MOVEMENTS OF FEMALE WHITE-TAILED DEER (*ODOCOILEUS VIRGINIANUS*)

AT CHESAPEAKE FARMS, MARYLAND AND

THE GREAT CYPRESS SWAMP, DELAWARE

by

Jeffrey J. Kolodzinski

(Under the Direction of Karl V. Miller)

ABSTRACT

I used GPS collars and frequent sampling (≥24 locations/day) to document the movements of 27 female white-tailed deer (*Odocoileus virginianus)* at two study sites with high-density herds and equal sex ratios. I used monthly datasets to describe the accuracy of home range analyses based on differing sampling regimes and quantified the errors associated with each regime. Results confirmed that kernel home range calculations were more reliable than minimum convex polygon (MCP) methods; however, large errors were also associated with kernel areas calculated from small datasets. Intensive sampling regimes also allowed me to report short-term excursions by female deer during the suspected time conception. This is one of the first studies to document these movements in high-density, well-managed herds. Finally, intensive sampling regimes helped to reveal a rhythmic-like pattern in the daily-distance traveled by female deer. The cause for this pattern was not determined but opens the door for future research.

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I extend significant thanks to David Osborn. David was instrumental to getting this project off the ground. When I first arrived at Warnell, David was always willing to lend a helping hand and was always there to help guide me through the procedures and stacks of paperwork that are required of a graduate student. I thank David for the hours he spent driving from Georgia to Alabama and Maryland to come help me in the field. David's advice, assistance, and encouragement throughout my time here were extremely helpful and priceless.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW, STUDY AREA, OBJECTIVES, AND THESIS FORMAT

INTRODUCTION

The breeding strategy of female white-tailed deer (*Odocoileus virginianus*) has been reported to differ among herds with differing demographic characteristics (Ivey and Causey 1981, Holzenbein and Schwede 1989, Beir and McCullough 1990, Labisky and Fritzen 1998, D'Angelo et al. 2004). Traditional beliefs, stemming from observations of rutting males pursuing females, suggest that females play a passive role in the reproductive process. This paradigm is supported by research demonstrating that male deer travel large distances during the breeding season (Tomberlin 2007) and other studies showing female deer exhibiting sedentary movement patterns during the same time period (Holzenbein and Schwede 1989, Beir and McCullough 1990). However, Ozoga and Verme (1975) reported increased activity of females just prior to conception. Consequent field studies have also reported increased activity and movement of some females during the time of conception (Ivey and Causey 1981, Labisky and Fritzen 1998, D'Angelo et al. 2004). Most studies reporting increased movements among females during conception were conducted in low-density deer herds, or in herds where the sex ratio was female biased. Studies conducted on high-density herds often failed to note increases in movement or activity among females. As such, Holzenbein and Schwede (1989) hypothesized that females will adopt sedentary breeding strategies when presented with an abundance of suitable males, whereas a more active mate-searching strategy will be employed when there is a lack of fit mates.

Although this mate-searching hypothesis has empirical support, the role that females play in the breeding process is unclear. In Georgia, Sawyer et al. (1989) documented excursions by three female deer outside of their normal home range in an unhunted, high-density population. Presumably, these excursions occurred at the time of estrus. In Virginia, Holzenbien and Schwede (1989) also observed an excursion by a single female under high-density conditions during the breeding season.

In prior studies, excursive movements may not have been recorded due to relatively low-intensity sampling regimes. The period during which females increase their movements and activity is of short time, usually less than 24 hours (D'Angelo et al. 2004). Studies using radio-telemetry often obtain locations only a few times per day or less frequently, and therefore may have failed to document short-term excursions. Additionally, a low sampling rate may have resulted in an overestimate of the normal areas of use. With computer simulations, Seaman et al. (1999), and with datasets collected from moose (*Alces alces*) Girard et al. (2002) have shown that smaller datasets tend to overestimate kernel home ranges. Overestimations in home range size may cause researchers to falsely conclude that females are using their normal area of use when they actually are traveling outside their normal home range.

Newer technologies and improved battery life have made Global Positioning Systems (GPS) collars an affordable and practical tool for wildlife research. These technologies have greatly increased our understanding of white-tailed deer movement ecology and may help determine what role female deer play in the breeding process. GPS collars allow animal locations to be collected several times per hour for extended periods of time, thereby allowing researchers to more precisely describe kernel areas. These devices also may enhance our ability to discover and describe new aspects of white-tailed deer behavior.

