover have been made (Maehr and Cox, 1995; Kerkhoff et al., 2000; Comiskey et al., 2002), those conclusions have been directly criticized by colleagues and professionals implicated in panther research and recovery (Comiskey et al., 2002; Beier et al., 2003). An analysis on the past 25 years of Florida panther research and scientific literature (Beier et al., 2003) identified several major weaknesses in current research: 1) the findings that panthers prefer large forest patches and are reluctant to travel from forests are unreliable due to questionable analysis techniques, and 2) research on panther reintroduction in other areas has been severely lacking and little has been done on this area since Belden and Hagedorn (1993) and Jordan (1994). The review also identified issues of concern in panther research methodologies, some of which include the use of diurnal telemetry data to establish 24-hour habitat attributes and patterns, the selective use of the telemetry dataset, the use of individual locations as the sampling unit, the currency of landcover data used in habitat analyses, and the calculation of home range size and its relationship to amount and fragmentation of forest cover.

Reliable knowledge of a species' habitat plays a prominent role in land management and policy decisions on land development where there are species in danger of losing habitats, such as the Florida panther. For example, consultations on land development made by the USFWS Section 7 are based on the "best available science" (Beier et al., 2003). Undoubtedly, the lack of consistent habitat knowledge can inhibit protection and lead to the continued fragmentation and destruction of the Florida panther's last occupied available habitat. Additionally, research on the establishment of panther populations outside of their current south Florida habitat is paramount to the panthers' recovery from an endangered species into sustainable populations (Beier et al., 2003). While it has been well established that the most important threat to panthers include limited habitat area and continued habitat loss and fragmentation, the importance of roads in this context has not been determined. A solid understanding of this influence is necessary to determine the viability of the current population in South Florida, to add to the existing knowledge base of panther-habitat relationships, and to identify possible reintroduction areas necessary to reestablish a successful population.

1.2 Goal

The goal of this research is to develop a better understanding of the influence of roads on the Florida panther.

1.3 Objectives

In order to fill the aforementioned gaps in Florida panther research, the following objectives will be accomplished:

1) Determine the importance of road mortality relative to the other causes of mortality for the Florida panther population and any spatial, temporal, age, or gender patterns in road mortality;

2) Determine patterns in road crossing behavior, by gender and by road type and class;

3) Determine the degree to which roads and lack of forest cover represent a barrier to panther movement, by gender and by road type and class; and

4) Determine effectiveness of the preventative measures applied, such as wildlife underpasses and right-of-way fencing.

Based on preliminary examination, the hypothesis is that road mortality plays a prominent role in overall Florida panther mortality; however the effectiveness of wildlife crossings and right-of-way fencing installed on several major highways is high in the prevention of road mortalities in those areas.

Additionally, Florida panther crossing behavior and movement patterns are influenced by this barrier effect which is strongest near major roads while minor roads have lesser influence.

Chapter Two

Literature Review

Despite the controversy surrounding current Florida panther habitat research, there are several examined issues that are considered defendable in methodology and conclusion. According to Beier et al. (2003), 25 years of Florida panther research indicate that 1) forests are important daytime rest sites, 2) white tailed deer and feral hogs are the most significant prey to the panther, 3) the most prominent threats to panther survival as a species are habitat loss and fragmentation and the increasingly limited habitat area in south Florida, and 4) that the recovery of the panther depends critically on establishing additional populations outside of south Florida (Beier et al., 2003). Research conclusions and methodologies from current and past analyses will be summarized and examined for reliability in order to determine their value in this study.

2.1 Panther Biology

The Florida panther (*Puma concolor coryi*) is one of 20 subspecies of cougar (*Puma concolor*). Generally a uniform tawny color, adult panthers are smaller than their relative cougars in the west, have longer legs, smaller feet, and a shorter darker coat (FFWCC, 1999). Males weigh approximately 100 to 150 pounds while female panthers can weigh between 65 and 100 pounds (FFWCC, 1999). White tailed deer are the most important prey for the Florida panther, although they also consume feral hog, raccoon, and armadillo (FFWCC, 1999). Like most large cats, the Florida panther is a solitary hunter.

Sexual maturity is reached at about 1 ½ to 2 ½ years of age for the female Florida panther and at about 3 years of age for males (FFWCC,1999). Litters generally consist of 1 to 4 kittens, and young adults leave their mothers between 1 ½ to 2 years of age to establish their own adult territories (FFWCC, 1999). Life expectancy in the wild is approximately 12 years, although females tend to live longer than male panthers (FFWCC, 1999).

Adult males have larger home ranges, are more territorial, and disperse farther than females which frequently share established home ranges with their mother and tolerate home range overlaps (FFWCC, 1999).

2.2 Vegetation Preferences

Vegetation preferences of the Florida panther are a widely contested issue, particularly in the amount of forest cover the panther requires for a suitable habitat. Maehr and Cox (1995), cited as one of the most influential papers on panther habitat requirements by Beier et al. (2003, p6), identified the importance of forests as part of the panther habitat. In this work they also deduced that panthers require large patches of forest (mean = 20,816 ha), and that forest patches over 500 ha are considered the most important to Florida panther habitat home range. Additionally, Maehr and Cox (1995) concluded that 96% of all panther locations occurred within 90 meters of preferred forest types; however this analysis ignored the effects of telemetry error, which Beier et al. (2003)

estimate to be between 100 and 500 meters. Beier et al. (2003) criticized Maehr and Cox for also excluding panther locations in the analysis that occurred outside of what Maehr considered “typical of preferred habitat (Beier et al., 2003: p8).” Obviously, this choice of data subset potentially created a very serious bias in the study’s conclusions, and the resulting inferences may not be legitimate and will not be used in this analysis. Additionally, the “90 meter” conclusion has been construed (Maehr et al., 2001; Maehr and Deason, 2002) to indicate that panthers are reluctant to cross non-forested areas between habitats that are over 90 meters apart, where there is no evidence to point to such a deduction (Beier et al., 2003). Comiskey et al. (2002) also criticized the research because of the use of biased samples of the telemetry dataset, the discounting of location error inherent in telemetry data, and the use of diurnal telemetry data to make conclusions about 24-hour panther habitat characteristics (Beier et al., 2003). Unfortunately, the Maehr and Cox (1995) work has been cited, and miscited, on numerous occasions, compounding the error, and their conclusions have been applied to land management decisions that involve the remaining Florida panther habitat (Beier et al., 2003).

The proportion of forest cover within an individual panther’s home range necessary for livelihood is also considered a debatable aspect of existing panther-habitat research. Both Maehr and Cox (1995) and Kerkhoff et al. (2000) concluded that there was an inverse relationship between panther home range size and percent forest in the home range. Kerkhoff et al. (2000) also deduced that panther habitat is most likely to contain at least 25% forest cover. However, Beier et al. (2003) criticized this study for using fractal techniques in habitat analysis, which had not been previously established as appropriate. Using the same fractal techniques, Comiskey et al. (2002) concluded that the aforementioned inverse relationship between panther home range size and forest cover was weak and that some panthers regularly used habitats with less than 25% forest cover, opposing the conclusions of Kerkhoff et al. (2000). Finally, Beier et al. (2003) states, despite the oversights of the above analyses, that there is reasonable evidence to support the conclusion that “forests are the most important habitat for diurnal locations of panthers (p12).” Although this connection has been established, there has been no defendable comparison of available forest patch distribution to those patches used by Florida panthers as indicated by the diurnal telemetry dataset and no viable statistics exist to highlight this relationship.

2.3 Home Range

The size and shape of required habitat for a Florida panther, as an individual and a population, is equal in importance to the proportion of forest cover and patch size that is necessary. Belden et al. (1988), Maehr et al. (1991), and Comiskey et al. (2002) all reported that both male and female panthers require comparatively large patches of suitable habitat, 435-650 km^2 and 193-396 km^2, respectively. It is also the suggestion of Beier et al. (2003) that these estimates are defendable, since those statistical algorithms used in the aforementioned analyses (Minimum Convex Polygon and Kernel techniques) are not very sensitive to telemetry location error or the necessary use of diurnal locations.

2.4 Panther-Road Ecology

The general types of impacts of roads on wildlife have been well documented and include: road mortality, reduced access to habitat due to road avoidance, fragmentation of wildlife populations, restriction of wildlife movements and the disruption of gene flow and metapopulation dynamics (Jackson, 2000). However, these impacts have received very little attention in the research on the Florida panther. Some influence of roads on behavior is assumed (e.g. Cramer and Portier, 2001), and the annual reports by the Florida Fish and Wildlife Service make reference to the importance of road mortality, but no empirical evidence has been presented in the literature on the influence of roads on the Florida panther. Those several analyses that have indicated an assumed avoidance of roads (Cramer and Portier, 2001; Cramer, 1999; Jordan, 1994; and Maehr and Cox, 1995) lack the empirical evidence to characterize this influence and highlight the importance of the need for a concrete understanding of panther-road relationships. Jordan (1994) incorporated a variable to estimate the influence of roads on the Florida panther in his evaluation of potential panther population reestablishment sites, but did not differentiate between road types and size, treating six lane highways the same as a public dirt road. Cramer and Portier (2001) cite the use of “perceived Florida panther preferences based on empirical evidence (p65)” and make distinctions for road influence between male and female panthers, but these values are based on the telemetry observations of only a few panthers with established home ranges adjacent to both I75 and SR29 (Maehr et al., 1991; Maehr, 1990). Using the same model, Cramer (1999) applied weights to several classes of roads to simulate the influence of roads in panther movement and also estimated mortality probability rates based on “personal assumptions (p78).” This further highlights the need for advanced empirical research in panther-road relationships.

The use of wildlife highway underpasses by the Florida panther has been explored to some degree (Foster and Humphrey, 1995; Lotz et al., 1996; and Lotz et al., 1997), and it has been suggested that a necessary natural adaptation to the structures is the cause of a slow increase in use over time. Foster and Humphrey (1995) also assert that the use of wildlife underpasses not only mitigates road mortality, but also reduces habitat fragmentation, although certain underpasses were more favorable for panther use (surrounding forested habitat, drier conditions, etc.) and therefore more frequently used than others. This may permit movement between fragmented habitats at specific underpass locations; however the inherent territoriality of Florida panthers can prevent the use of an underpass by more than one individual, essentially isolating adults whose reproductive success is critical to species propagation.

Cougar (*Puma concolor*) road-ecology research includes studies of road crossing behavior, roads as barriers, and wildlife underpass use. Cougars have been found to generally avoid 2-lane roads or larger, but dirt roads may have facilitated movement, particularly during travel and hunting (Dickson et al. 2005).

Dickson et al. (2002) found cougars tend to avoid human-dominated habitats and establish home ranges at a distance from major roads, except where preferred habitat dominated the area.

Clevenger and Waltho (2005) surveyed highway crossing structures (wildlife underpasses) in Banff National Park to determine attributes of the structures most desirable for several species of large mammal, including the cougar. Cougars were found to have preferred structures that were most constricted than other designs and where distance to forest cover was minimal. Gloyne and Clevenger (2001) also monitored cougar movements through crossing structures in Banff National Park and found cougars to use the underpasses more frequently in the winter than the summer. This investigation also found that cougars preferred underpass structures more than overpass structures, and those underpasses located in high-quality cougar habitat.

2.5 Techniques in Wildlife-Road Ecology

The influence of roads on other species of wildlife is a relatively well researched issue, particularly for those species under threat of anthropogenic habitat loss and population fragmentation. Methodologies for estimating the influence of roads for several large mammals vary from estimating survivorship of individuals based on characteristics of nearby road networks (Kerley et al., 2002) to the simulation of road networks and crossings created by an animal movement path (O'Neill et al., 2000).

Dickson et al. (2005) simulated movement paths of cougars in southern California, calculated crossings with a local road network, and compared them to the crossings of an actual movement path. These simulated movement paths were limited to the calculated home range for each individual panther under study. The results indicated that cougars tend to avoid human-dominated habitats and establish home ranges at a distance from major roads, except where preferred habitat dominated the area.

The influence of roads and vehicular mortality on Amur Tigers was investigated through the use of survivorship estimates of radiocollared tigers and their cubs (Kerley et al., 2002). These survivorship values were based on road types found bisecting the tigers' home ranges. Over nine years of study, adult female survivorship was greatest in home ranges that did not include any major roads, while all adult females in the study with home ranges bisected by major roads either died or disappeared prematurely (Kerley et al., 2002). Cub survivorship was also substantially lower in range of major roads.

A behavioral study of the influence of roads on bobcats and coyotes by Tigas, et al. (2002) used a Minimum Convex Polygon technique for home range calculation, and then estimated activity patterns based on rates of movement between telemetry recordings in association with nearby human activity and road networks. Results indicate behavioral adaptation to anthropogenic disturbances through temporal and spatial avoidance.

Florida Fish and Wildlife Conservation Commission recently conducted a road impact study on Florida black bears in Ocala National Forest (McCown et al., 2004). The analysis used radio-telemetry to track 138 adult Florida black bears and estimated crossings and seasonal home ranges using telemetry records taken by fixed-wing aircraft. Results indicate males crossed more than females, and bears with higher crossing frequencies are more likely to be involved in vehicular collision.

Road avoidance by grizzly bears as a function of distance to roads was the focus of a study by Gibeau et al (2002). Distances were measured from telemetry points of radiocollared grizzly bears to the nearest human use feature, including roads. These distances were then compared to random points placed in the study area and statistical significance was tested using a paired sample T-test. Results indicated a gender difference between male and female grizzly bears, where females were most influenced by human development and roads and established territories further from roads than males.

In the study of the effects of industrial development on caribou, O'Neill et al. (2000) used a Minimum Convex Polygon technique for home range delineation, and then simulated random sets of roads within an individual caribou's home range. Calculated crossings between the caribou travel path, using telemetry locations, and the actual and simulated road networks were then compared and tested for statistical significance using paired sample T-tests. The results of this study indicated significant habitat loss through avoidance patterns.

2.6 Suitability Modeling and Reintroduction

As mentioned above, the reintroduction of breeding populations of Florida panthers in sites other than the current south Florida habitat is essential to the survival and persistence of the species. Additionally, successful breeding populations in areas of reintroduction would require the maintenance of demographic links between populations, effectively a corridor for male dispersal. In any reintroduction research, the importance of connectivity between populations is paramount in order to avoid inevitable inbreeding and habitat overpopulation (Beier et al., 2003; Jordan, 1994).

Recently, Maehr et al. (2002) provided evidence of male dispersal to areas north of Caloosahatchee River, which is essentially the first indication of a natural reintroduction into this area. However, female subadults would need to be transported there in order to maintain a successful breeding population (Maehr et al., 2002) and ecological corridors would be necessary for sustainable links between established populations. Beier et al. (2003) agree with Maehr et al. (2002) and assert that this is a viable option.

Chapter Three

Methodology

3.1 Study Area

The study area for this analysis is defined by the telemetry dataset of radiocollared Florida panthers. This area of southwest Florida specifically includes the counties of Lee, Hendry, Collier, Broward, Monroe, and Miami-Dade as well as Everglades National Park and Big Cypress National Preserve. This region also includes the intersection of SR29 and Interstate 75, known to include several wildlife underpasses and also contains relatively high forest content (see Figure 3.1), as the panther's dependence on forested areas has been well established (Beier et al., 2003).

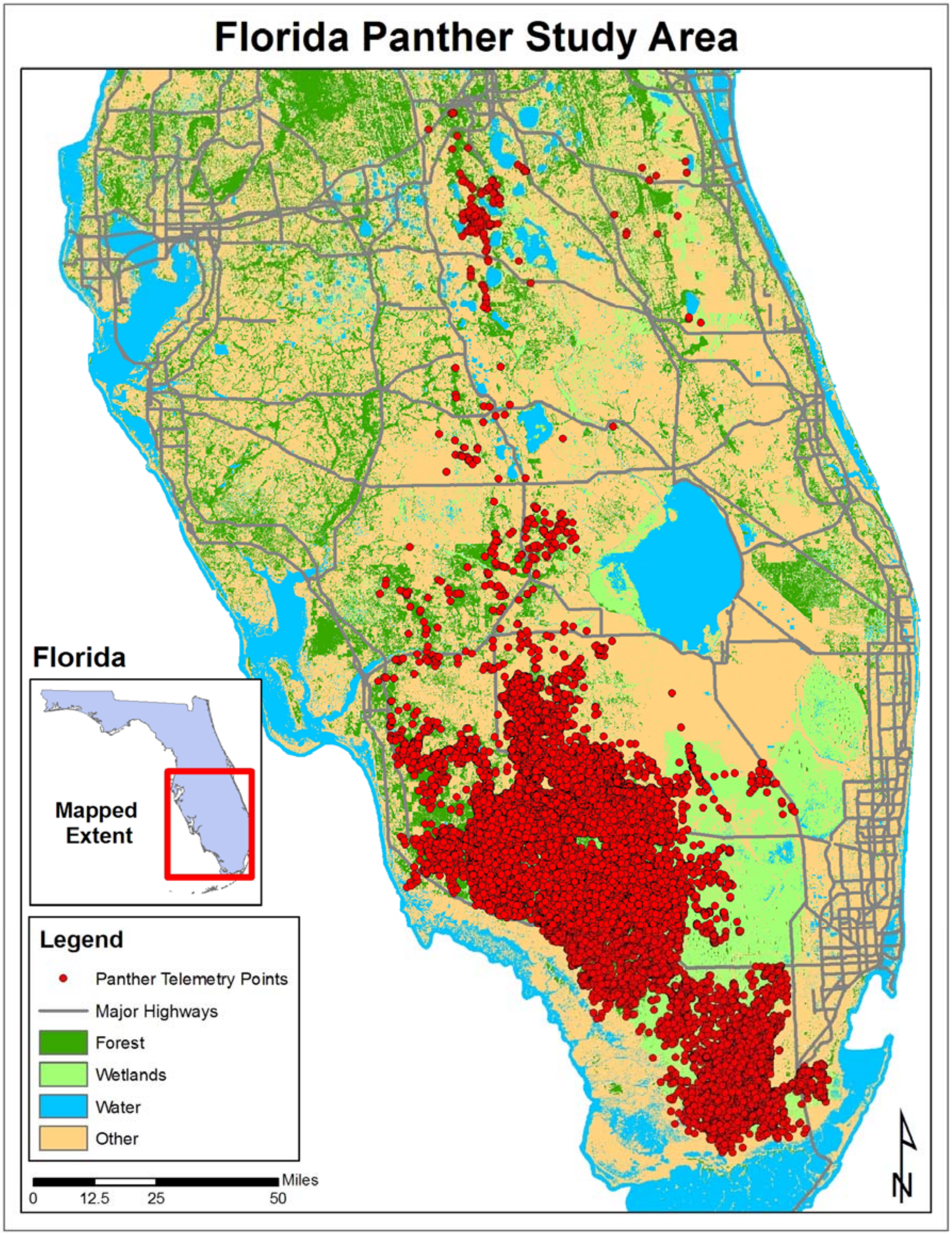


Figure 3.1: Florida Panther Study Area.

3.2 Data Sources

The most prominent dataset of this analysis is the Florida panther radio-telemetry location dataset, provided by the Florida Fish and Wildlife Conservation Commission (FFWCC). This dataset is annually updated and includes statewide telemetry locations from February 1981 to December 2004, although most of them are located in southwest Florida, the last significant Florida panther habitat (Beier et al., 2003). There are 71,220 records for 145 individual cats, including the eight Texas pumas integrated into the population for the 1995 genetic restoration project.

Telemetry is a technology that typically refers the use of wireless radiofrequency systems which allow the remote tracking and/or measuring of information desired by the operator. In wildlife management, telemetry is most commonly implemented through the use of radio collars equipped with transceivers and/or GPS to provide location and medical information of the collared individual. The FFWCC Florida panther telemetry dataset was collected through the use of these telemetry techniques. According to the 2003-2004 Florida Panther Genetic Restoration and Management Annual Report (Land et al., 2004), "instrumented animals were monitored approximately every other day (M, W, F) from fixed-wing aircraft. Locations were plotted on 7.5-minute USGS topographic maps and recorded as Universal Transverse Mercator points (p9)." This sampling design limits analysis, primarily because individuals cannot be tracked during their exact movement pattern, and these recordings are all diurnal when panthers are most likely at rest. Positional accuracy, based on the differences between aerial measurements and GPS locations of 36 panther dens or carcasses, is approximately 115 meters (± 29.7 meters) (Land et al., 2004). Other estimates of the error associated with this particular panther telemetry dataset were derived by Belden et al. (1988), Janis and Clark (2002), and Dees et al. (2001), whose estimates ranged from 77 to 230 meters with varying degrees of confidence.

A second FFWCC dataset of collared and uncollared Florida panther mortalities and injuries, which includes georeferenced locations from 1972 to 2004, was used in the analysis of mortality. This dataset also includes locational information on several Florida panther injuries resulting from contact with vehicles. There are 170 records in this mortality dataset, 11 of those are recorded injuries.

A 1:24,000 USGS road network (1998), downloaded from the online Florida Geographic Data Library was also used. This road network contains road type descriptions, varying from class 1 primary routes to class 5 trails. Table 3.1 describes the translation from original road segment descriptions to road classes and then categorized into major or minor road types. Figure 3.2 shows the final road network within the study area of southwest Florida. The analyses use both road class and type in order to discriminate patterns of influence on individual panthers that may not be identified using just one road classification system. Duplicate segments in the road network that represent divided highways, roads, and streets, and those segments with a class of zero (cul-de-sacs, highway onramps, etc) were removed from the dataset for the analyses so as not to bias estimates for road lengths and crossings.

A vegetation landcover grid derived from 1997 30m Landsat imagery (received from Florida Fish and Wildlife Conservation Commission) was used in the analyses as well. The grid was reclassified into forest or non-forest, according to preferred panther forest types (Kerkhoff, 2000). Table 3.2 shows the vegetation classification. These forest types were considered equal in weight in this analysis. All other vegetation types (including non-preferred forest) were classified as non-forest.