Despite the promise in GPS technology, the power of home range analyses on these large datasets has not been explored completely. Previous research has failed to determine the number of points necessary to accurately describe an animal's home range (Silverman 1986, Seaman et al. 1999, Girard et al. 2002). However, Seaman et al. (1999) and Girard et al. (2002) found that higher sampling rates and larger datasets tended to result in smaller kernel home range estimates because the wealth of data helped pinpoint precise areas of use. Their analyses were conducted with relatively small datasets (≤ 200 locations). However, it is unknown if the higher sampling rates of GPS collars will result in significant improvements in home range precision or if an asymptotic trend is reached at sampling rates lower than that possible with current GPS technology.

OBJECTIVES

The purpose of my research was to examine the use of GPS collars with intensive sampling regimes on white-tailed deer. Specifically, my goals were to: (1) determine what effect intensive sampling regimes have on traditional home range analyses, (2) use these intensive sampling regimes to describe the breeding behavior of adult female deer in high-density deer herds with balanced sex ratios at two study sites in the mid-Atlantic region, and (3) describe any unreported behaviors revealed by the high-intensity sampling regime.

STUDY SITES

I collected data for my study at Chesapeake Farms (CF) in Kent County, Maryland (Figure 1.1) and the Great Cypress Swamp (GCS) in Sussex County, Delaware (Figure 1.2). Both study sites are located on the Delmarva Peninsula of the Atlantic Coastal Plain and have a flat, low-lying landscape with elevations less than 50 m above sea level. Chesapeake Farms, owned by Dupont Agricultural Enterprise, is a 13.4-km^2 property composed of a deciduous mixed-hardwood forest land significantly fragmented by agricultural fields. The Great Cypress Swamp, owned by Delaware Wild Lands Inc., is a 44.5-km^2, unfragmented forested habitat surrounded by productive agricultural land.

Historically, both study sites were composed of bottomland forest habitats populated with large stands of *Chamaecyparis thyoides* and *Taxodium distichum*; however, most of the wetland habitat has been drained to support agriculture activities and development (Maryland Department of Natural Resources 2007). Both study sites still maintain some plant species characteristic of a bottomland forest; however, the current plant composition is more mesophilic in nature. The forested habitat at both study sites contains tree species common to southern forests, including *Acer rubrum, Diospyros virginiana, Ilex opaca, Liquidambar styraciflua, Liriodendron tulipifera, Pinus taeda, Quercus alba,* and *Q. nigr*a. The Great Cypress Swamp has a greater abundance of *Pinus taeda* stands but the majority of its landscape is composed of a mixed hardwood forest. The Great Cypress Swamp also contains isolated stands of *Chamaecyparis thyoides* and *Taxodium distichum.*

Chesapeake Farms engages in habitat management activities, such as prescribed burning and forest thinning to help increase the natural browse available to deer. The Great Cypress Swamp has only recently begun to pursue habitat and timber management programs. For this reason, the understories, mostly composed of *Clethra alnifoia, Smilax* spp., and *Vaccinium* spp, are considerably denser at CF, whereas the average stand age is considerable older at GCS.

The agricultural activities surrounding CF and GCS are almost exclusively devoted to corn (*Zea mays*) and soybean (*Glycine max*) production. According to Tomberlin (2007), CF maintains 13% of its land for wildlife food crops such as *Lolium multiflorum, Sorghum biocolor, Trifolim* spp., and *Triticum aestivum* and another 14% is maintained natural habitats for wildlife. Within and around the GCS there are several privately maintained wildlife food plots composed primarily of *Lolium multiflorum, Trifolim* spp., and *Triticum aestivum*.

Both study sites support deer densities between 30-40 deer/km^2 and are intensively managed by selective harvest guidelines to promote healthy deer herds with balanced sex ratios. Shaw (2005) determined the CF preharvest deer density to be 33 deer/km^2. In 2006, the CF deer population had a sex ratio around 1:1.5 (M.C. Conner, Chesapeake Farms, unpublished data). In 2005, the GCS area was determined to have one of the highest deer densities in Delaware, around 36 deer/km^2 (DNREC 2006). A camera survey in 2006 determined the GCS deer sex ratio to be near 1:1.

The 2006 hunting season at CF opened on Sept. 15 and concluded on Dec. 29, although, hunting at the Farm was focused between Nov. 24 and Dec. 8. Hunting seasons at GCS spans from Sept. 1 – Jan. 31, although shotguns and or muzzleloaders are only permitted Oct. 6 – 30, Nov. 10 – 18, Dec. 9 – 16, and Jan. 13 – 27. Although liberal, either-sex permits are issued throughout most of the season in both states, CF and GCS allow hunters to harvest one antlered deer per season. Hunters at GCS have the opportunity to harvest a second buck after they harvest two does. Sixty-one deer were harvested at CF during the 2005 hunting season, of which

46 were does (G. R. Karns, unpublished data). Yearly harvests at GCS range between 100-125 deer with a 75% doe harvest (R. Haas, Delaware Wildlands Inc., personal communication).

THESIS FORMAT

My thesis is presented in manuscript format. Chapter 2 focuses on the performance of the GPS collars chosen for this study. Chapter 3 examines the effects of a high-intensity sampling regime on MCP and kernel home range analyses. Chapter 4 documents excursive behaviors of female white-tailed deer during the breeding season at Chesapeake Farms and the Great Cypress Swamp. Chapter 5 described a rhythmic-like pattern in the daily movements of female deer. Chapter 6 provides an overall analysis of the research presented in previous chapters as well as a summary of the implications derived from this research. Chapters 3 and 4 are individual manuscripts that will be submitted for publication in peer-reviewed scientific journals. Chapter 5 will be submitted to a peer-reviewed scientific journal in note format.

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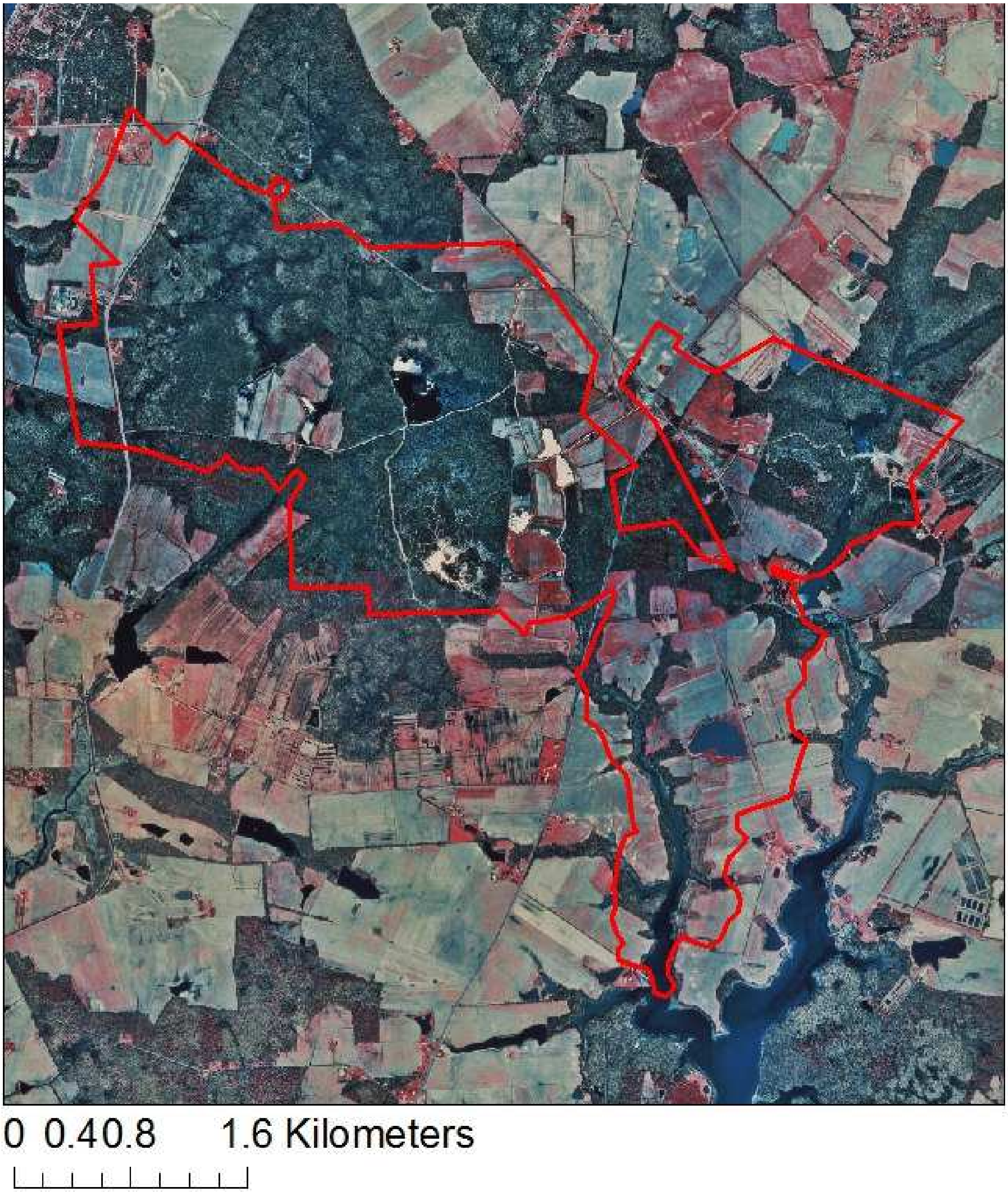