Wildlife crossings locations derived from the July 2004 version of the Florida Department of Transportation Roads Characteristics inventory (RCI) dataset were also used in the analyses.

Table 3.1: Road Network Classification. USGS road network classification scheme from original descriptions to road class and type.

Road Network Classification		
Type	Class	Description
Major	1	Class 1 primary routes, divided and undivided, such as Interstate 75
	2	Class 2 secondary routes, divided and undivided, such as State Route 29
Minor	3	Class 3 roads or streets, divided and undivided (most major residential streets)
	4	Class 4 roads or streets (smaller residential streets, some one-way)
	5	Class 5 trails, navigable by some vehicles, most only by four-wheel-drive

Table 3.2: Vegetation Landcover Reclassification. Classification scheme from original vegetation descriptions to forest/non-forest.

Vegetation Landcover Reclassification	
Original Class	Analysis Assignment
Barren	Non-Forest
Bay swamp	Non-Forest
Bottomland hardwoods	Non-Forest
Coastal salt marsh	Non-Forest
Coastal strand	Non-Forest
Cypress swamp	Forest
Dry prairie	Non-Forest
Exotic plant communities	Non-Forest
Freshwater marsh and wet prairie	Non-Forest
Grassland (agriculture)	Non-Forest
Hardwood hammocks and forests	Forest
Hardwood swamp	Forest
Mangrove swamp	Non-Forest
Mixed hardwood-pine forests	Forest
Open water	Non-Forest
Pinelands	Forest
Sand pine scrub	Non-Forest
Sandhill	Non-Forest
Shrub and brushland	Non-Forest
Shrub swamp	Non-Forest
Tropical hardwood hammock	Non-Forest
Xeric oak scrub	Non-Forest

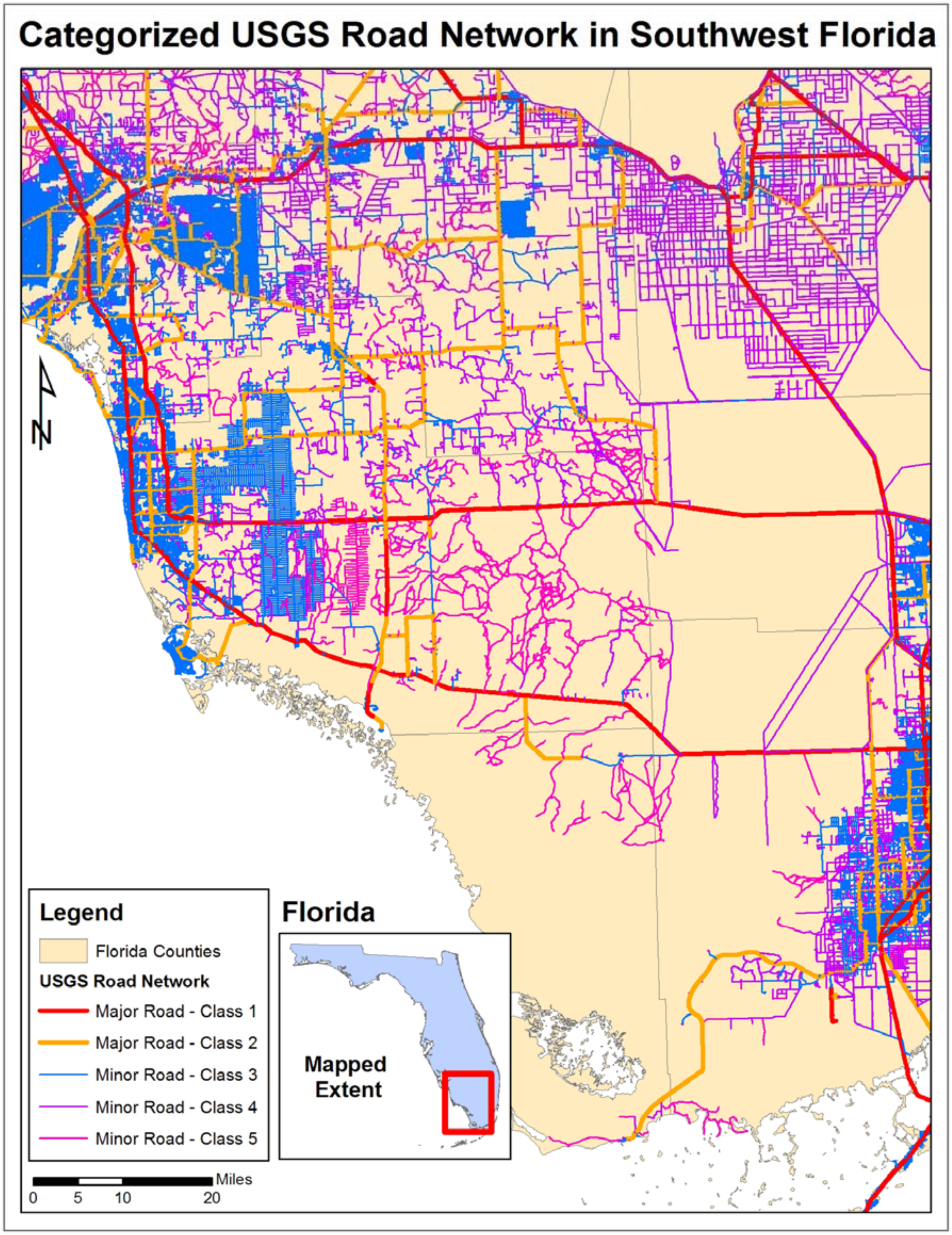


Figure 3.2: Categorized USGS Road Network in Southwest Florida. Map of final USGS road network used in analyses, categorized by both type and class.

For the purposes of this analysis, a subset of the telemetry data was extracted for use based on several qualifying features. The analysis utilizes only those telemetry observations recorded when the individual panther was an adult, or at least two years of age[1] (FFWCC, 1999). Generally, adult panthers exhibit more stable home ranges than juveniles, which demonstrate much more erratic movement patterns and travel far distances as they search for a suitable area to establish their adult home range (Maehr et al., 2002). This study does not use juvenile telemetry points to describe adult habitat characteristics and movement patterns. The frequency of telemetry observations for an individual panther over the span of a year must have exceeded 100 records over a minimum of three years. Since the analyses depended on home range estimations and calculated movement paths, bias was reduced by choosing individuals with more frequent observations and longer telemetry records. These subset requirements resulted in a group of individual panthers[2] with better models for movement patterns and estimates for home range size and location, and higher statistical power than most of the telemetry dataset. The telemetry records for the eight female Texas pumas included in the dataset were also not used in the analyses.

The preference of subsetting and organizing the data by individual panther is supported by both logic and literature. Grouping the data as a set of locations as opposed to individual panthers can create serious bias in that some of the

[1] The reported birth month and year (Land et al., 2004) was used to calculate age of each individual through their telemetry record.
[2] Using these qualifying attributes, the final telemetry subset included 21 males and 35 females. Female panther 83 was included, except for one erratic telemetry point that was approximately 45 miles from the outermost point of the remaining locations. Additionally, male panther 62 was removed from the subset to avoid statistical influence in the analyses from atypical behavior.

panthers have substantial telemetry records (10 years +) and others are represented with less than two years of data. It is the opinion of the FFWCC scientific review team (Beier et al., 2003) that performing analysis on individual panthers and then drawing conclusions across those individuals is preferred to using the entire dataset as a pooled sample. This is an opinion also reproduced by Dickson et al. (2005). Analysis of the data in this manner would highlight those differences and minimize error associated with the sampling bias in the panther telemetry dataset. Dividing the dataset into individual panther telemetry records is a logical organization and is used in this study.

3.3 Analysis

3.3.1 Home Range Characterization

In order to characterize an individual Florida panther's established diurnal territory, size and location of the home range for each panther were estimated. Lifetime home ranges were calculated using all adult telemetry locations for each individual in the subset and annual home ranges were calculated to explore any lifetime shifts in home range size and location. All home ranges were calculated using a 100% Minimum Convex Polygon method.

3.3.2 Road Mortality

Florida panther mortality by roads was investigated through the use of the FFWCC Florida panther mortalities dataset. Composition of radiocollared and uncollared panther deaths over time, by gender, age, road type and class, and relative location of wildlife underpasses was examined.

3.3.3 Crossing Behavior

In order to determine patterns of road crossings by collared Florida panthers, individual lifetime movement paths were delineated from the radio-telemetry data subset using a point-to-polyline tool. These movement paths were then intersected with the comprehensive road layer to determine points of crossing for all road classes and types. This method does not determine the exact location of crossing, but provides a reasonable estimate of the number of crossings per road class and type by connecting daytime resting sites, typically 2 or more days apart. In order to remove the bias of observation length, these crossing totals were then divided by the total length of observation[3] for each individual panther. Total number of crossings (per year) by road class and type and crossing densities (#crossings/km)[4] by road class and type were calculated from the intersections and statistically compared using paired t-tests. The statistical comparisons were performed separately for each gender, in order to minimize any error associated with aggregation by gender since the movement patterns and habitat size requirements for males and females differ substantially (Maehr, 1995).

3.3.4 Barrier Effect of Roads and Forest on Panther Movement

Since the above described crossing behavior analysis does not highlight the individual panther whose home range does not encompass roads that might

[3] Total observation length, in years, was calculated as the difference between the first and last observation date used in the subset.
[4] Crossing densities were calculated as the ratio between the number of crossings for each road class and total length of each road class. Road lengths include only those road segments that are contained by an individual's lifetime home range, as delineated using a 100% Minimum Convex Polygon technique.

have been considered major barriers to movement, road and forest density changes just outside of individual panthers' home ranges were determined. This methodology considered significant road and forest density changes as potential habitat selection barriers, particularly for individuals whose home ranges are elongated against major roads which they never cross (e.g. see Figures 4.4 – 4.6).

In order to determine these changes in density, road densities (km/km^2) by class and type were calculated within each lifetime home range and within a 1 km buffer area just outside of the home range. Differences between these road densities, by type and class, were compared using a one-sample t-test against a mean of zero[5]. Since panther daytime habitat selection is also influenced greatly by forest content (Beier et al., 2003), forest densities (as a percentage of total area) inside the home range and within the buffered area were also compared using the same statistical methods. Again, these analyses were separated by gender. The use of the 1 km buffer was determined through initial exploratory testing. A 1 km buffer proved to be a best fit in terms of percentage increase in home range size versus other tested buffer sizes (100 m, 500 m, and 1.5 km, etc).

3.3.5 Effectiveness of Preventative Measures

The effectiveness of wildlife underpasses and right-of-way fencing installed on several major highways in the study area was determined through

[5] A difference of zero would indicate no difference between the densities within the home range and within the buffered area. Using a t-test against a mean of zero tests whether the range of calculated differences significantly departs from zero.

the examination of the FFWCC panther mortality data and the locations of those wildlife underpasses and stretches of fenced highway. The rate of panther road mortalities and location of adjacent home ranges, as determined through the use of the telemetry dataset, were compared before and after the installation of the right-of-way fencing.

Chapter Four

Results

4.1 Home Range Characteristics

In order to explore an individual Florida panther's established diurnal territory, size and location of both the lifetime and annual home ranges for each panther were estimated using a 100% Minimum Convex Polygon technique. Figure 4.1 presents the extent of all lifetime home ranges for the 56 individual panthers in the telemetry subset. Most home ranges of both genders are located in areas of higher forest density, specifically around the I-75 corridor of southwest Florida.

Some panthers, mostly female, have established themselves in the extreme south of the peninsula, creating a sort of sub-population, as there are expansive wetlands and little forest cover between the two established habitats. This region is part of the Everglades National Park and is under the Comprehensive Everglades Restoration Plan which would increase water flow through this area over the next 30 years (U.S. Army Corps of Engineers, 2006), essentially cutting off the smaller sub-population at the southern tip of Florida. There are also several individuals, particularly one male, that have extended their home ranges north and west, beyond the more panther-friendly forested rural areas.

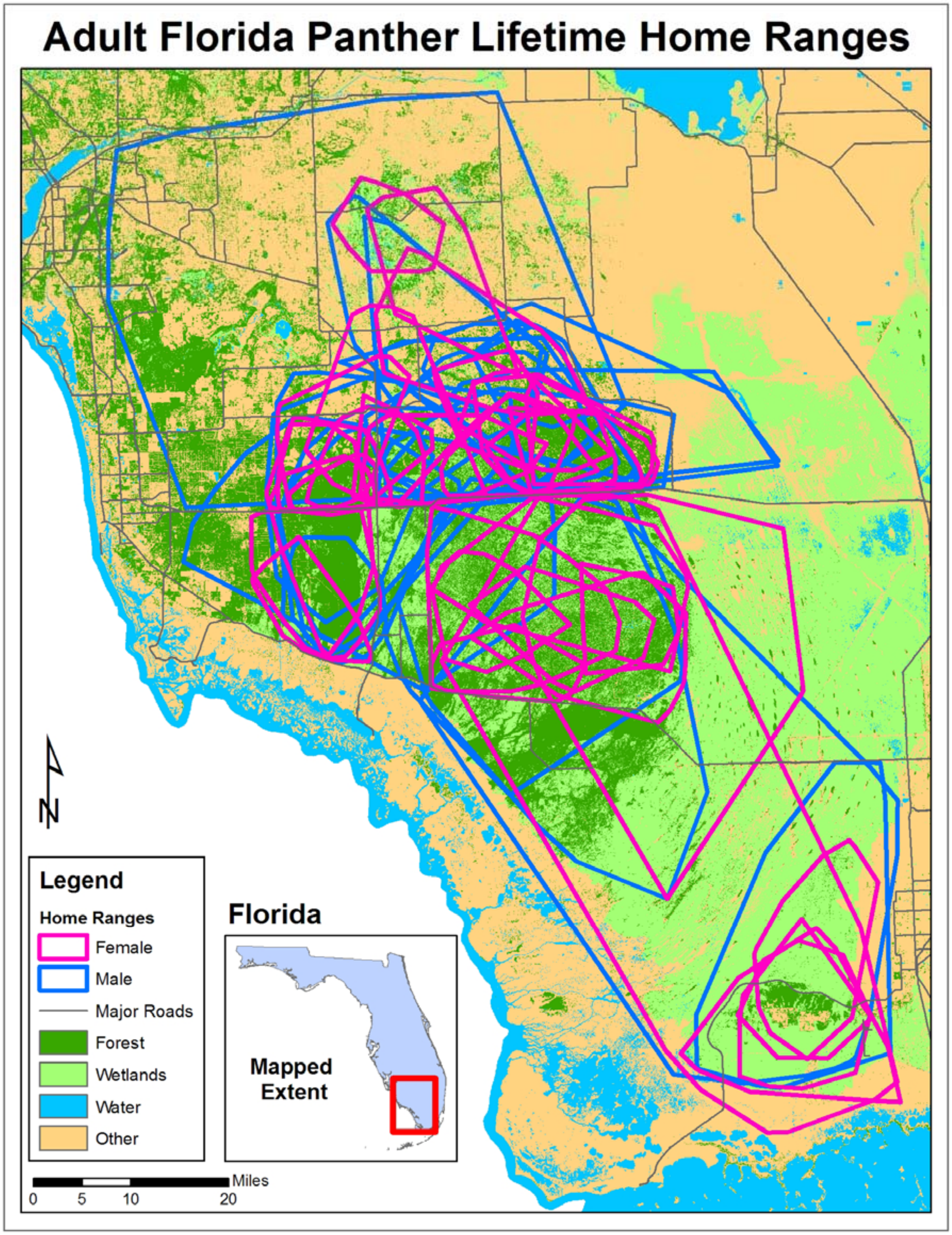


Figure 4.1: Adult Florida Panther Lifetime Home Ranges. Includes only those panthers in telemetry subset.

The diversity of size and shape among the calculated home ranges points to several trends, some by location and others by gender. Many of the female lifetime home ranges overlap in both time and space (see Figure 4.2), further confirming that females generally tolerate overlapping territories, particularly with their own offspring (FFWCC, 1999). For example, in Figure 4.2, female Florida panther 87 is the offspring of female 55, and both share a considerable amount of habitat over several years as adults. The rest of the females shown in the figure are not related by mother, but most are sired by the same male. Males, alternatively, have much larger home ranges and tolerate overlaps much less than females do as seen in Figure 4.3. This figure shows the annual home ranges for all adult male Florida panthers collared in 2002. Most of these annual home ranges have only slight overlaps and do not coincide as the females do, except for one sizeable overlap between males 59 and 60.

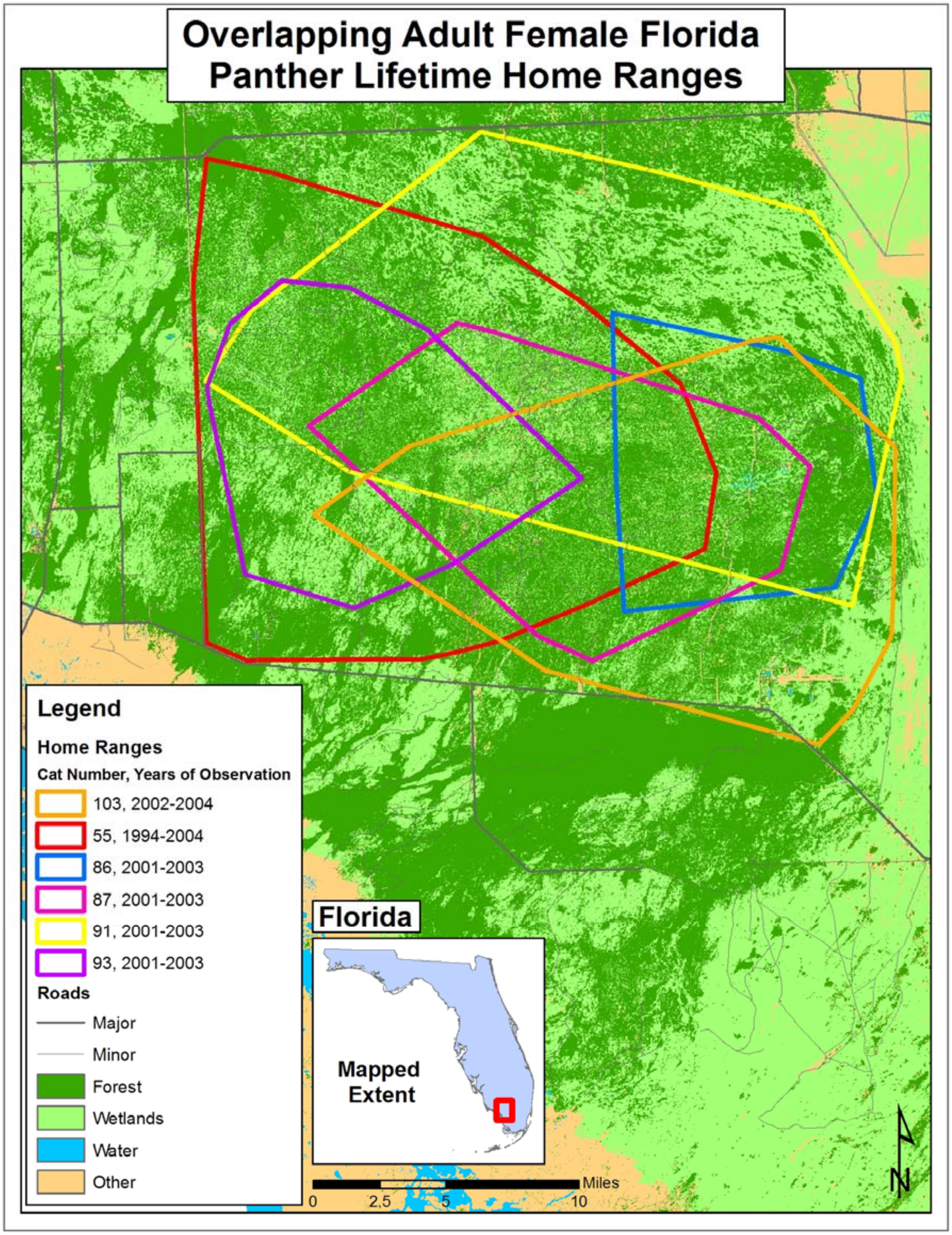


Figure 4.2: Overlapping Adult Female Florida Panther Lifetime Home Ranges.

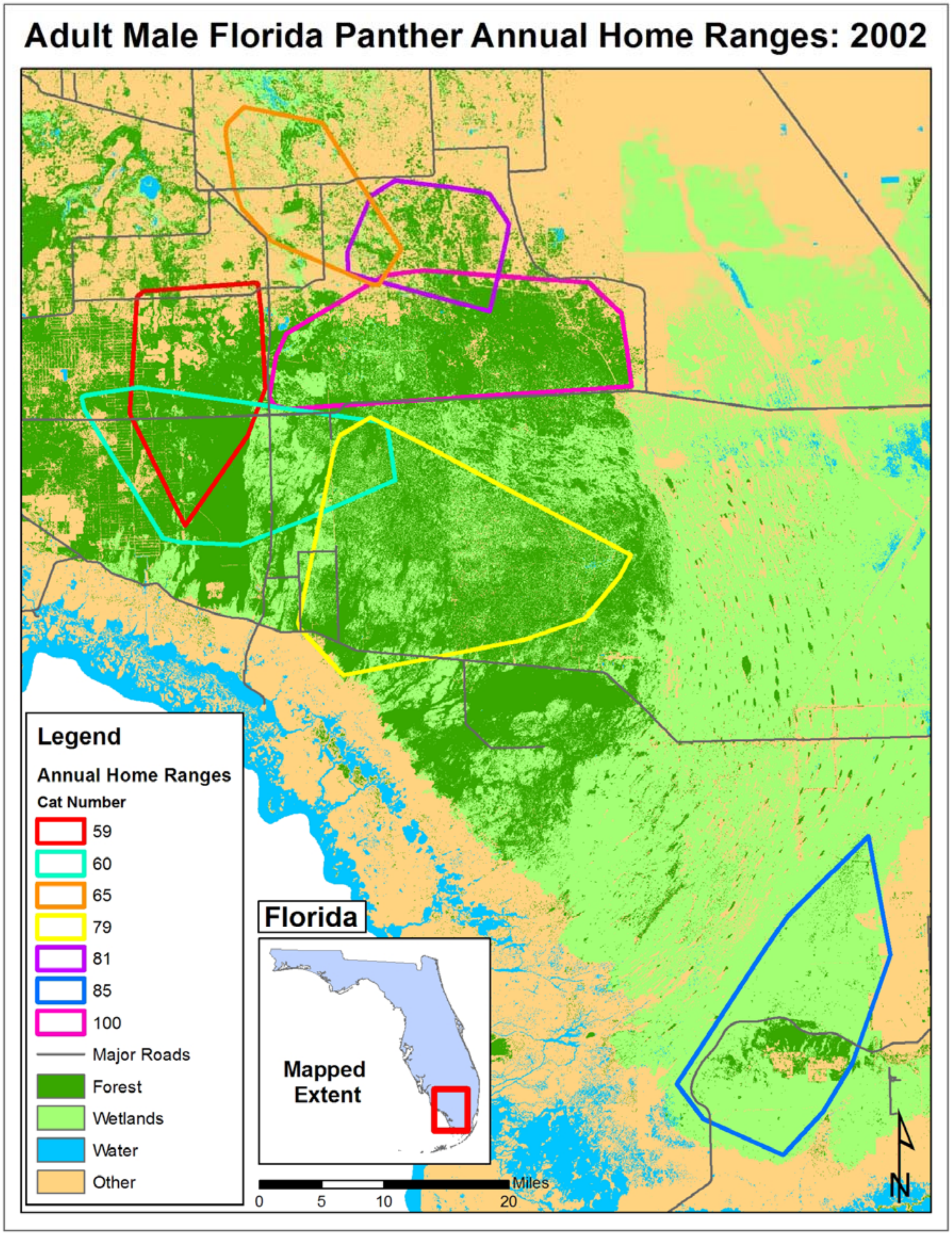


Figure 4.3: Adult Male Florida Panther Home Ranges for 2002.

This exploration of the home range characteristics of the telemetry subset also pointed toward a trend where the home ranges of several Florida panthers were shaped according to the surrounding major road network (see Figures 4.4 - 4.6). The telemetry records for several of these individuals also reveal a clustering against the road, much as a captive animal paces the length of its cage. Interestingly, the most striking examples of this “caged effect” (Figures 4.4 – 4.6) are all females, indicative of a trend in gender differences of the influence of roads on panther movement. All are along the same section of SR-29 and I-75, both of which provide numerous wildlife underpasses for safe crossing. This suggests roads, even with guaranteed safe crossings, act as a barrier for movement for some panthers, since there is available forest cover directly on the other side of these roads. Alternatively, there are several examples of males which regularly cross this section of highway, and are discussed in section 4.5 of this document.

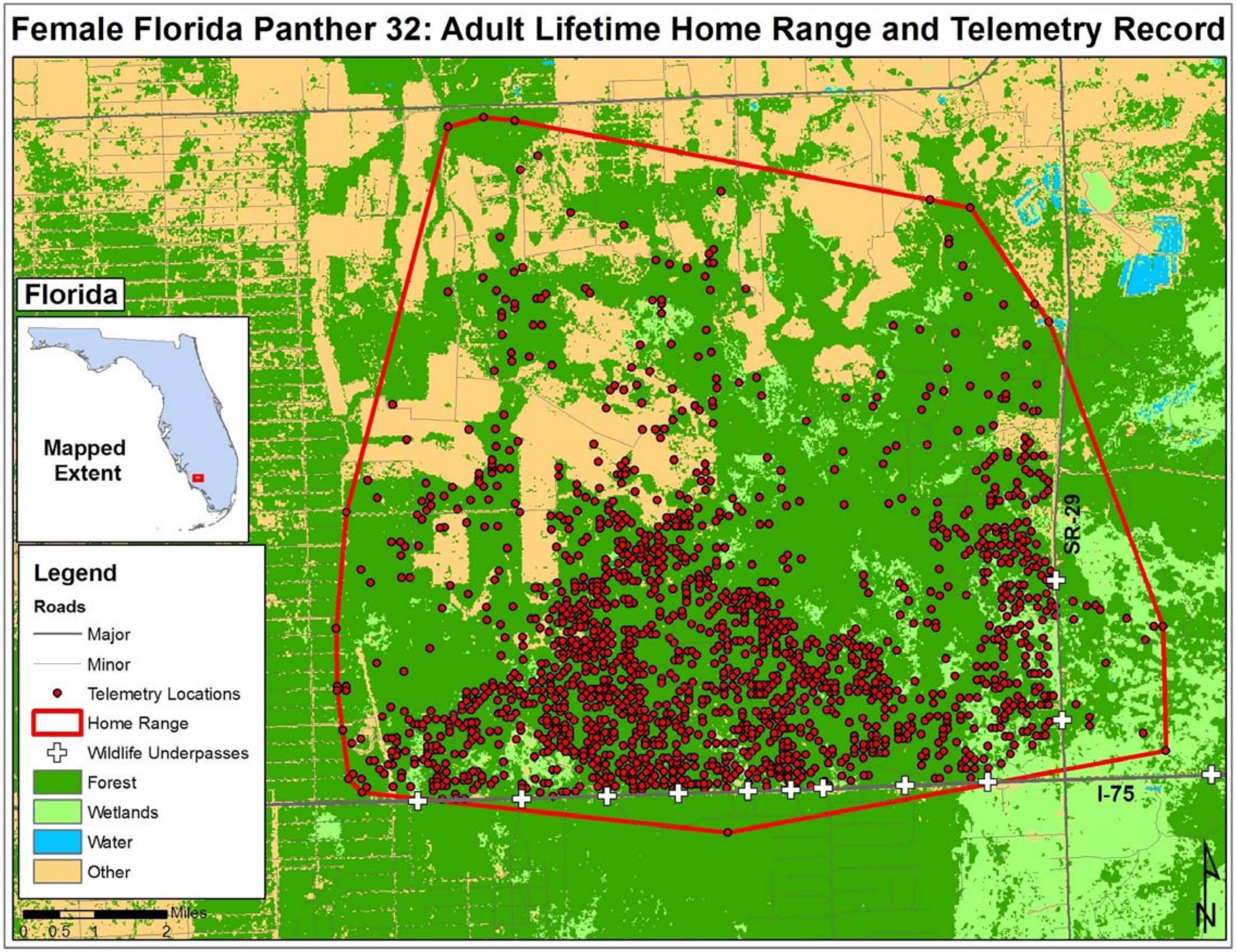


Figure 4.4: Female Florida Panther 32: Adult Lifetime Home Range and Telemetry Record.

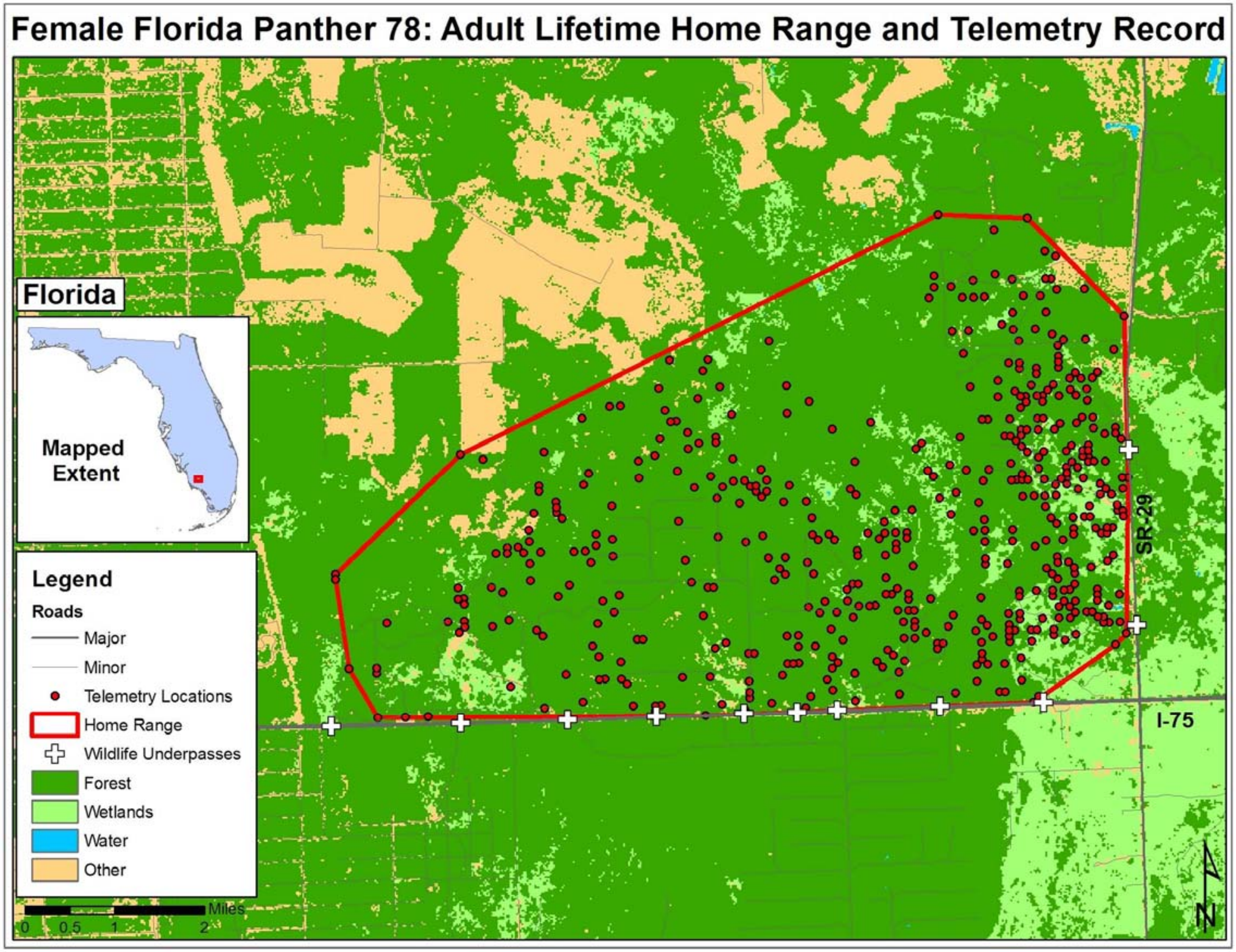


Figure 4.5: Female Florida Panther 78: Adult Lifetime Home Range and Telemetry Record.

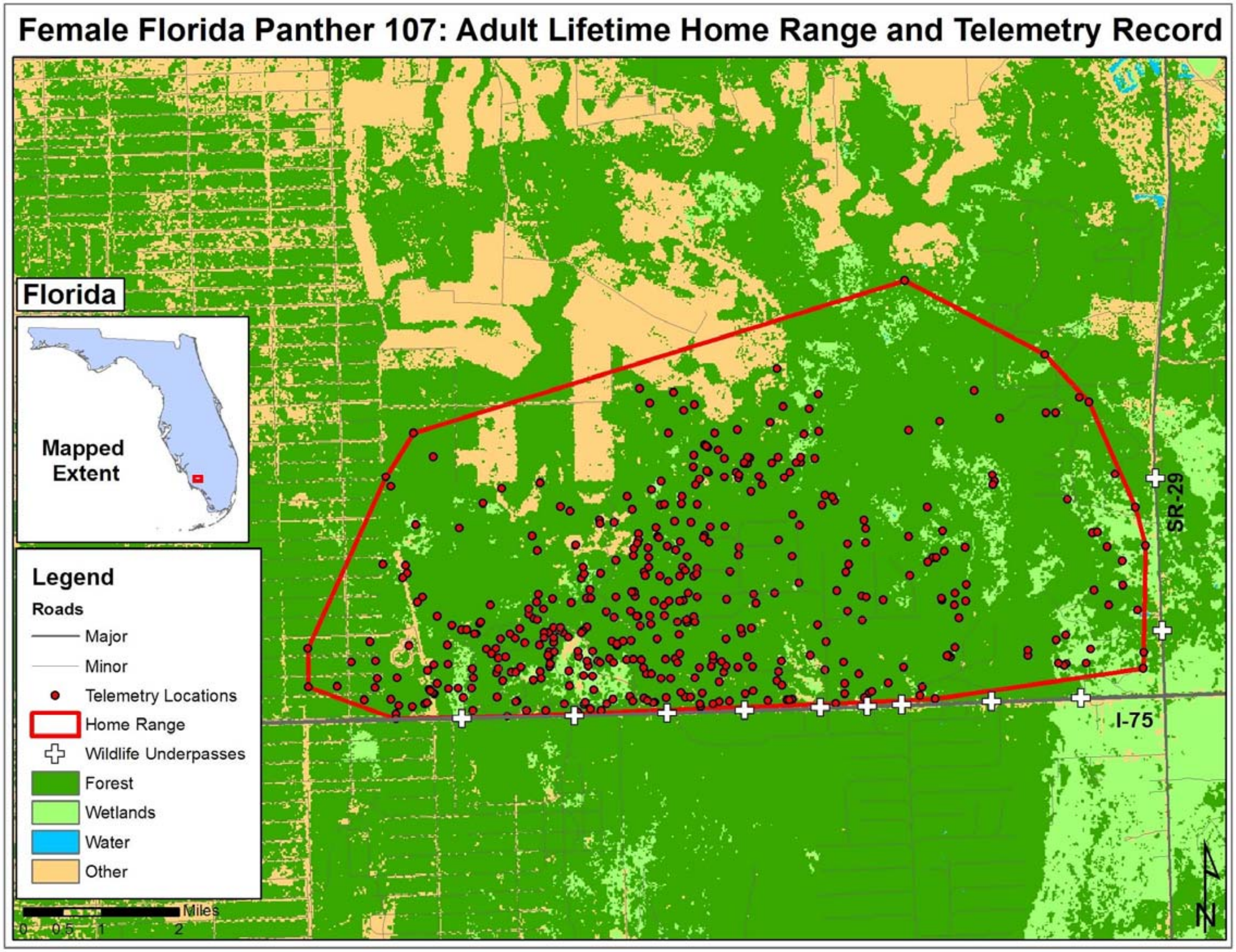


Figure 4.6: Female Florida Panther 107: Adult Lifetime Home Range and Telemetry Record.

Home range characteristics across the population subset were used to statistically confirm some of the major differences between the male and female Florida panther habitat requirements. Trends in annual home range sizes by age for both genders are shown in Figures 4.7A and 4.7B. While both figures show some variability between individuals, average male annual home range size (540.7 km^2) is much higher than the female annual average (211.3 km^2).

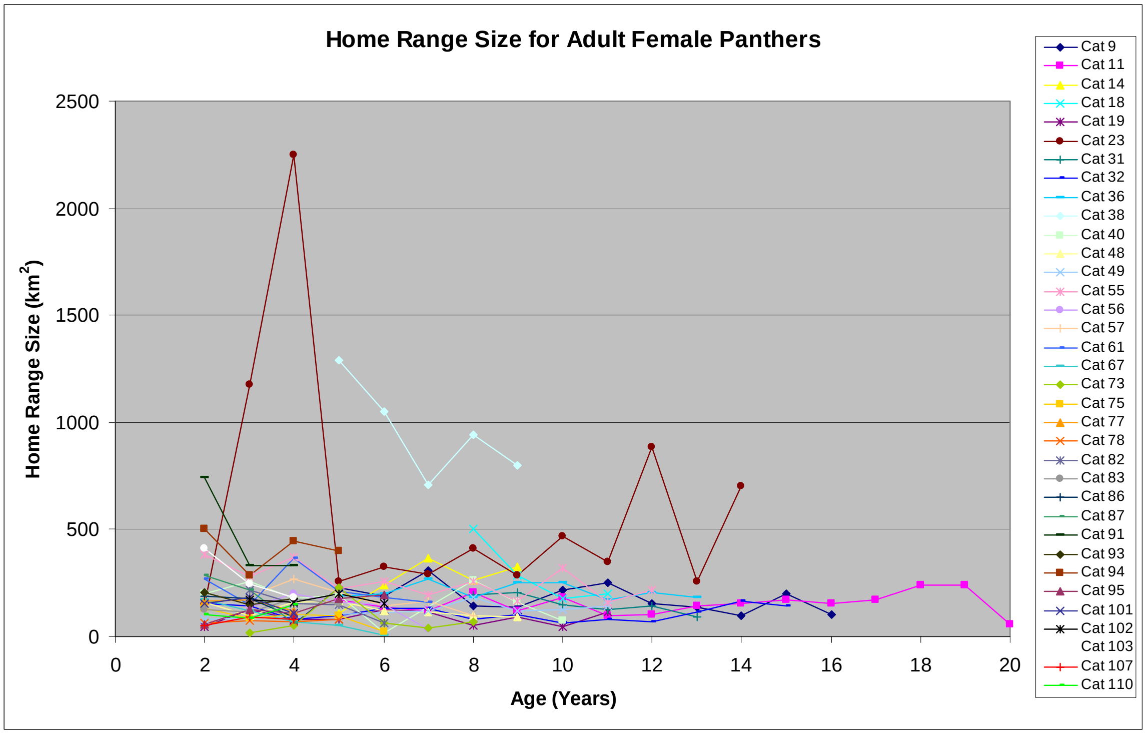


Figure 4.7A: Home Range Size for Adult Female Florida Panthers by Age.

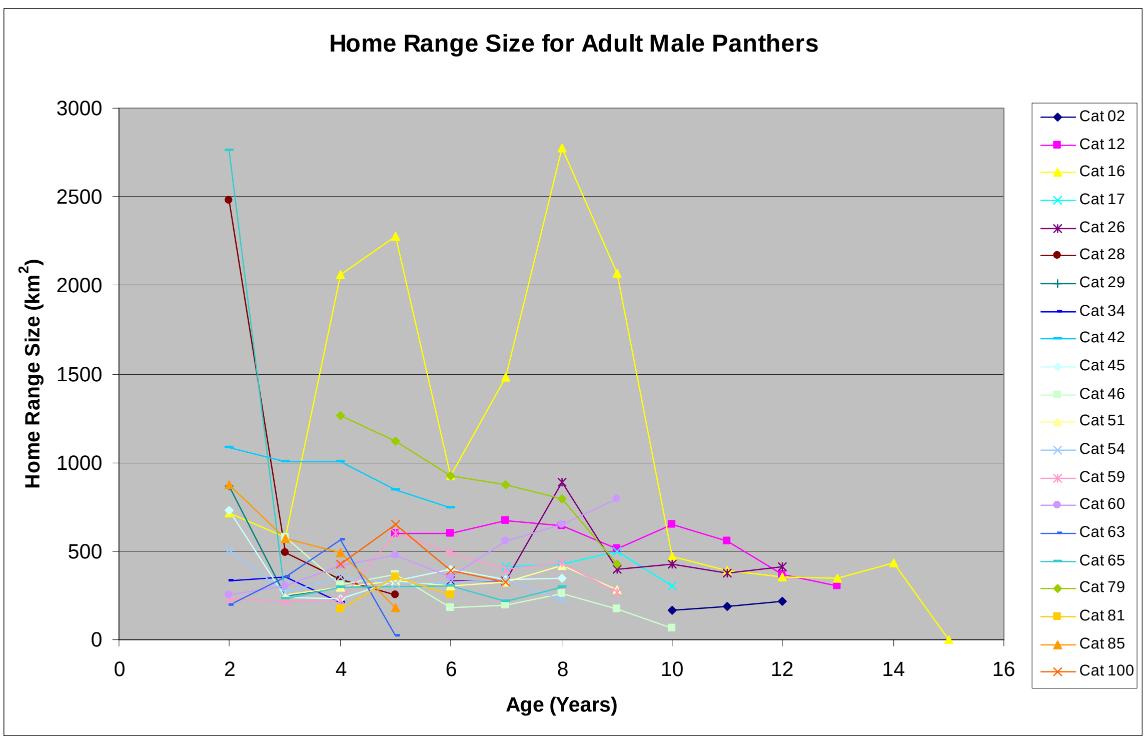


Figure 4.7B: Home Range Size for Adult Male Florida Panthers by Age.

Similarly, lifetime home range characteristics differ between the genders as well, as seen in Table 4.1 and Figure 4.8, a box-plot that shows the distribution of lifetime home range sizes for the population subset. An independent samples t-test[6] between the lifetime home range sizes of males and females demonstrates a significant difference ($t = 2.780$, sig. $= 0.010$). This test only further justifies the subsequent split of analyses between the genders in order to minimize any error associated with aggregation by sex since the movement patterns and habitat size requirements for males and females differ substantially.

Table 4.1: Descriptive Statistics of Lifetime Home Range Size by Gender.

Descriptive Statistics of Home Range Size (km^2)					
Sex	N	Minimum	Maximum	Mean	Std. Deviation
Females	35	93.248	4082.501	502.998	702.533
Males	21	276.021	4595.330	1292.357	1182.005

[6] A test for equality of variances (Levene's test) was initially performed, and the null hypothesis was rejected.