Figure 1.1 A 100 m X 100 m infrared aerial photograph of Chesapeake Farms (outlined in red) and its surrounding area taken 1992.

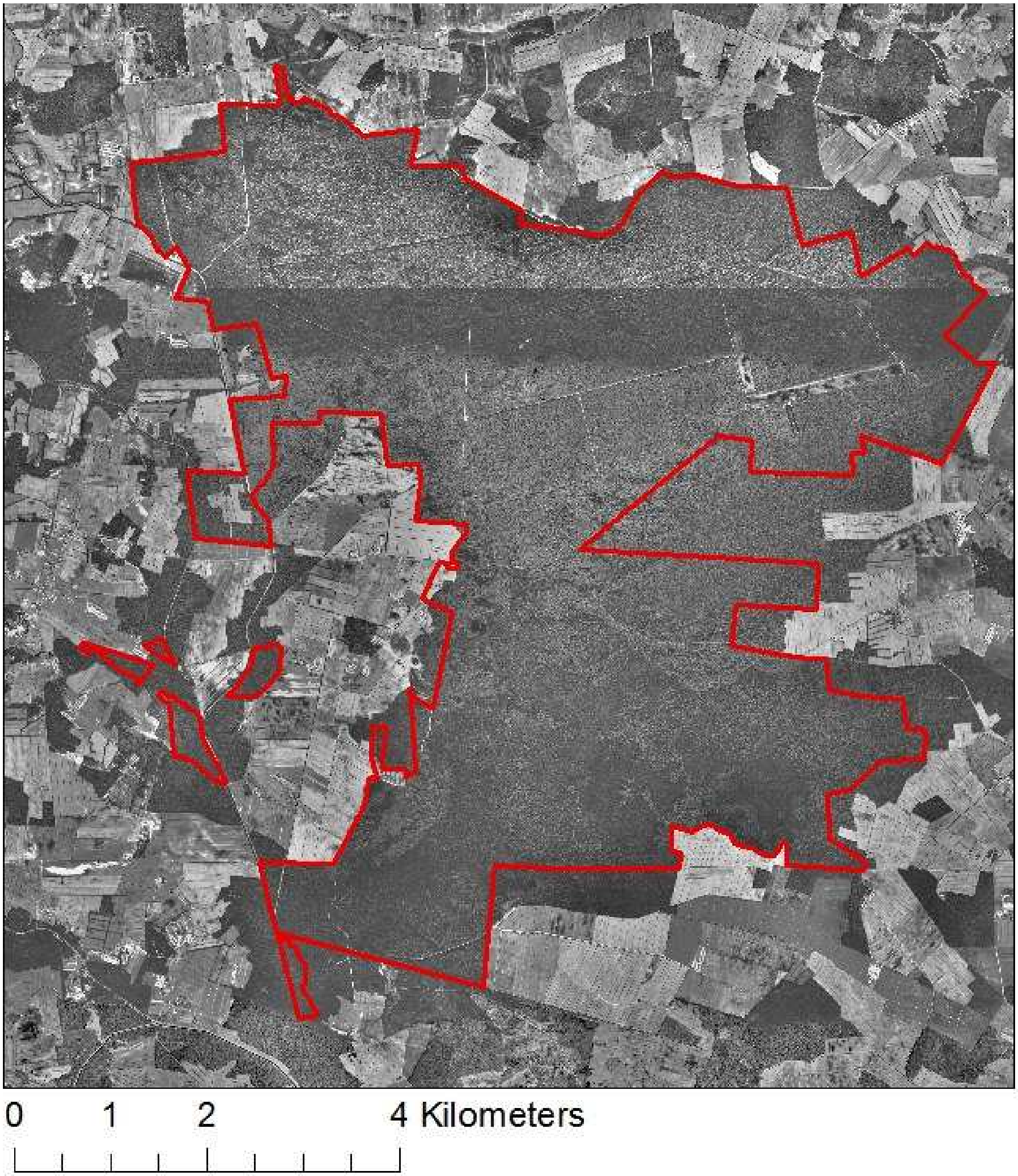

Figure 1.2 A 10 m X 10m digital aerial photograph of the Great Cypress Swamp (outlined in red) and its surrounding area taken in 1992.

CHAPTER 2

PERFORMANCE OF THE TELEVILT TELLUS® BASIC GPS COLLAR

ABSTRACT

Global positioning systems (GPS) have provided many benefits to wildlife research. However, collar reliability may differ among manufacturers. In 2006 I deployed 27 Televilt Tellus® Basic GPS collars on 27 white-tailed deer (*Odocoileus virginianus*) for a one-year period at two study sites on the Delmarva Peninsula. During the study, five collars functioned for the entire study period, 13 failed due to battery drain, two sustained water damage, and seven others malfunctioned and were not retrieved. Retrieved collars collected data for an average of 186. 3 days (range 9 – 394, SD = 131.2, N = 18) and collected 4,604 locations (Range 249 – 11,117, SD = 3,456, N = 18). There was an average fix rate of 91.9% (SD = 2.7%, N = 18) and 90% and 95% of the data fell within 75 m and 100 m of truth, respectively. The high failure rates were unexpected and the accuracy was lower than the reported accuracy of other GPS collars. However, the degree of accuracy in these data is unlikely to have large effects on home range analyses of white-tailed deer.

INTRODUCTION

Global positioning systems (GPS) have provided many benefits to wildlife research and are replacing their less advanced precursors because they allow researchers to collect larger, more accurate datasets on more individuals. Despite the promise of GPS collars, malfunctions and equipment failures have plagued some studies. For example, research conducted with