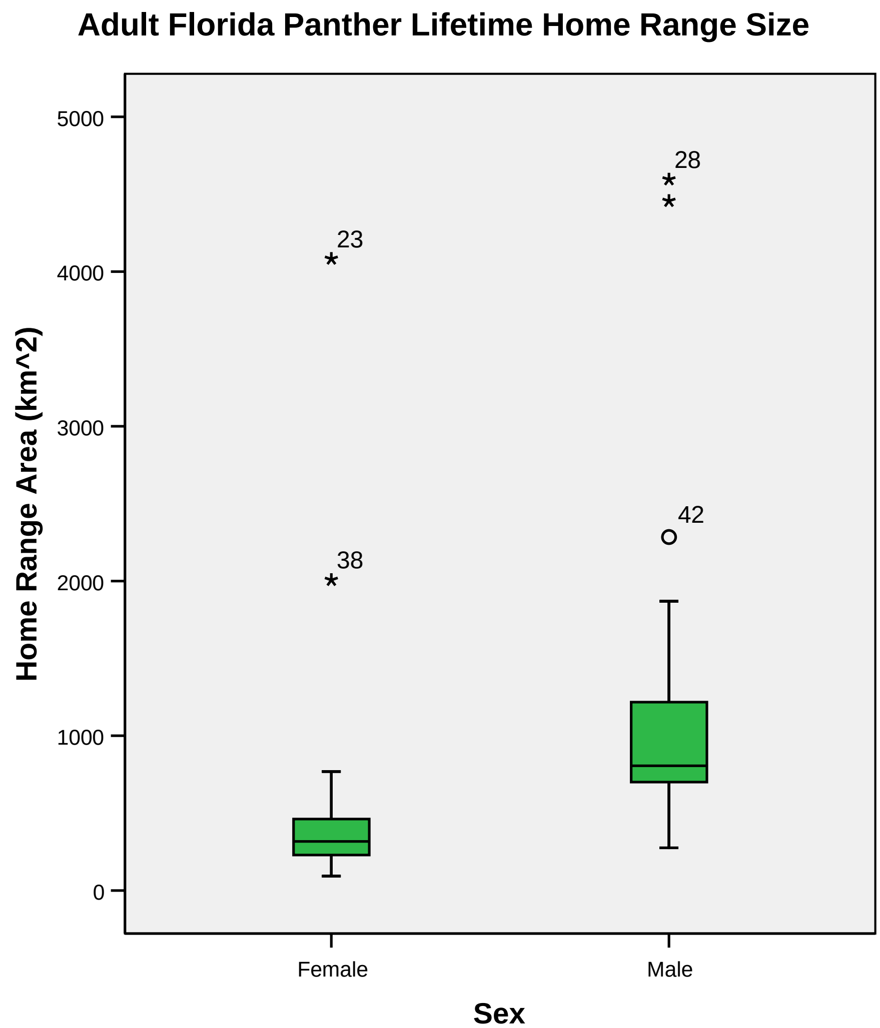


Figure 4.8: Adult Florida Panther Lifetime Home Range Size. Outliers are labeled by panther ID number.

4.2 Road Mortality

An examination of the FFWCC Florida panther mortality dataset highlights the significance of vehicular deaths as a major cause of mortality among the population. Figure 4.9 depicts the major causes of mortality and injury among radiocollared Florida panthers, both natural and anthropogenic. Although intraspecific aggression is the most prominent cause of death, one out of five deaths or major injuries of radiocollared Florida panthers occurs as a result of vehicle collision.

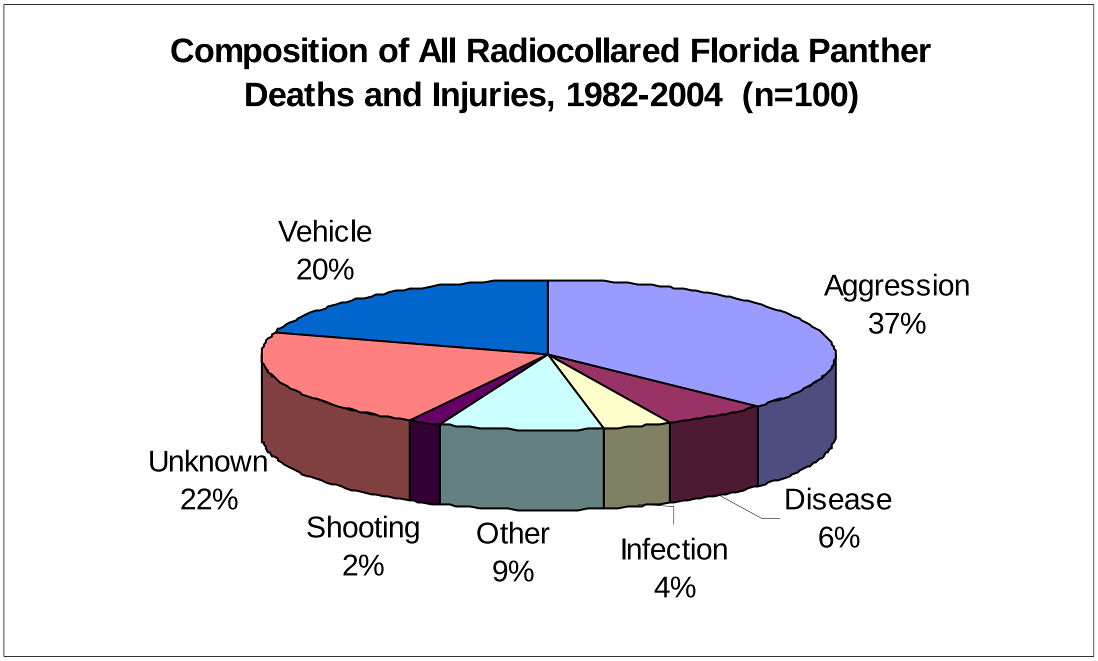
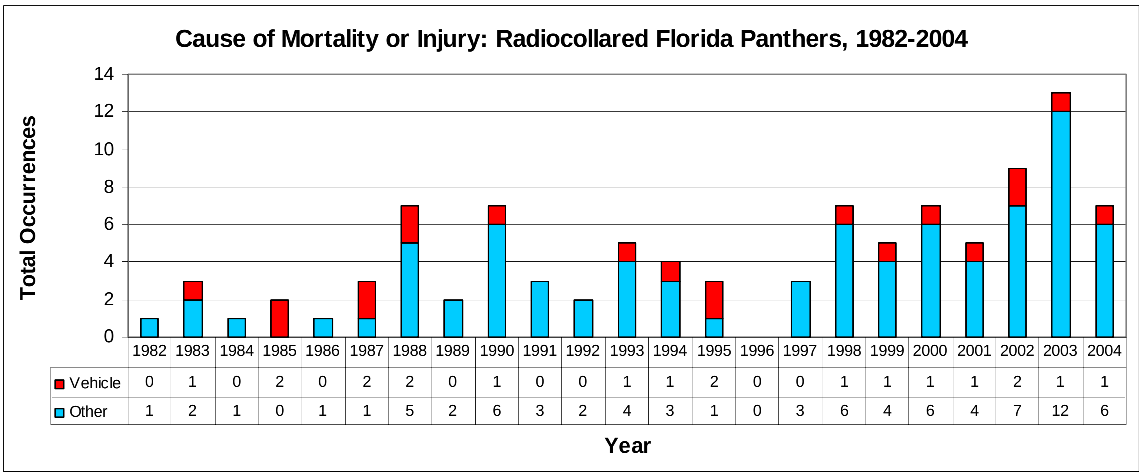


Figure 4.9: Composition of All Radiocollared Florida Panther Deaths and Injuries, 1982-2004.

Figure 4.10 describes causes of mortality or injury among radiocollared Florida panthers from 1982 to 2004. There is a general increase in the amount of recorded deaths, however this is likely not a reflection of an increase in mortality rates, but an increase in population. The FFWCC reported a population of about “70 adult panthers [remaining] in national and state parks and nearby private lands in southwest Florida” in 1999 and a little less than 100 adults in 2001 (FFWCC, 1999; FFWCC, 2001). The FFWCC (2001) affirms that the 1995 genetic restoration project substantially increased the population of the Florida panther, resulting in an increased number of recorded deaths. Additionally, the large percentage of intraspecific aggression mortalities reflects considerable aggression between panthers as the notoriously territorial population grows in an increasingly fragmented habitat.



	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Vehicle	0	1	0	2	0	2	2	0	1	0	0	1
Other	1	2	1	0	1	1	5	2	6	3	2	4

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Vehicle	1	2	0	0	1	1	1	1	2	1	1
Other	3	1	0	3	6	4	6	4	7	12	6

Figure 4.10: Cause of Mortality or Injury: Radiocollared Florida Panthers, 1982-2004.

The original FFWCC Florida panther mortality dataset does not catalog all deaths, but only those which are recorded from previously radiocollared panthers and those uncollared panthers whose death was easily found (i.e. vehicle collisions or deaths located on private lands). Most of the records in the dataset are those of radiocollared panthers, and are not representative of the entire Florida panther population. The deaths of the uncollared population cannot be completely described. Figure 4.11[7] represents mortality and injury totals for all

[7] The FFWCC Florida panther mortality dataset describes zero recorded deaths and injuries from 1973-1977. This does not depict zero deaths among the panther population, but zero recorded deaths within this timeframe.

records in this dataset, collared and uncollared. However, this is a biased representation showing an increase in vehicular deaths and vehicular deaths as the primary cause of mortality among Florida panthers because it includes the group of uncollared panther mortalities that are mostly vehicle-related.

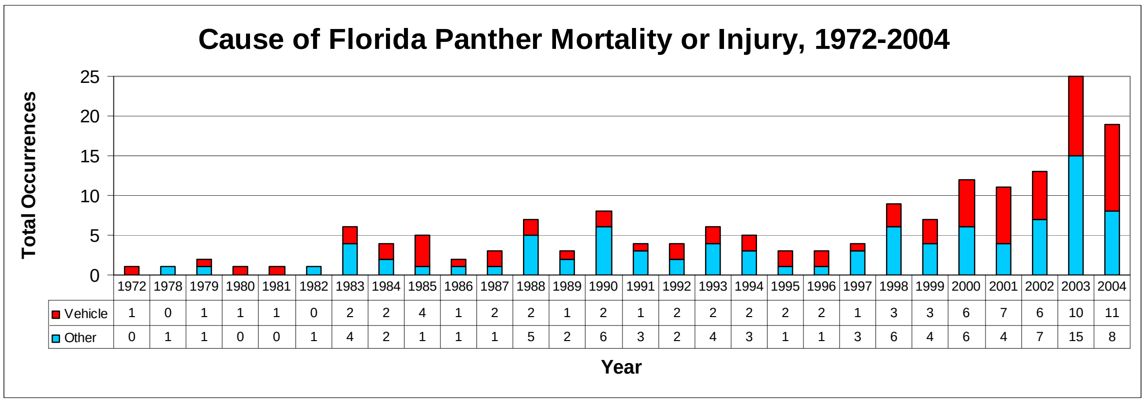


Figure 4.11: Cause of Florida Panther Mortality or Injury, 1972-2004

Figure 4.12 presents the locations of Florida panther vehicular mortalities and injuries from 1972 to 2004 of both radiocollared and uncollared panthers, and depicts high numbers of vehicular mortalities on major class roads, such as SR29. Female vehicular deaths occurred most on SR 29 and CR846, and are more centrally clustered than the males. Male vehicular deaths are generally more isolated, with the exception of SR29, and the greater distribution could be a result of dispersal behavior and a greater need for habitat space. SR29, however, is a considerable “hotspot” for vehicular deaths of both genders over the last twenty-five years and is a major contributor to the overall vehicular death composition. Figure 4.13 shows the spatial distribution of non-vehicle-related deaths and injuries. There is no major gender difference, except there are some male mortalities found further north than the group of female mortalities.

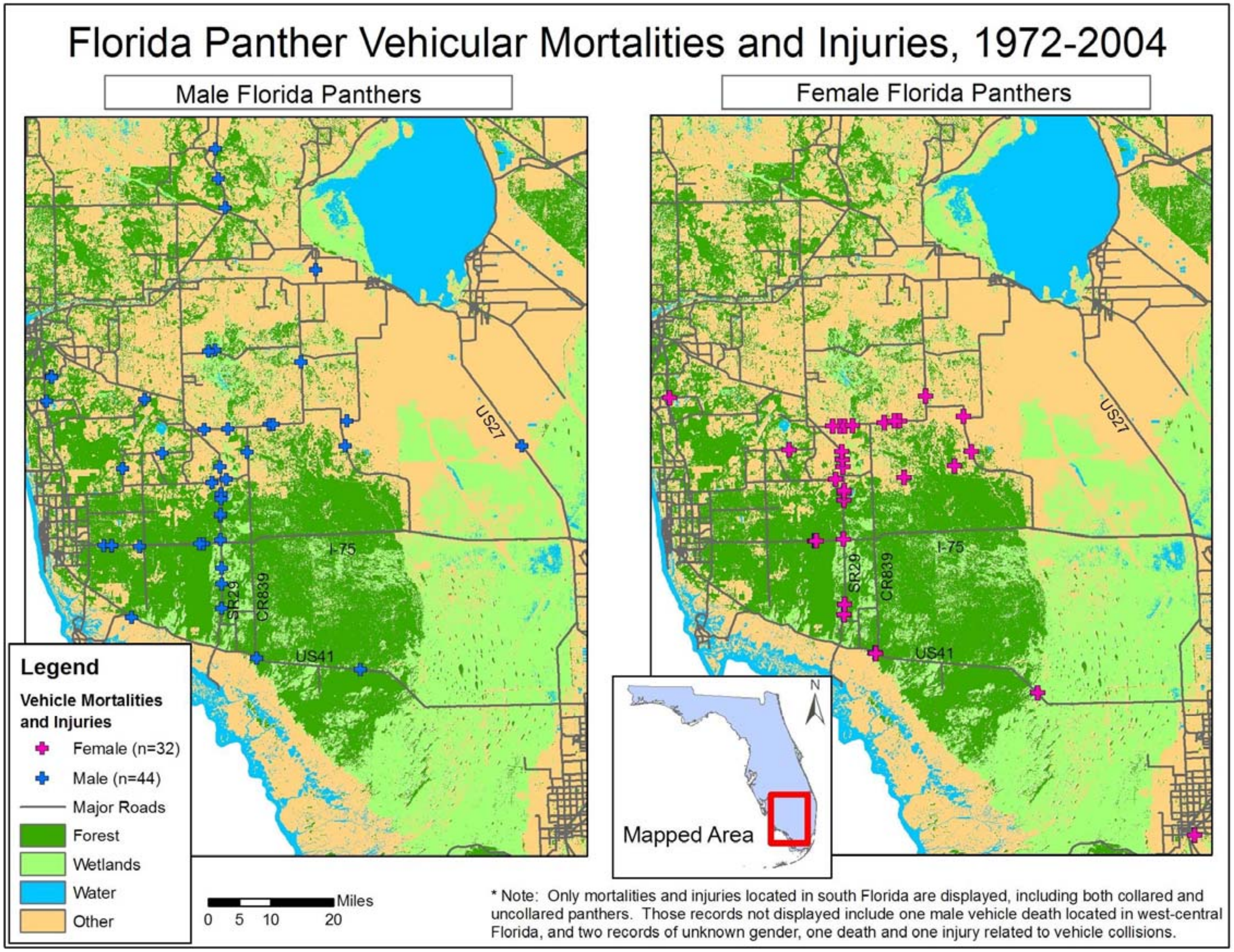


Figure 4.12: Florida Panther Vehicular Mortalities and Injuries by Gender, 1972-2004.

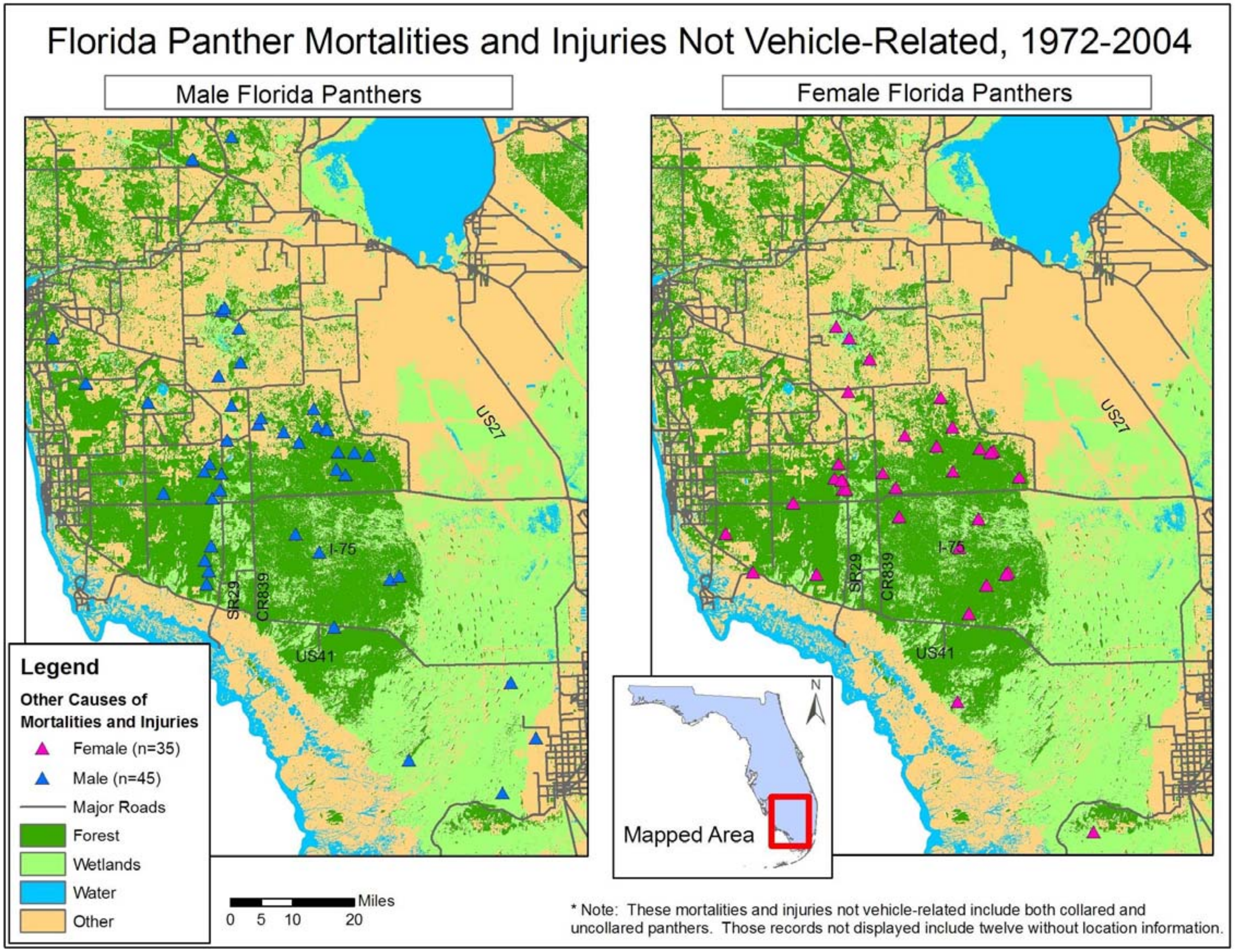


Figure 4.13: Florida Panther Mortalities and Injuries Not Vehicle-Related, by Gender, 1972-2004.

In order to examine some of the spatial trends of vehicular mortality, road class was determined by joining the class of the nearest road to the recorded location of vehicular mortality or injury[8]. These deaths and injuries are very likely to have occurred on the road class assigned, but there is a chance of an incorrect assignment if an individual panther traveled far enough after a collision. Table 4.2 presents a summary of total deaths and injuries by road class and deaths per kilometer[9] of road in each road class. Road classes 1 and 2 (major roads) total the lowest total length within the study area and have by far the highest number of deaths per kilometer than the remaining minor classes. These major roads prove to be a chief cause in the total vehicular mortality rates of the remaining Florida panther population.

Table 4.2: Number of Vehicle-Related Mortalities by Road Class.

Number of Vehicle-Related Mortalities by Road Class				
Road Class	Deaths	Injuries	Total study area length (km)	Deaths/km
1	19	2	274.1979	0.06929
2	42	5	637.9647	0.06583
3	6	2	5604.6227	0.00107
4	2	0	3184.9835	0.00063
5	1	0	2017.349	0.00050

A summary of vehicular mortalities and injuries by gender and age was performed by tabulating the mortality dataset into those categories. Table 4.3

[8] Both collared and uncollared panther vehicle mortalities and injuries were used in the summaries of road class, sex, and age.
[9] Total road lengths were determined through the delineation of a “study area” using the 100% minimum convex polygon technique on all telemetry locations of the subset population used in the analysis.

highlights the differences in vehicular mortality trends between males and females, and adults and juveniles. According to this summary, males tend to have higher numbers of vehicular deaths and injuries than females, and adults are killed more often than juveniles. There is little difference between the genders at the juvenile level, suggesting an equal risk of vehicular death at this age when movement between habitats is high for both males and females as they search for their own adult home range. Once a home range has been established, females are at a lower risk, as indicated by the lower number of vehicular deaths than male adults. These estimates are not controlled for total population, however, and do not take into account the true ratio of males to females and adults to juveniles in the entire Florida panther population.

Table 4.3: Number of Vehicle-Related Mortalities by Gender and Age.

Number of Vehicle Related Mortalities by Gender and Age			
Sex	**Age**	**Deaths**	**Injuries**
Female	Adult	16	2
	Juvenile	13	0
	Unknown	0	1
Male	Adult	27	2
	Juvenile	13	1
	Unknown	0	2
Unknown	Unknown	1	1

The importance of road mortality relative to the other causes of mortality for the remaining Florida panther population is apparent. According to this investigation, there have been no deaths on the stretch of I-75 that contains wildlife underpasses and high fencing since 1993, when the wildlife underpasses were constructed. Additionally, the FFWCC (2001) claims that no panthers have been killed by vehicle collision on the over 40 miles of highway that include the right-of-way fencing and wildlife underpasses since their construction. However, there are still frequent vehicular deaths on SR29, containing two underpasses just north of I-75 but little fencing.

The mortality dataset also indicates higher vehicular mortalities on road classes 1 and 2, compared to the minor class roads. Adult males seem to be more at risk in terms of road mortality than adult females, but there is no gender difference for juveniles.

4.3 Crossing Behavior

Road crossings were determined through the calculation of lifetime movement paths which were then intersected with the comprehensive road layer and summarized by road class for each individual panther. In order to remove the bias of observation length, each crossings total was divided by the total length of observation.   If a panther's home range did not include any segments of a road class, the number of crossings (zero) for that class was entered as *null* and was not included in the calculations. Alternatively, if a panther's home range did include a road class that was never crossed, the number of crossings (zero) was left as zero. Figure 4.14 depicts the total number of crossings per year by road type, which shows a substantial difference between the range of values and mean for major and minor road crossings (see Table 4.4 for descriptive statistics of crossing behavior analysis). Minor roads are crossed much more often per year than major roads in the case of both male and female Florida panthers, although males cross both major and minor roads on average more frequently than females do. Figure 4.15 shows the annual road crossing totals split by road class. Again, major roads (classes 1 and 2) are crossed much less frequently per year than the three minor classes of 3, 4, and 5, and follow an upward trend of crossings with increasing class numbers (decreasing road size). There is also a difference between males and females, with slightly lower total annual crossings for females, but the distinction is less dramatic by road class than by road type.

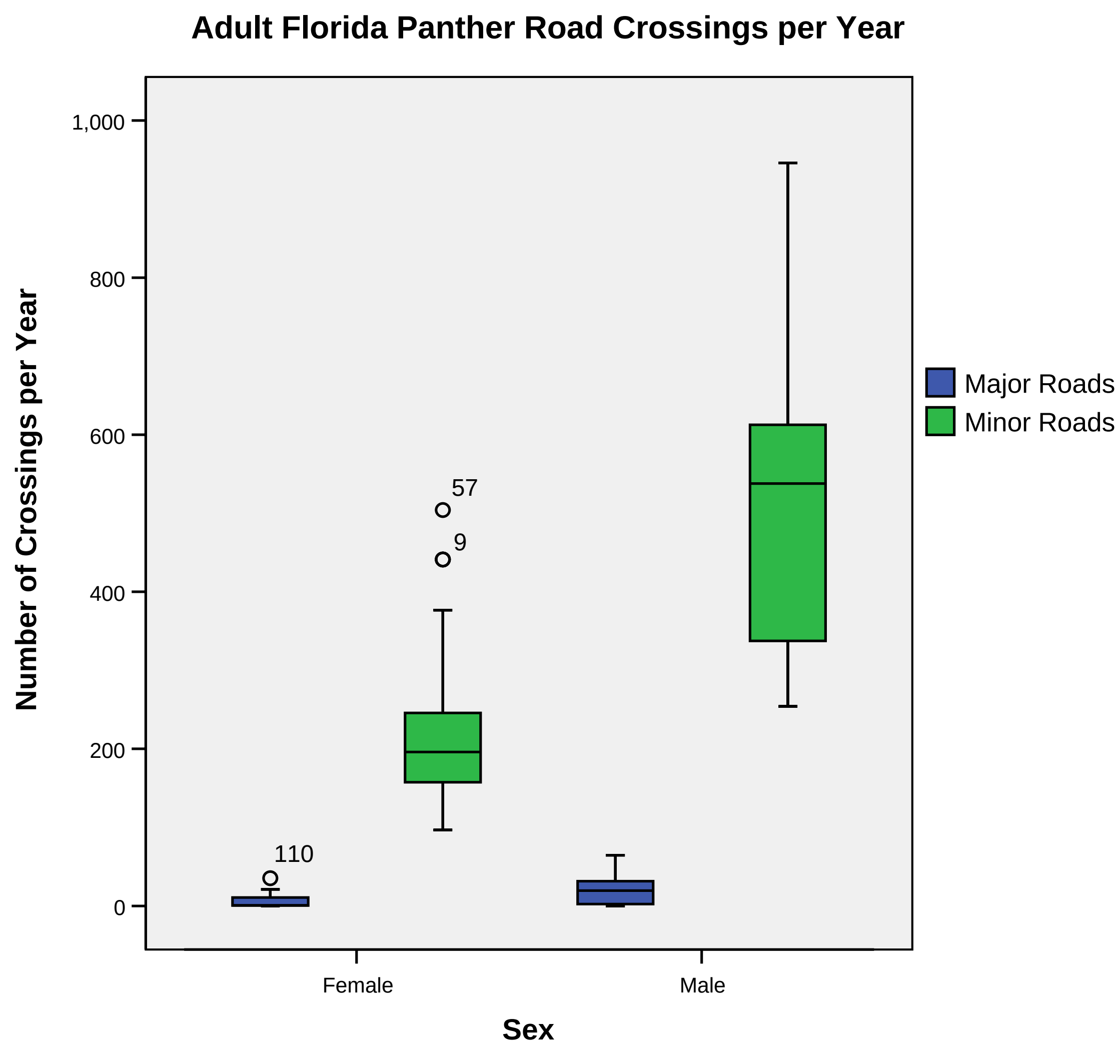


Figure 4.14: Adult Florida Panther Road Crossings per Year by Road Type. Outliers are labeled by panther ID number.

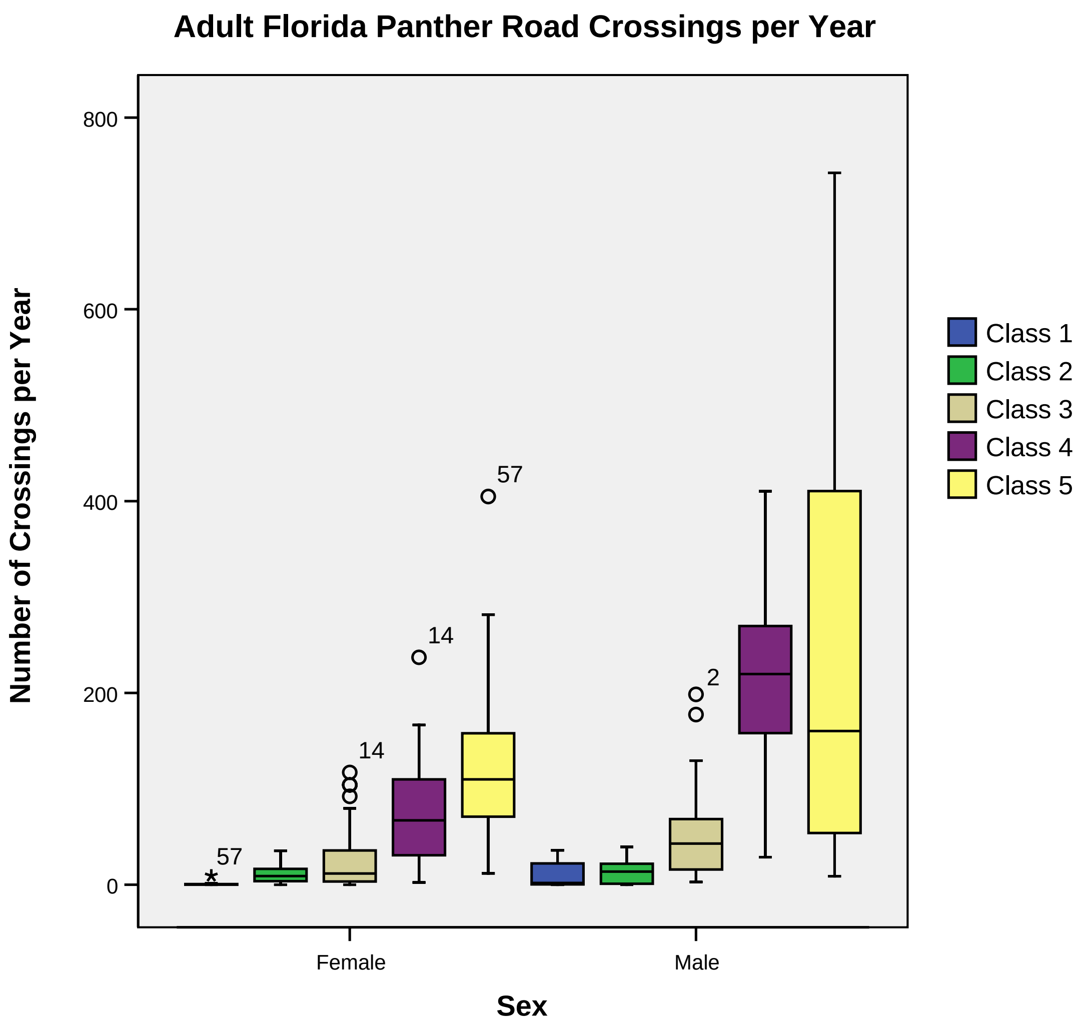


Figure 4.15: Adult Florida Panther Road Crossings per Year by Road Class. Outliers are labeled by panther ID number.

Annual crossing densities (crossings per year/km road within individual home ranges) for each road class of each individual panther were calculated and investigated for significant differences. Again, if a panther did not have any crossings for a road class because there were no roads to cross within the home range, the values were removed and reported as null, so as not to skew the results toward zero. Figures 4.16 and 4.17 show crossing densities for males and females by road type and road class. Both figures, like those preceding, depict an increase in number of crossings per kilometer of road as the road size diminishes (increase in road class number). However, females have higher crossing densities for the minor class roads (3, 4, and 5) on average than males, differing from the gender trend for total number of crossings, because female home ranges tend to have lower road densities than male home ranges.

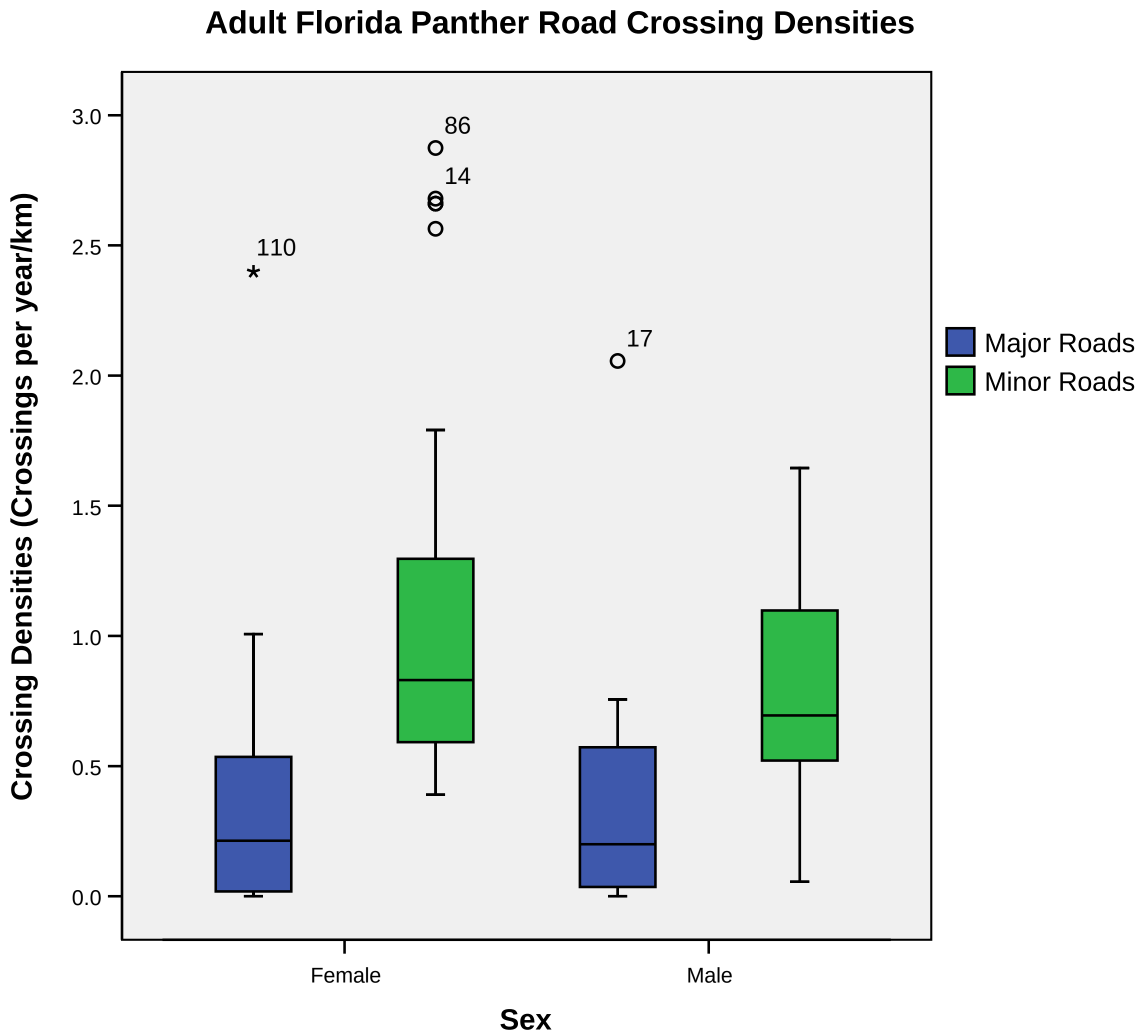


Figure 4.16: Adult Florida Panther Road Crossing Densities by Road Type. Outliers are labeled by panther ID number.

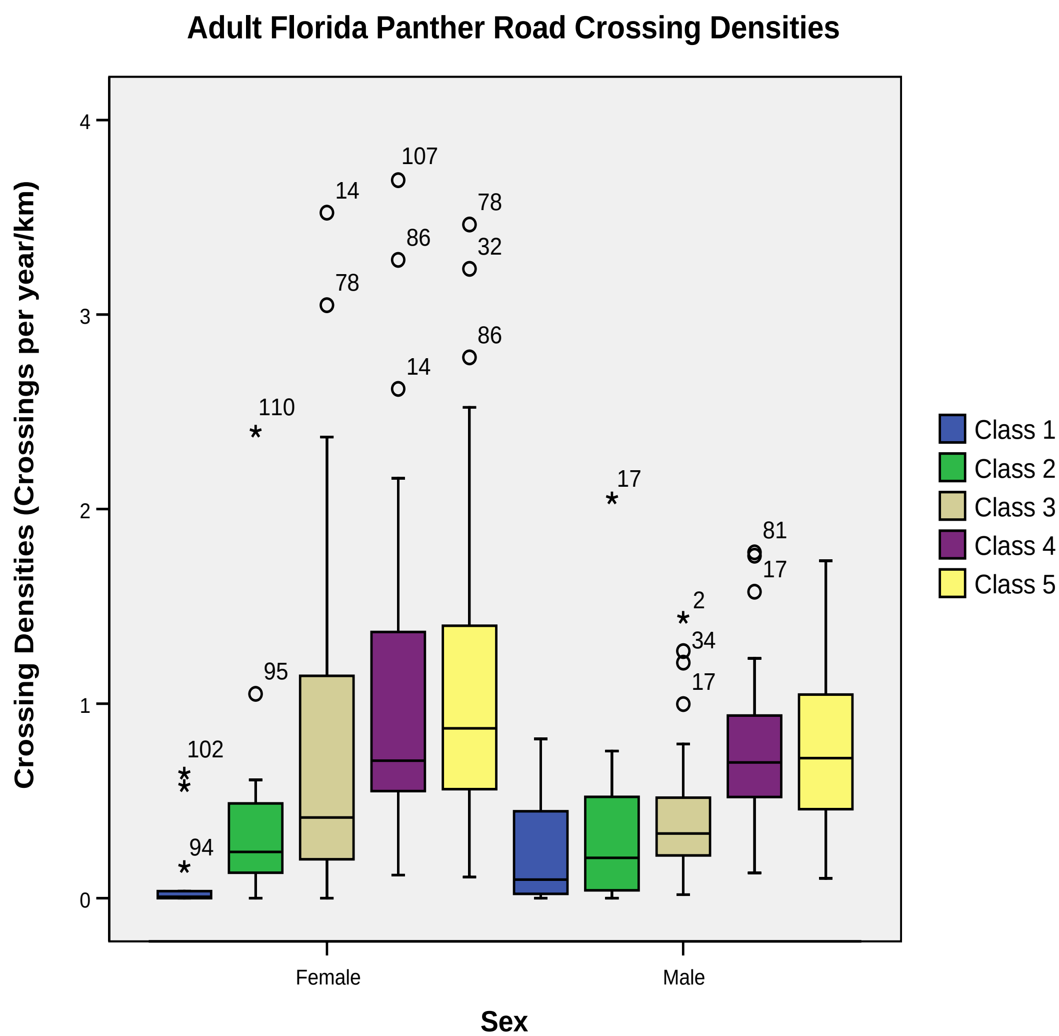


Figure 4.17: Adult Florida Panther Road Crossing Densities by Road Class. Outliers are labeled by panther ID number.

Table 4.4: Descriptive Statistics of Road Crossing Analysis.

Descriptive Statistics of Road Crossing Analysis											
Measures of Crossings		Females					Males				
		N	Minimum	Maximum	Mean	Std. Deviation	N	Minimum	Maximum	Mean	Std. Deviation
Crossings per Year	Major Roads	21	0.000	35.336	7.915	9.396	21	0.000	64.480	20.004	18.195
	Minor Roads	35	96.784	504.070	211.464	87.378	21	253.943	945.926	500.814	203.592
Crossing Densities by Type	Major Density (# per year/km)	21	0.000	2.399	0.365	0.540	21	0.000	2.056	0.376	0.459
	Minor Density (# per year/km)	35	0.200	2.874	1.030	0.701	21	0.056	1.645	0.782	0.434
Crossings per Year	Class 1	14	0.000	9.302	0.896	2.443	14	0.000	35.852	10.494	12.553
	Class 2	15	0.000	35.336	10.244	9.947	21	0.000	39.367	13.008	12.759
	Class 3	30	0.000	117.067	24.244	32.371	21	2.806	198.400	55.854	53.679
	Class 4	34	2.303	237.067	81.024	50.661	21	28.571	410.286	213.132	100.576
	Class 5	35	4.000	404.845	111.975	87.595	21	8.727	742.370	231.828	208.641
Crossing Densities by Class	Class 1 (# per year/km)	14	0.000	0.641	0.104	0.218	14	0.000	0.819	0.246	0.285
	Class 2 (# per year/km)	15	0.000	2.399	0.444	0.607	21	0.000	2.056	0.379	0.463
	Class 3 (# per year/km)	30	0.000	3.523	0.804	0.911	21	0.018	1.442	0.487	0.410
	Class 4 (# per year/km)	34	0.119	3.691	1.043	0.842	21	0.130	1.777	0.814	0.461
	Class 5 (# per year/km)	35	0.108	3.463	1.134	0.821	21	0.102	1.735	0.783	0.499

Crossing densities by road type and class were tested for significant differences within each gender using paired sample t-tests. Table 4.5 shows the results of these tests. A negative t-value indicates an increase in crossing densities as the road size decreases. For example, t-test results for major versus minor roads for both genders indicate a negative t-value, because crossing densities increased from major to minor road types (as road size decreases). In fact, almost all of the t-test values are negative, indicating a general trend of increasing crossing densities as road size decreases. The differences between the crossing densities of major and minor roads, for both genders, are both highly significant at the 0.01 level. When the crossing densities are split between the classes, however, significance is lost using these step-wise tests. The difference between contiguous classes is apparently not large enough to produce significant results. The t-test between class 3 and 4 roads for males resulted in a significant value, because a substantial number of males in the subset have home ranges that are located closer to residential areas (north of the I-75/SR29 intersection), which contain more class 4 roads than most of the remaining study area. This is also the reason for the small positive t-value for the class 4 versus 5 t-test for males. Since there is a substantial number of class 4 roads in this area, crossing densities are higher for class 4 roads than for class 5, which are associated with highly forested areas. The significance of grouping by type as opposed to class shows that both classes 1 and 2 (major roads) are both considered less desirable for crossing than minor roads as a group, and are more of a barrier for panther movement than minor roads for both males and females.

Table 4.5: T-test Results for Adult Florida Panther Crossing Density Analysis.

T-test Results for Adult Florida Panther Crossing Density Analysis				
Female	N	t	p-value	df
Major - Minor	21	-3.850	0.001**	20
Class 1 - Class 2	8	-2.038	0.081	7
Class 2 - Class 3	15	-1.379	0.189	14
Class 3 - Class 4	30	-1.212	0.235	29
Class 4 - Class 5	34	-0.745	0.462	33
Male	N	t	p-value	df
Major - Minor	21	-3.412	0.003	20
Class 1 - Class 2	14	-0.741	0.472	13
Class 2 - Class 3	21	-0.846	0.407	20
Class 3 - Class 4	21	-6.943	0.000**	20
Class 4 - Class 5	21	0.304	0.764	20

** = significant at 0.01

4.4 Barrier Effect of Roads and Forest on Panther Movement

To capture the impact of roads as barriers to movement, the area just outside of the panther's selected habitat was explored for both forest and road density changes. This makes it possible to include those panthers which never cross a major road but whose home range is immediately adjacent to it. Road density (km/km^2) by type and class were calculated within the home range and within a 1 km buffer area just outside of the home range. If both the home range and the buffered area did not contain a type or class of road, then the values were entered as *null* to avoid bias toward a zero difference. Differences between these road densities, by type and class, were compared using a one-sample t-test against a mean of zero.

Because forest density is so important to panther daytime habitat selection, forest densities (as a percentage of total area) inside the home range and within the buffered area were also compared using the same statistical methods.

Figures 4.18 and 4.19 illustrate road and forest densities, respectively, within the individual panthers' home ranges. Figure 4.18 shows little apparent gender difference between calculated road densities for both road types, but there are much higher values for minor road densities than major roads. In Figure 4.19, there is a definite distinction in terms of forest densities (see Table 4.6 for descriptive statistics of road and forest densities). Female home ranges have higher average forest densities than males. It has been suggested that forest cover is a good predictor of panther habitat selection, but high variability in both male and female forest densities indicates that forest cover alone is an insufficient predictor for habitat selection.

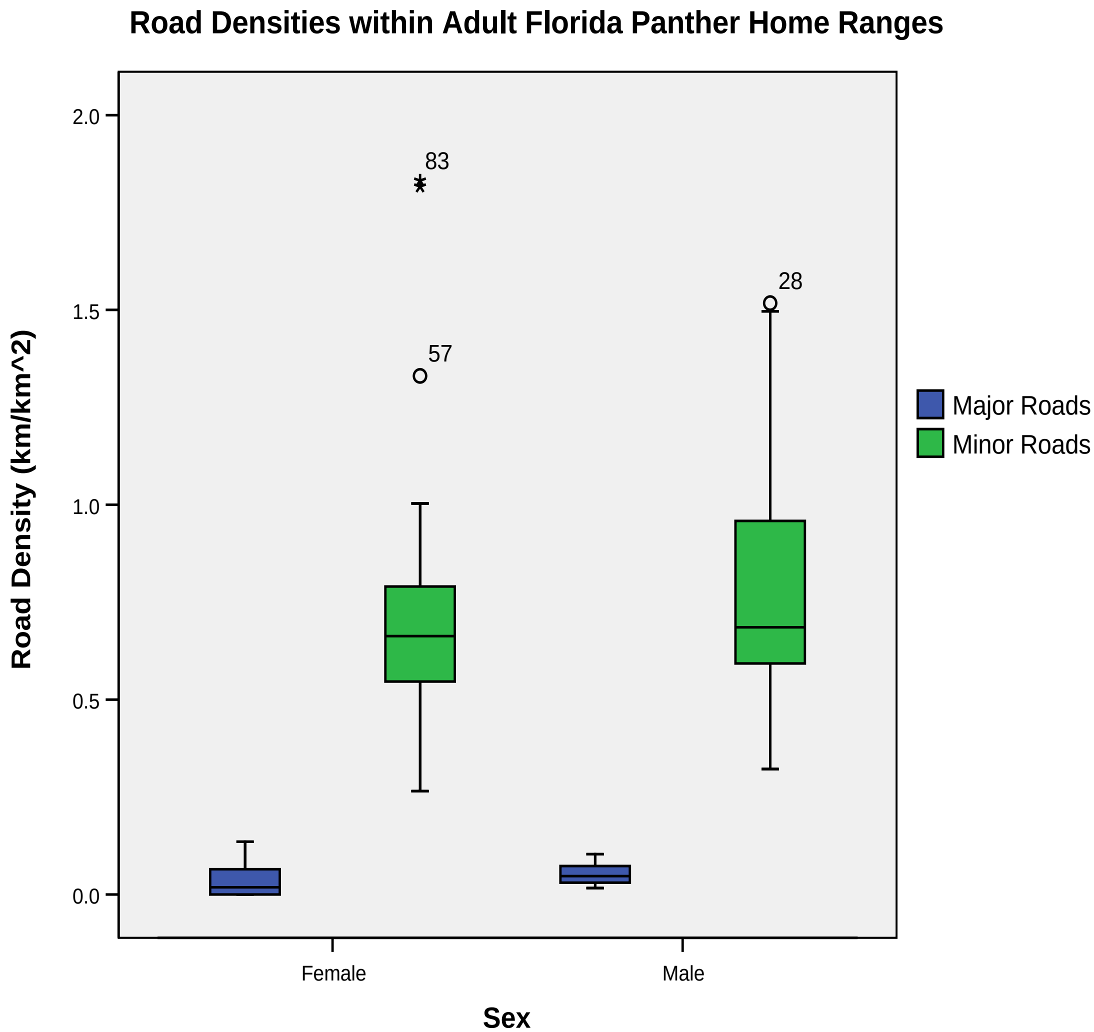


Figure 4.18: Road Densities within Adult Florida Panther Home Ranges. Outliers are labeled by panther ID number.

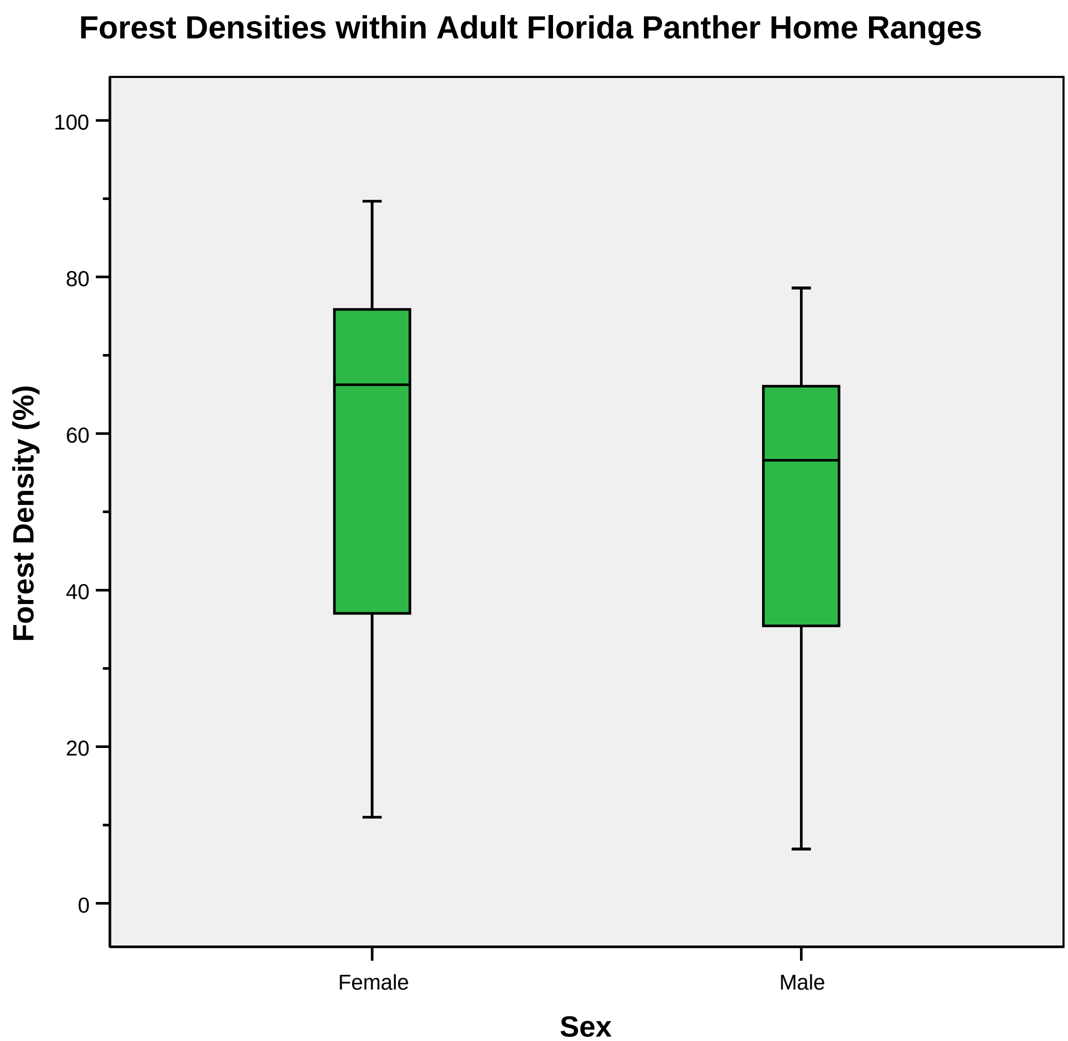


Figure 4.19: Forest Densities within Adult Florida Panther Home Ranges. Outliers are labeled by panther ID number.

Differences in road and forest densities between the home range and buffered area were calculated and tested for significant differences using a t-test against a mean of zero across the subset population (see Table 4.7 for descriptive statistics on density differences analysis.) Figure 4.20 shows the differences in road densities by road type and by gender. According to this box-plot, major road densities are higher, more often than not, within the buffer area than within the home range for both males and females. Minor road densities reveal an opposite, but weaker, trend. Figure 4.21 shows road density differences by class in box-plot form, and illustrates a general trend for both genders from higher densities in the buffer area than in the home range for major classes to lower densities in the buffer area than in the home range for minor classes. This suggests that panthers frequently establish home ranges that do not include the adjacent major road network and that the major roads frequently have a greater barrier effect on panther movement patterns than minor roads.

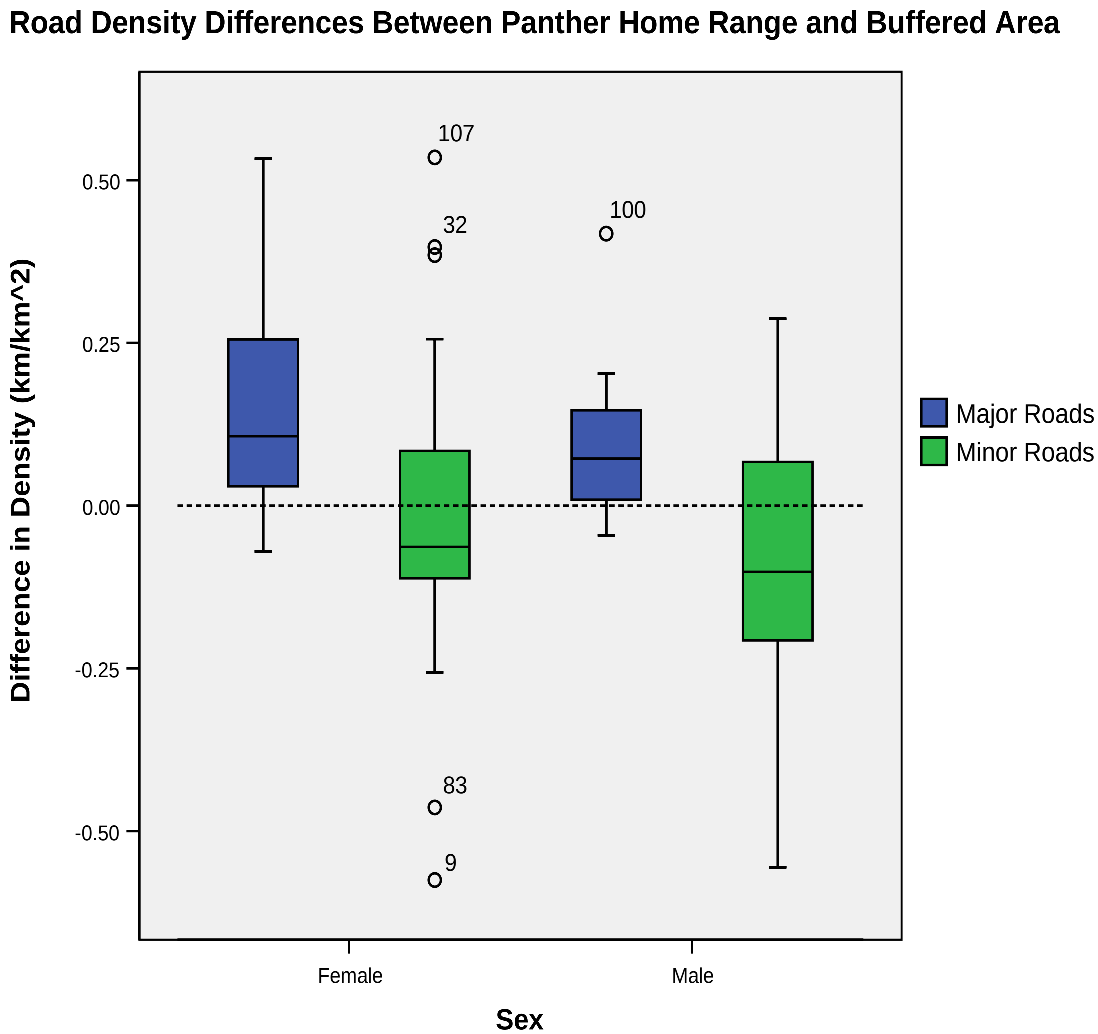


Figure 4.20: Road Density Differences by Type between Panther Home Range and Buffered Area. Outliers are labeled by panther ID number.

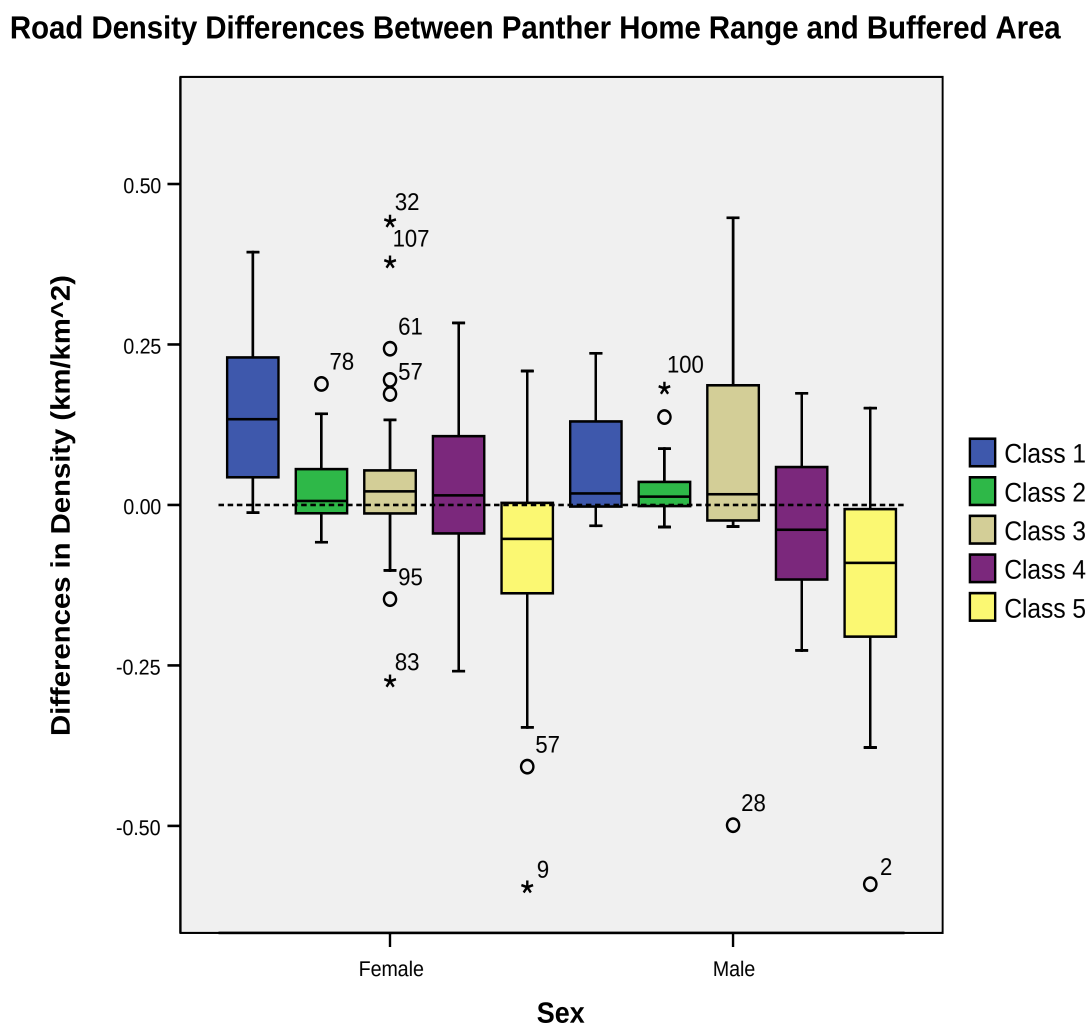


Figure 4.21: Road Density Differences by Class between Panther Home Range and Buffered Area. Outliers are labeled by panther ID number.

Table 4.6: Descriptive Statistics of Road and Forest Densities within Panther Home Ranges.

Descriptive Statistics of Road and Forest Densities within Home Ranges											
Measures of Density		Females					Males				
		N	Minimum	Maximum	Mean	Std. Deviation	N	Minimum	Maximum	Mean	Std. Deviation
Density by Type	Major Roads	35	0.000	0.135	0.035	0.040	21	0.017	0.104	0.052	0.027
	Minor Roads	35	0.266	1.832	0.717	0.346	21	0.322	1.518	0.797	0.324
Density by Class	Class 1	35	0.000	0.052	0.008	0.013	21	0.000	0.061	0.018	0.019
	Class 2	35	0.000	0.135	0.027	0.039	21	0.004	0.097	0.034	0.020
	Class 3	35	0.000	1.051	0.115	0.220	21	0.016	0.972	0.185	0.223
	Class 4	35	0.000	0.528	0.287	0.173	21	0.030	0.485	0.323	0.142
	Class 5	35	0.033	0.734	0.315	0.192	21	0.039	0.855	0.289	0.203
Forest Density	Density (%)	35	10.985	89.671	58.028	24.192	21	6.923	78.595	51.745	18.874

Table 4.7: Descriptive Statistics of Density Differences Analysis.

Descriptive Statistics of Density Differences Analysis											
Measures of Density (Buffered Area - MCP Area)		Females					Males				
		N	Minimum	Maximum	Mean	Std. Deviation	N	Minimum	Maximum	Mean	Std. Deviation
Difference by Type	Major Roads	30	-0.070	0.533	0.149	0.158	21	-0.045	0.418	0.088	0.109
	Minor Roads	35	-0.575	0.535	-0.018	0.223	21	-0.555	0.287	-0.085	0.226
Difference by Class	Class 1	26	-0.012	0.394	0.150	0.115	19	-0.032	0.236	0.066	0.086
	Class 2	23	-0.058	0.188	0.025	0.066	21	-0.034	0.182	0.028	0.053
	Class 3	33	-0.275	0.442	0.039	0.135	21	-0.499	0.447	0.060	0.185
	Class 4	35	-0.259	0.283	0.023	0.123	21	-0.226	0.174	-0.031	0.111
	Class 5	35	-0.595	0.208	-0.077	0.151	21	-0.591	0.151	-0.114	0.173
Forest Density	Density Difference (%)	35	-21.390	7.190	-7.499	6.832	21	-19.840	10.610	-8.717	7.235

Forest densities were also calculated and compared between home ranges and buffered areas for both males and females, since it has been suggested that forest density is a reliable panther daytime habitat predictor. Overall forest densities are lower, on average, for both males and females (Figure 4.22) just outside of their home ranges, although variability in the differences is high.

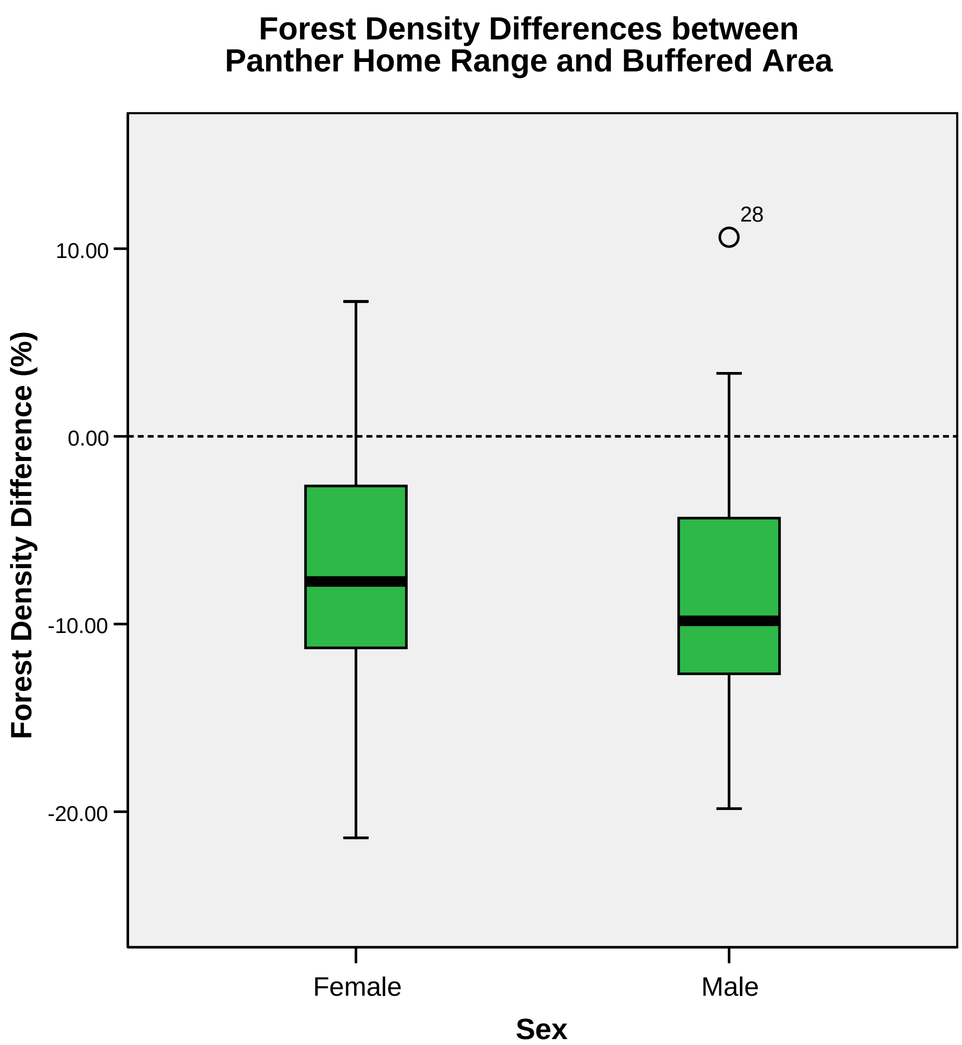


Figure 4.22: Forest Density Differences between Panther Home Range and Buffered Area. Outliers are labeled by panther ID number.

One sample t-tests against a mean of zero were performed on the differences in road densities by type and class and forest densities. Summary statistics are shown in Table 4.8. A positive t-value indicates an increase in density from the home range to the buffered area, and a negative t-value indicates a decrease in density. For example, the t-values for the major road density difference tests for both genders are positive, indicating an increase in major road densities from within the home range to the buffered area. Alternatively, the t-values for the minor road density difference tests for both genders are negative, indicating a decrease in minor road densities from within the home range to the external buffered area.

Results for both major roads and class 1 roads are significant at the 0.01 level of significance for both genders. This indicates that major roads, specifically class 1 roads, are frequently located just outside of a panther's home range, suggesting a substantial influence on movement between habitats. The t-value for females for class 1 roads is twice that of males, indicating a stronger barrier effect on movement and habitat selection for female panthers. Results for minor roads and class 2, 3, and 4 roads are not significant at the 0.01 level for either gender. Results for class 5 roads are significant at the 0.01 level for both genders, but show a decrease in densities from the home range to the buffered area. Class 5 roads include trails and remote access roads that are usually found in highly forested areas, and it supplements the findings of higher forest densities within the home ranges as opposed to inside the buffer. Forest density changes (decreases) are also found to be significant, as expected, since forest is necessary for panther survival.

Table 4.8: One Sample T-test Results for Density Difference Analyses.

One Sample T-test Results for Density Difference Analysis								
Measures of Density (Buffered Area - MCP Area)		Female			Male			
		N	t	Significance	N	t	Significance	
Road Type	Major	30	5.167	0.000**	21	3.725	0.001**
	Minor	35	-0.475	0.638	21	-1.726	0.100
Road Class	Class 1	26	6.654	0.000**	19	3.353	0.004**
	Class 2	23	1.821	0.082	21	2.442	0.024*
	Class 3	33	1.646	0.109	21	1.478	0.155
	Class 4	35	1.095	0.281	21	-1.290	0.212
	Class 5	35	-3.022	0.005**	21	-3.008	0.007**
Forest Density		35	-6.494	0.000**	21	-5.521	0.000**

** = significant at 0.01
* = significant at 0.05

Since both forest cover and major roads were found to be significant in terms of the density difference between the home ranges and buffered areas for both genders, the two measures of density differences were plotted against each other on a graph to uncover any trends in the two types of barriers. Figure 4.23 shows these plotted values, and the meaning of each quadrant of the scatterplot is briefly described along with an assigned panther ID number for ease of discussion.

Any panthers plotted in quadrant one would indicate an individual for which roads and lack of forest are not considered barriers. Markedly, quadrant one contains no plotted individuals, indicating that there are no panthers in the telemetry subset for which roads and lack of forest cannot be considered barriers to movement. In short, all individuals in the telemetry subset live in home ranges that are either surrounded by higher road densities or lower forest densities.

Quadrant two indicates panthers for which roads are a barrier, but lack of forest is not. Male panther 28 for example, is located in the second quadrant of the plot, indicating that there was an increase in road density outside of his home range but an increase in forest density as well. In this case, roads can be considered a barrier for his movement, but lack of forest is not since the surrounding habitat is well forested.

Quadrant three indicates panthers for which both roads and lack of forest can be considered barriers to movement. Most of the panthers in the subset fall in this quadrant, where the road density increased and the forest density decreased outside of the home ranges for each individual. Female panthers 107 and 78, discussed earlier, for example, are to the most extreme right of the graph, as their home ranges were elongated against the intersection of I-75 and SR29. A gender difference is apparent here as there are a high number of females at the right of this quadrant of the graph, towards large values for road density difference. This indicates that those individuals that have home ranges for which lack of forest and roads are the most substantial barrier are mostly female.

Quadrant four reveals individuals for which major roads are not a barrier, but lack of forest is. These panthers' home ranges show a decrease in major road density and a decrease in forest cover from home range to buffered area.

These results indicate that for most panthers, both major roads and lack of forest cover present possible barriers, making it very difficult to determine the relative importance of each. A more detailed analysis would be required to pull apart the significance of each as barriers to movement and habitat selection.

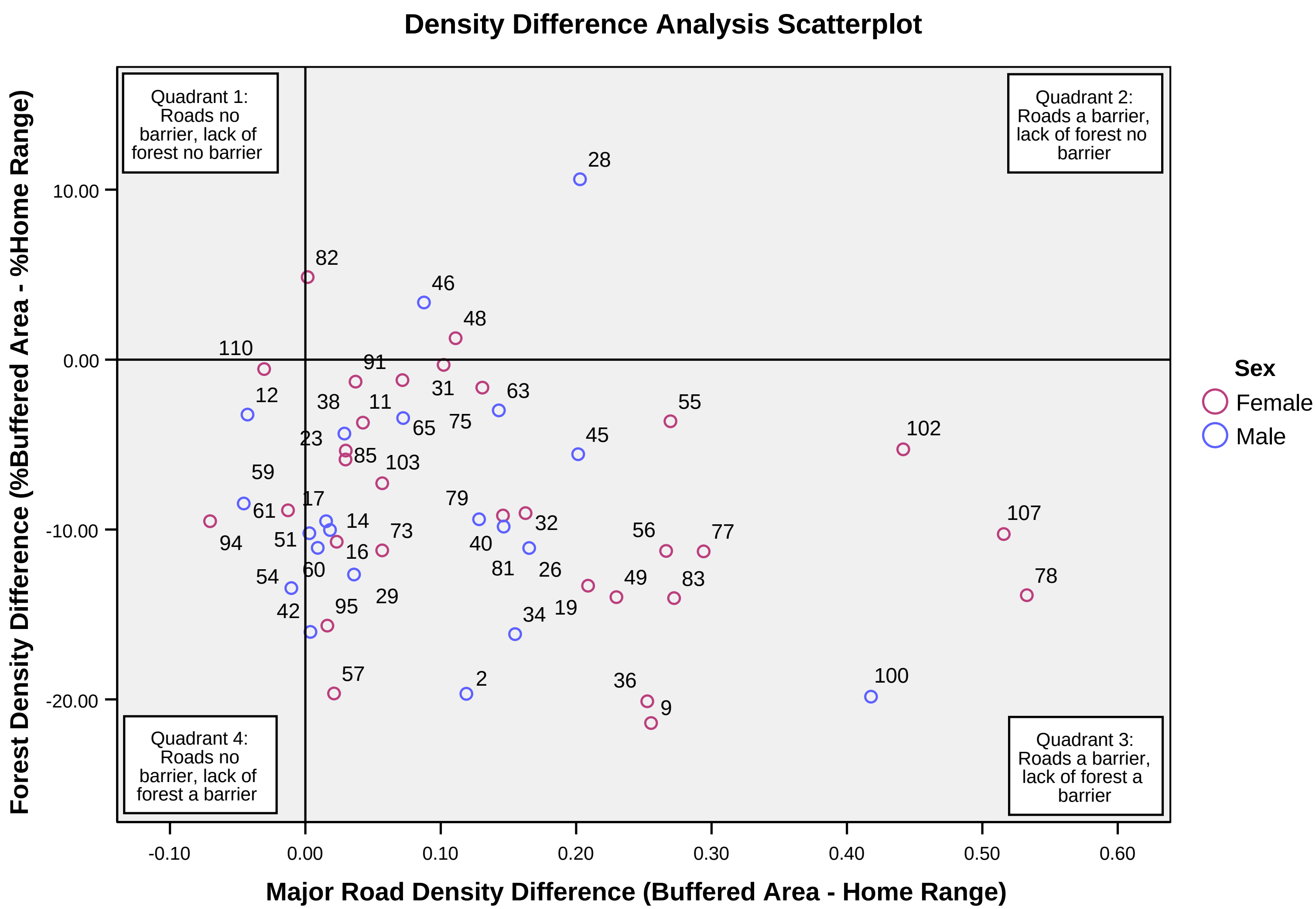


Figure 4.23: Density Difference Analysis Scatterplot. Points are labeled by panther ID number.

4.5 Effectiveness of Preventative Measures

In an attempt to provide safe crossings for local wildlife and to mitigate vehicular mortalities, a series of wildlife underpasses and fencing were constructed in 1993 along the I-75 corridor that stretches through preserved lands and in 1995 on a small portion of SR29, just north of I-75. Designed specifically to facilitate road crossings of the Florida panther, these measures have been exemplary at mitigating local vehicular mortalities (Foster and Humphrey, 1995). According to several investigations (Foster and Humphrey, 1995; Lotz et al., 1997), use of these underpasses by Florida panthers, however, varies with location.

There are two types of wildlife underpasses in use within the Florida panther habitat. The first is designed for the four-lane divided highway of I-75, completed in 1993, and consists essentially of a set of two bridges (one for each half of the highway) that are each 36.6 meters long and 13.1 meters wide from shoulder to shoulder (Foster and Humphrey, 1995). These two underpasses are separated by the median, which remains open overhead for 22.3 meters, and the entire structure is fenced with a 3 meter high chain link fence topped with three strands of barbed wire to keep wildlife from crossing the right-of-way (Foster and Humphrey, 1995). From the perspective of the potential crossing animal, the entire underpass (including open median) is approximately 25 meters wide at ground level and 48.5 meters long, from habitat to habitat (Foster and Humphrey, 1995). This series of underpasses and fencing stretches along 64 km of I-75, through several areas of preserved land.

The second type of underpass is in use on SR29, just north of the intersection of I-75, and is much smaller than the first, as it is intended for two lane highways. Construction was completed in 1995 and they were designed out of a need for a less expensive alternative for more rural roadways. These underpasses consist of concrete culverts 2.4 meters high, 7.3 meters wide, and 14.6 meters long that rest at ground level as the roadway rises gradually over the structure (Lotz et al., 1997). These structures are also accompanied by the same fencing as the larger underpass type, and extends 1.9 km north of the most northern wildlife crossing, for at total of 6.4 km of fencing north of the I-75/SR29 intersection (Lotz et al., 1997).

An examination of the FFWCC panther mortality data and the locations of those wildlife underpasses and stretches of fenced highway reveal that there have been no deaths on the stretch of I-75 that contains wildlife underpasses and high fencing since 1993, when the wildlife underpasses were constructed (see Figure 4.24). Before the construction, there were 7 vehicular mortalities between 1979 and 1990 on this stretch of protected highway. Additionally, the FFWCC (2001) claims that no panthers have been killed by vehicle collision on the over 40 miles of highway that include the right-of-way fencing and wildlife underpasses since their construction. SR29 contains two underpasses just north of I-75 and 6.4 km of fencing, but there are still frequent vehicular mortalities on the rest of the roadway. Both north and south of the fencing and underpasses, most of the road is open to wilderness. Figure 4.24 shows two vehicular mortalities, within 400 meters of each other, on SR29 just north of the right-of-way fencing and underpasses, suggesting these panthers walked the length of the fences until they found an opening to cross. These vehicle collision deaths continue to occur on nearby state and county roads (see Figure 4.12), even with the introduction of lower night-time speed limits on SR29 specifically designed for the panther's protection. These night-time speed zones should help reduce vehicular fatalities, but they do not prevent the panther from entering the highway corridor (FFWCC, 2001).

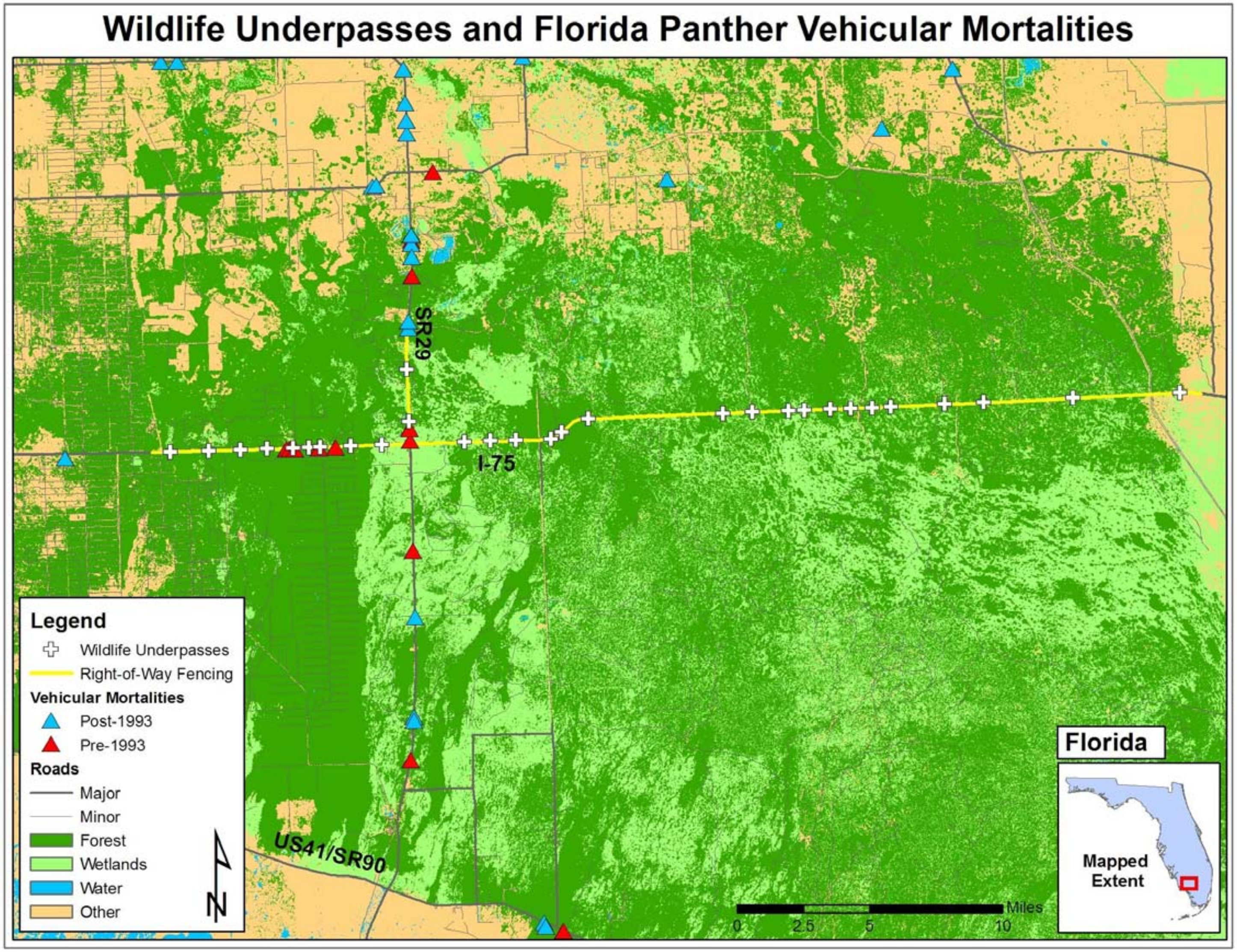


Figure 4.24: Wildlife Underpasses and Florida Panther Vehicular Mortalities.

The rate of panther road mortalities and location and shape of adjacent home ranges, as determined through the use of the telemetry dataset, were compared before and after the installation of the right-of-way fencing. The panthers whose home ranges are adjacent to the major road network with the underpasses and fencing show some unique movement patterns and home range shifts. Table 4.9 shows for all the panthers whether or not they crossed I-75 during lifetime movement paths and whether or not the crossings occurred before or after the underpass construction of 1993. The panthers were divided into three categories based on the telemetry record: those that had records only pre-1993, both pre and post-1993, and just post-1993. This table also reports those individuals whose telemetry record never came within 2km of I-75, and should not be considered to have been affected by the interstate as a barrier since their home ranges were established at a greater distance. There were two females that were recorded to cross only one time[10], both of which were counted as "never crossed." Considering this is one incident out of an entire telemetry record for each individual and the inherent error in the telemetry dataset, this one crossing cannot be counted as an indication of habitual interstate crossings.

[10] The single telemetry locations not counted as crossings for these two panthers were 280 and 890 meters from I-75.

Table 4.9: Florida Panthers that Crossed Interstate75.

Florida Panthers that Crossed Interstate 75						
Time Period	Scenarios	Males	Males (>2km)	Females	Females (>2km)
Pre 1993	Crossed	-	-	-	-
	Never crossed	3	1	-	2
Pre/Post 1993	Never crossed	5	-	11	-
	Crossed before only	1	-	-	-
	Crossed after only	-	-	-	-
	Crossed before and after	1	-	-	-
Post 1993	Crossed	3	-	2	-
	Never crossed	3	4	7	13
Totals		16	5	20	15

Examination of the home ranges adjacent to the underpass corridor uncovered a substantial difference in gender. Results of this table indicate that out of 20 females within close quarters of the interstate, only two had crossed on a regular basis. In fact, the majority of the individuals within close range of the interstate are females that never cross, either before or after the construction. Out of the post-1993 group, an equal number of males crossed and did not cross the interstate, but a much smaller proportion of females crossed than did not cross.

For example, Figure 4.25 shows annual home ranges and telemetry points for Florida panther 9. This female had a telemetry record that indicates no recorded crossings over I-75, despite the fact that her established habitat was right against the roadway from 1985-1988, after which her home range shifted south. These years are also pre-underpass construction, so the roadway (then only referred to as Alligator Alley) was not fenced as it is today to restrict wildlife movement across the right-of-way. The previously described elongated home ranges, shown in Figures 4.4 to 4.6, are also part of this group of female panthers that never cross I-75. They also show the same “caged effect” as the panthers spend more time along the highway than in the rest of the home range, but do not cross, according to the records, despite ample forested habitat on the other side.

Males, alternatively, crossed more frequently with a total of five panthers out of 16 that crossed either before and/or after the construction the underpass corridor. Figure 4.26 shows the telemetry record and home ranges for Florida panther 54, which frequently crosses I-75. This individual’s home range includes large portions of I-75 and regularly spends time on both sides of the highway. Considering the fencing along I-75 in this area, it can only be assumed that this male panther, and others that follow this trend, frequently use the underpasses available.

There is one male with a telemetry record which indicates a change in crossing behavior before and after the construction of the underpass corridor. Figure 4.27 shows the telemetry record and annual home ranges for male Florida panther 12, which indicates frequent crossings over I-75 from 1986-1992. During and after the construction (1993) of the fencing and underpass combination in this area, however, the panther’s home range shifted north and there were no more recorded crossings over I-75 despite the measures to connect the two habitats and simultaneously mitigate mortalities. There is an obvious change in his movement patterns and an unmistakable shift in his annual home range that coincides with the construction of the fencing and underpass combination.

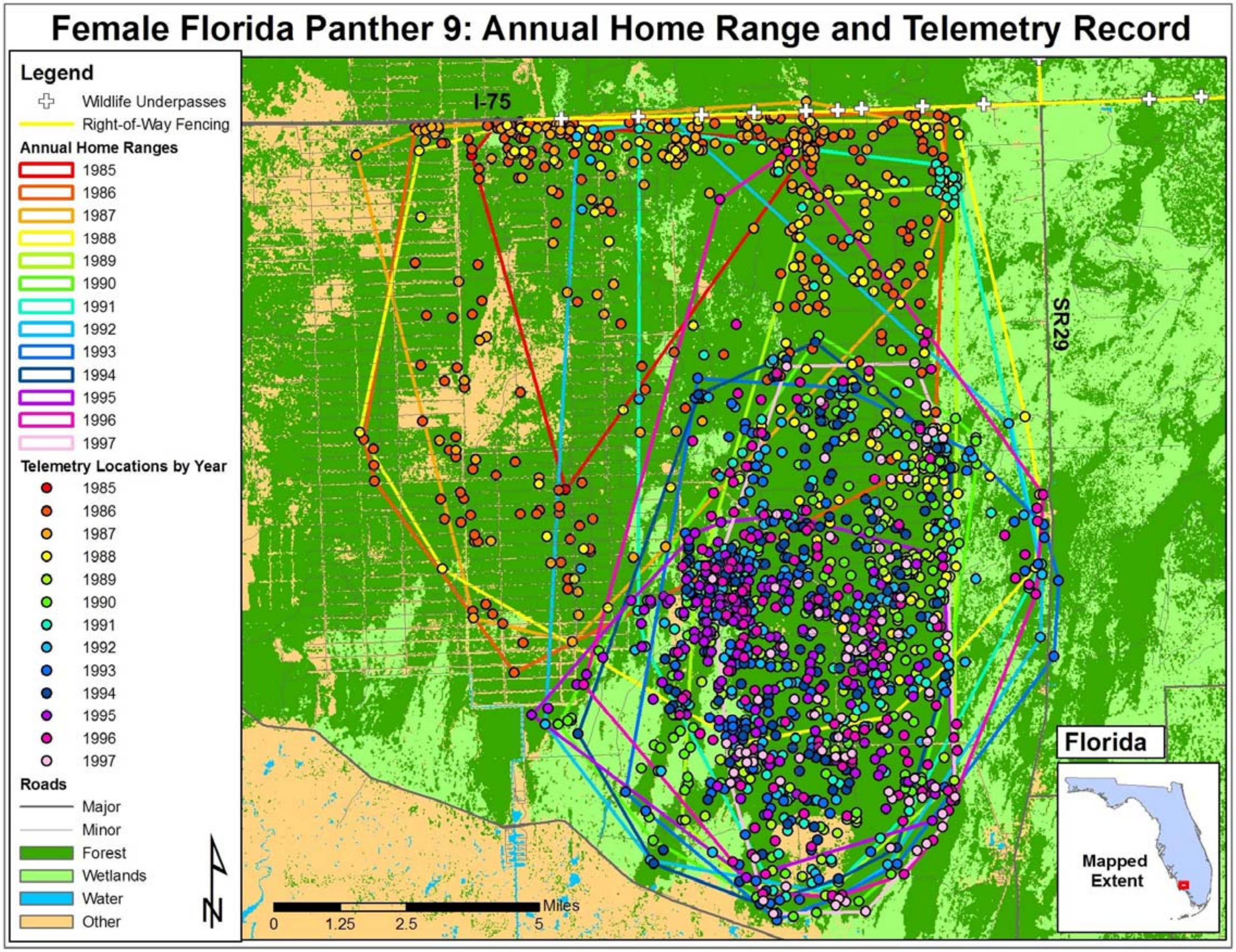


Figure 4.25: Female Florida Panther 9: Annual Home Ranges and Telemetry Record.

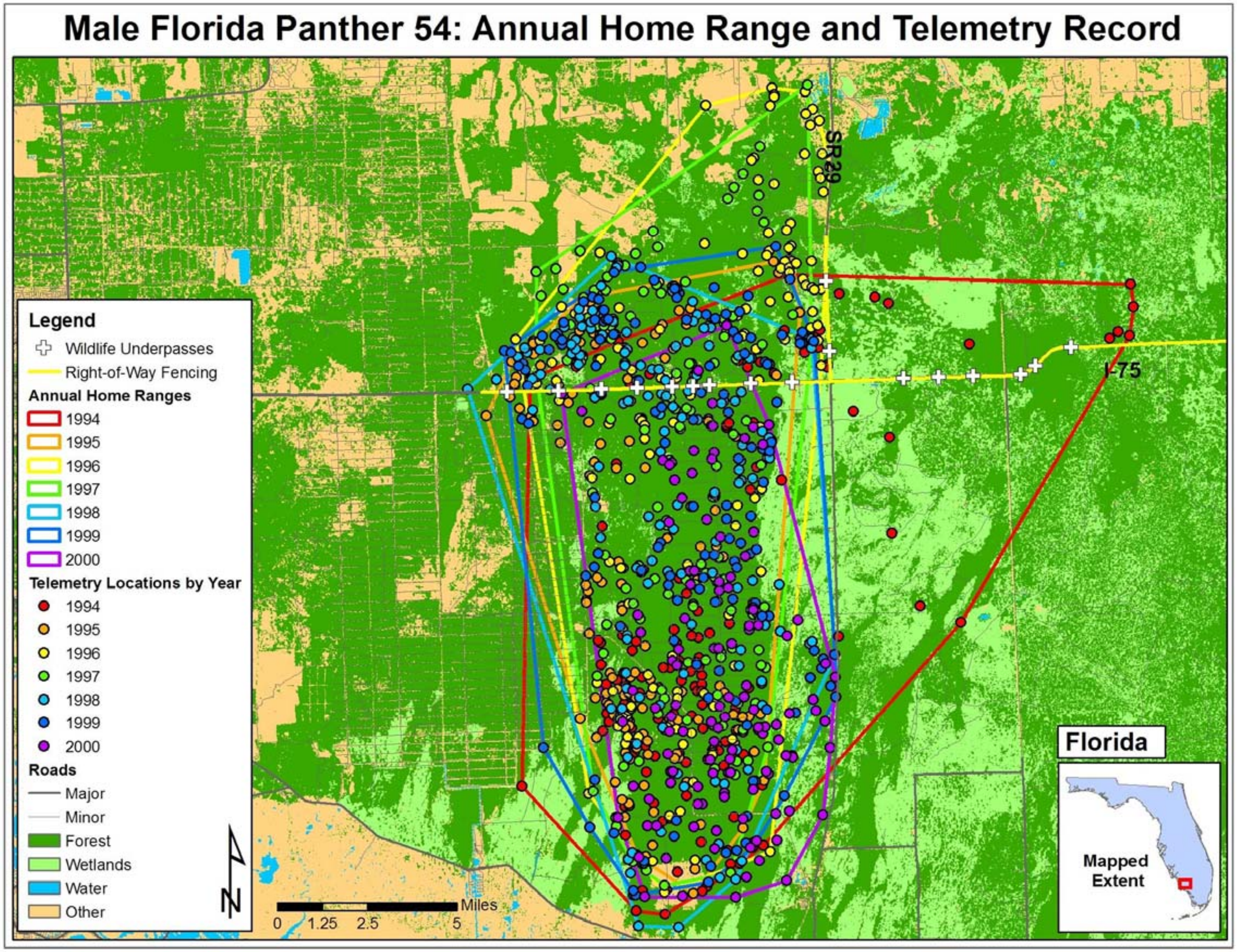


Figure 4.26: Male Florida Panther 54: Annual Home Ranges and Telemetry Record.

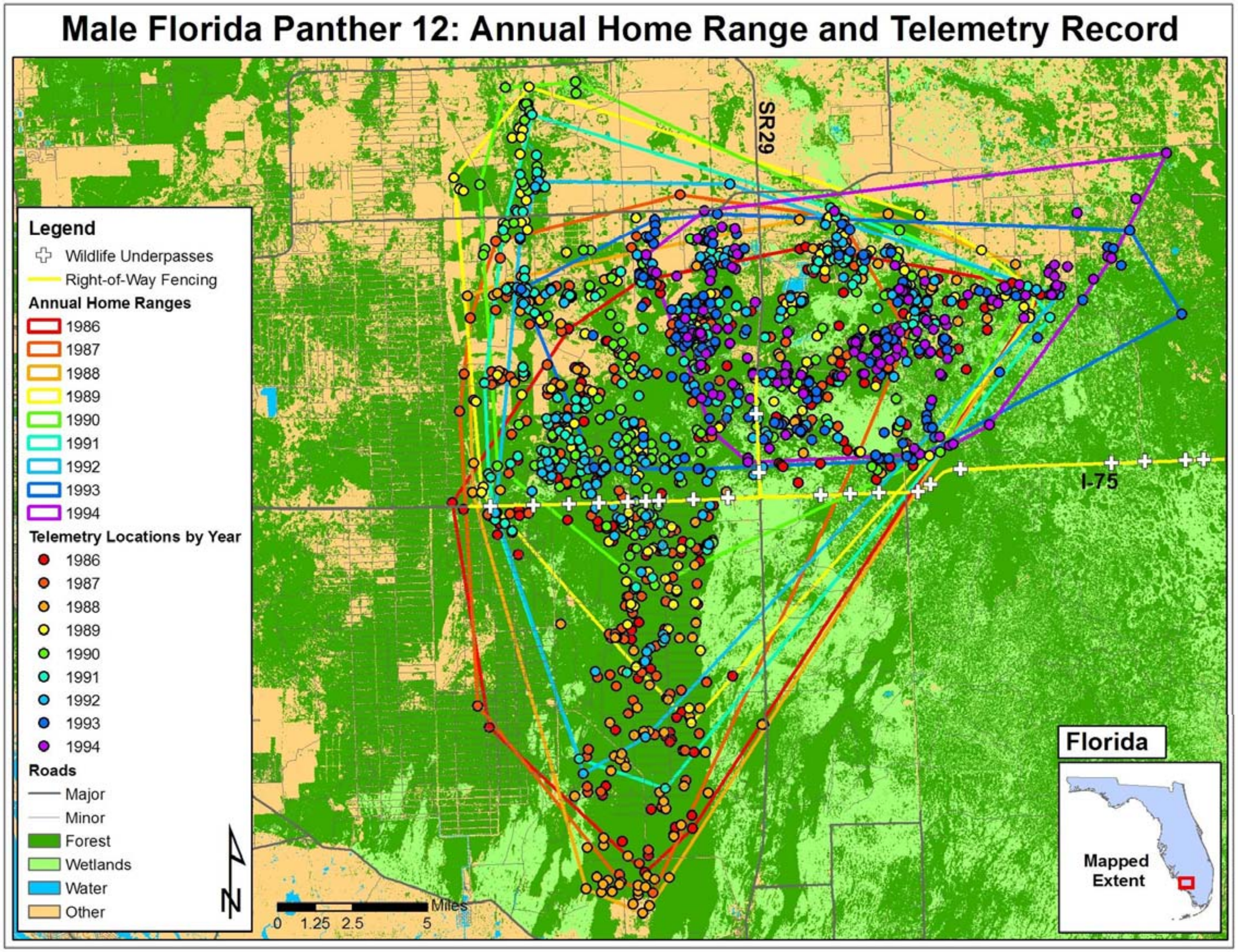


Figure 4.27: Male Florida Panther 12: Annual Home Ranges and Telemetry Record.

Territoriality and intraspecific interactions may be a deterrent for many panthers to use the wildlife underpasses, in particular for females. Foster and Humphrey (1995) monitored underpasses most likely to be used by panthers, and recorded only a few individuals frequently using the same underpasses, despite the fact that the surrounding area has a relatively high panther population. This may also deter female movement through panther-friendly underpasses “claimed” by males, or other females, that frequent specific crossings.

Results of this examination indicate that the individual panthers in the telemetry subset either use the wildlife underpasses frequently or avoid crossing the highway altogether. Many females have home ranges that demonstrate confinement, even in areas without the underpass and fencing construction. More males are willing to cross areas with underpasses to access additional habitat, but this part of the population is small. It appears that females rarely crossed Alligator Alley to begin with and the addition of the underpass corridor of I-75 did nothing to change this.

The combination of wildlife underpasses and high right-of-way fencing initially appears an ideal measure to prevent vehicle collision mortalities of the Florida panther because there have been no mortalities since their construction. However, analysis of the telemetry data for individual panthers shows that a large number of panthers do not use the available underpasses and their home ranges become elongated along the highway corridors as they search for additional territory. For a substantial part of the population, many of them female, these fenced roadways not only fragment the limited habitat of the Florida panther but also separate some of the adult population critical to the propagation of the species.

Chapter Five

Conclusions

While it has been well established that the most important threat to panthers include limited habitat area and continued habitat loss and fragmentation, the importance of roads in this context had not been determined prior to this study. This investigation has utilized several forms of analysis to uncover different types of influence that the road network has on the movement patterns of the remaining Florida panther population of south Florida.

The general characterization of Florida panther home ranges was investigated through the use of a select subset from the panther telemetry dataset, a local road network, and a land cover grid. Males have significantly larger average home ranges than females, both annual and lifetime. Several individuals located adjacent to the major road network show an elongation of their home range, essentially shaped to fit the surrounding road network. This “caged effect” is most striking in the cases of females, specifically along the wildlife underpass corridor of I-75. This strongly suggests roads as barriers to movement, even with the availability of constructed safe crossings.

The influence of vehicular mortalities on a population already struggling for survival is substantial. An investigation of the Florida panther mortality dataset revealed that vehicular mortalities contribute a considerable twenty percent to the overall mortality rates of radiocollared cats. It can be speculated that a similar rate applies to the population of uncollared Florida panthers as well. With an estimated total population of a little over 100 adults, 40 vehicular mortalities (collared and uncollared) since the year 2000 is considerable. The use of wildlife underpasses in conjunction with right-of-way fencing is very effective at reducing road mortality, but has not mitigated the substantial barrier effect of major roads.

Spatial trends include a gender difference in distribution, where male vehicular mortalities are less clustered than females, most likely due to greater dispersal behavior of males. For both genders, however, SR29 is a major "hotspot" for vehicular mortalities. Additionally, major roads (classes 1 and 2) contain the highest ratio of deaths per kilometer within the study area, and are a major contributor to vehicular mortalities. Demographically, adult males seem to be most at risk in terms of road mortality, while females and juveniles of both genders total fewer deaths and injuries over time.

The movement patterns of panthers in conjunction with an underlying road network were examined through a survey of crossing behavior. This analysis showed that major roads influence panther movement more than minor roads for both genders.

Crossing density was determined as the number of crossings by a panther per year per km of road in each individual panther's home range. The increasing crossing densities with decreasing road size trend was evident for both genders, although females had higher crossing densities than males because of overall lower road densities in female home ranges. A series of paired-sample t-tests between crossing densities of road types and classes revealed significant results for the difference between major and minor road crossing densities for both genders, although this significance was lost when the analysis was split by class. Major roads, in the crossing behavior analysis, proved to have a greater barrier effect on Florida panther movement than minor roads, particularly for females.

Road and forest densities within home ranges and a buffered area were examined to identify any barrier effects on panther movement. Females had higher forest densities than males within home ranges, but road densities, both major and minor, were relatively similar. The differences in road densities between the home range and the buffered area were significant for major and class 1 roads for both genders. This indicates major roads, specifically class 1 roads, are frequently located just outside of a panther's home range. The results also pointed toward a stronger barrier effect for female panthers on movement and habitat selection than males. This suggests that panthers frequently establish home ranges that do not include the adjacent major road network and that the major roads are a greater barrier for panther movement patterns and minor roads are not. Forest density differences were also found to be significant, as most panthers of both genders live in home ranges that contain higher forest densities than the surrounding area.

Plotting major road density difference and forest density difference revealed that most panthers are located in the third quadrant, indicating that for most panthers both roads and lack of forest represent possible barriers to movement. There was also a slight gender difference in that those individuals that have home ranges for which lack of forest and roads are the most substantial barrier are mostly female. These results indicate that for most panthers, both major roads and lack of forest cover present possible barriers, making it very difficult to determine the relative importance of each.

Overall, these analyses point to substantial gender differences in several aspects. Female panthers suffer less from vehicular mortalities of the radiocollared population and have smaller average home ranges with higher forest densities. They also avoid crossing major roadways more often than males, even with the presence of safe crossings through wildlife underpasses. Adult males have higher road mortalities, and larger home ranges with slightly lower forest densities than females. They also cross roads, both minor and major, more often than females, suggesting they are the “risk takers” of the population. Major roads form a more significant barrier than minor roads for both genders, although for females the effect is strongest.

The preventative measures of right-of-way fencing and wildlife underpasses on the corridor of I-75 have been ideal for the mitigation of vehicular mortalities of the Florida panther. These measures, however, have not successfully bridged the fragmented habitat and the road remains a barrier. Examination of shape and location of home ranges and telemetry records of the subset have revealed that most panthers do not use the available crossings. In fact, the majority of the individuals within close range of the interstate are females that never cross, despite ample forest cover on both sides. More males cross areas with underpasses to access additional habitat, but this represents a small part of the population. For a substantial part of the population, many of them female, these fenced roadways not only fragment the limited habitat of the Florida panther but also separate some of the adult population critical to the propagation of the species.

Although this investigation covers several aspects of the influence of roads on the movement of the Florida panther, there are still many gaps to be filled with further research. For example, this study did not incorporate any data for juvenile panthers, since the movement patterns and home ranges differ from that of adults. It is necessary not only to determine the influence of roads on the juvenile Florida panther, but to determine vulnerability to roads of this important age group as well.

Using the methods in this investigation, the barrier effects of roads and lack of forest are difficult to separate. A deeper analysis to determine directionality and strength of this barrier effect would determine more meaningful estimates of these separate influences.

Steps should also be taken to utilize GPS tracking to determine the influence of roads. Most importantly, the use of GPS would result in the increase of data collection. GPS tracking would facilitate the use of location records for every hour, for example, and the researcher would be able to calculate a much more accurate movement path that could indicate near exact road crossings and estimates for times of those crossings. Additionally, this would allow for nocturnal locations and movement patterns to be determined and analyzed for the influence of roads and compared to diurnal movement patterns. The addition of nocturnal data and movement patterns would be incredibly significant for panther research, since they are most active during night hours.

Florida panther use of the combination of the wildlife underpasses and right-of-way fencing should also be investigated in further depth. Using the current telemetry dataset, specific underpass use is impossible to determine. Other methods of underpass data collection, such as digital event recorders and cameras (Foster and Humphrey, 1995), should be explored and applied to panther movement research, particularly as a resource for tracking underpass use by uncollared panthers. Alternatives to the underpass/fencing combination that ensures mortality mitigation but promotes more free movement between habitats should also be an integral part of future research, although the cost of current design is already substantial.

Finally, the application of the findings of this investigation to reintroduction research and efforts is critical. If any such effort is to be successful, the influence of roads, both major and minor, should be considered in the placement of subpopulations and ecological corridors for movement between populations.

As their last available habitat becomes too small for the remaining population, reintroduction efforts for the Florida panther are critical. Spacing and design of underpasses needs research as many panthers do not use them. Any reintroduction effort needs to carefully consider road mortality and any potential mitigation efforts such as additional protected lands, road closings, fencing, and appropriate wildlife underpasses. It is critical to pursue this research in further depth that will lead to a better understanding of the influence of roads on the endangered Florida panther in order to successfully save the species from extinction.

References

Beier, P., M. R. Vaughan, M. J. Conroy, and H. Quigley. 2003. An analysis of scientific literature related to the Florida panther. Final Report. Florida Fish and Wildlife Conservation Commission, Tallahassee, Florida, USA.

Belden, R. C., and B. W. Hagedorn. 1993. Feasibility of translocating panthers into northern Florida. Journal of Wildlife Management 57:388–397.

Belden, R. C., W. B. Frankenberger, R. T. McBride, and S. T. Schwikert. 1988. Panther habitat use in southern Florida. Journal of Wildlife Management 52:660–663.

Clevenger, Anthony P., and Nigel Waltho, 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. Biological Conservation 121: 453-464.

Comiskey, E. J., O. L. Bass Jr., L. J. Gross, R. T. McBride, and R. Salinas. 2002. Panthers and forests in south Florida: an ecological perspective. Conservation Ecology 6. Available: http://www.conservecol.org/vol6/iss1/art18/manuscript.html

Cramer, P.C., 1999. Modeling Florida panther movements to predict conservation strategies in north Florida. A dissertation presented to the graduate school of the University of Florida. Available: http://www.worldcatlibraries.org/wcpa/top3mset/dda63d9153cf587ea19afeb4da09e526.html

Cramer, P. C., and K. M. Portier. 2001. Modeling Florida panther movements in response to human attributes of the landscape and ecological settings. Ecological Modeling 140:51–80.

Dees, C. S., J. D. Clark, and F. T. van Manen. 2001. Florida panther habitat use in response to prescribed fire. Journal of Wildlife Management 65:141–147.

Dickson, B.G., and P. Beier, 2002. Home-range and habitat selection by adult cougars in Southern California. Journal of Wildlife Management 66 (4): 1235-1245.

Dickson, B. G., J. S. Jenness, and P. Beier, 2005. Influence of vegetation, topography, and roads on cougar movement in southern California. Journal of Wildlife Management 69 (1): 264-276.

Florida Fish and Wildlife Conservation Commission, 1999. Florida Panther Net. http://www.panther.state.fl.us/index.html Last accessed March15, 2006.

Florida Fish and Wildlife Conservation Commission, 2001. A Summary of Florida Panther Mortality Caused by Vehicle Collisions. Bureau of Wildlife Diversity Conservation. July 13, 2001. Available: http://www.panther.state.fl.us/pdfs/FloridaPantherMortalityCausedbyVehicular.pdf

Foster, Melissa L., and Stephen R. Humphrey, 1995. Use of highway underpasses by Florida panthers and other wildlife. Wildlife Society Bulletin 23 (1): 95-100.

Gibeau, Michael L., Anthony P. Clevenger, Stephen Hererro, and Jack Wierzchowski, 2002. Grizzly bear response to human development and activities in the Bow River Watershed, Alberta, Canada. Biological Conservation 103: 227-236.

Gloyne, C.C., and A. P. Clevenger, 2001. Cougar Puma concolor use of wildlife crossing structures on the Trans-Canada highway in Banff National Park, Alberta. Wildlife Biology 7 (2): 117-124.

Hooge, P. N. and B. Eichenlaub, 2001. Animal movement extension to ArcView 3.x. Alaska Science Center - Biological Science Office, US Geological Survey, Anchorage, AK, USA.

Jackson, S.D. 2000. Overview of Transportation Impacts on Wildlife Movement and Populations. Pp. 7-20 In Messmer, T.A. and B. West, (eds) Wildlife and Highways: Seeking Solutions to an Ecological and Socio-economic Dilemma. The Wildlife Society.

Janis, M. W., and J. D. Clark. 2002. Responses of Florida panthers to recreational deer and hog hunting. Journal of Wildlife Management 66:839–848.

Jordan, D. B. 1994. Final preliminary analysis of some potential Florida panther population reestablishment sites. U.S. Fish and Wildlife Service, Atlanta, Georgia, USA.

Kerkhoff, A. J., B. T. Milne, and D. S. Maehr. 2000. Toward a panther-centered view of the forests of south Florida. Conservation Ecology 4.

Kerley, Linda L., John M. Goodrich, Dale G. Miquelle, Evgeny M. Smirnov, Howard B. Quigley, and Maurice G. Hornocker, 2002. Effects of Roads and Human Disturbance on Amur Tigers. Conservation Biology 16 (1): 97-108.

Land, Darrell, Mark Cunningham, Mark Lotz, and David Shindle, 2004. Florida Panther Genetic Restoration and Management: Annual Report 2003–2004. Florida Fish and Wildlife Conservation Commission, Tallahassee, Florida, USA.

Lotz, Mark A., E. Darrell Land, and Kenneth G. Johnson, 1996. Evaluation of State Road 29 Wildlife Crossings. Final Report. Florida Game and Fresh Water Fish Commission, Tallahassee, Florida, USA.

Lotz, Mark A., E. Darrell Land, and Kenneth G. Johnson, 1997. Evaluation and Use of Precast Wildlife Crossings by Florida Wildlife. 1997 Proc. Annu. Conf. SEAFWA: 311-318.

Maehr, D. S. 1990. Florida panther movements, social organization, and habitat use. Final Performance Report. Florida Game and Fresh Water Fish Commission, Tallahassee, Florida, USA.

Maehr, D. S., and J. A. Cox. 1995. Landscape features and panthers in Florida. Conservation Biology 9:1008–1019.

Maehr, D. S., and J. P. Deason. 2002. Wide ranging carnivores and development permits: constructing a multi-scale model to evaluate impacts on the Florida panther. Clean Technologies and Environmental Policy 3:398–406.

Maehr, D.S., E.D. Land, and J. C. Roof, 1991. Social ecology of Florida panthers. National Geographic Research and Exploration 7, 414–431.

Maehr, D. S., T. S. Hoctor, and L. D. Harris. 2001. The Florida panther: a flagship for regional restoration. Pages 293–312 in D. S. Maehr, R. F. Noss, and J. L. Larkin, editors. Large mammal restoration. Island Press, Covelo, California, USA.

Maehr, D. S., E. D. Land, D. B. Shindle, O. L. Bass, and T. S. Hoctor. 2002. Florida panther dispersal and conservation. Biological Conservation 106: 187–197.

McCown, Walter, Paul Kubilis, Thomas Eason and Brian Scheick, 2004. Black bear movements and habitat use relative to roads in Ocala National Forest. Florida Fish and Wildlife Conservation Commission, Tallahassee, Florida, USA.

O'Neill, Jack, Simon Dyer, and Shawn Wasel, 2000. Using GPS and GIS Analysis to Investigate the Effects of Industrial Development on an Endangered Species. ESRI 2000 User Conference Proceedings. http://gis.esri.com/library/userconf/proc00/professional/papers/PAP116/p116.htm

Tigas, L. A., Dirk H. Van Vuren, and Raymond M Sauvajot, 2002. Behavioral responses of bobcats and coyotes to habitat fragmentation and corridors in an urban environment. Biological Conservation 108: 299-306.

U.S. Army Corps of Engineers, 2006. Comprehensive Everglades Restoration Plan Report, Jan-Feb 2006. Available: http://www.evergladesplan.org/docs/cerp_report_jan_feb_2006.pdf