Televilt® GPS-Simplex collars (Televilt/TVP Positioning AB, Lindesberg, Sweden), an early prototype, on grizzly bears (*Ursus arctos*) in Canada experienced some degree of failure in more than 46% of collars (N = 71) (Gau et al. 2004). However, in the interim, there have been a number of successful studies conducted with Televilt products. Gau (Wildlife and Fisheries Division, Department of Resources, Wildlife and Economic Development, Government of the Northwest Territories. personal communications) attributed the collar failures to the prototype model, the lifestyle of the bears, and the climate of the study area. Morse (2008) also successfully conducted a study with Televilt GPS collars on fallow deer (*Dama dama L.*) on Little Saint Simons Island, Georgia.

For my study, I decided to use Televilt's Tellus® Basic GPS collar fitted with a 1D battery. This decision was based on the recent positive reviews of Televilt's products and the difference in price between other manufactures. My objective for this research was to evaluate the performance of these collars.

STUDY SITES

My study was conducted at Chesapeake Farms (CF) in Kent County, Maryland and the Great Cypress Swamp (GCS) in Sussex County, Delaware. Both study sites are located on the Delmarva Peninsula of the Atlantic Coastal Plain and have a flat, low-lying landscape with elevations less than 50 m above sea level. Chesapeake Farms is composed of a mostly deciduous mixed-hardwood forest habitat significantly fragmented by agricultural fields. The Great Cypress Swamp has a greater abundance of evergreen stands (*Pinus taeda* and *Taxodium distichum*) but the majority of its landscape is composed of a mixed hardwood forest.

METHODS

I deployed Televilt Tellus® Basic GPS collars on 27 (N = 15 at CF, N = 12 at GCS) white-tailed deer (*Odocoileus virginianus*) between March and August of 2006. The collars were programmed to collect 24 locations/day at equal intervals during February, March, August, and September and 32 locations/day during the remaining months. A VHF beacon was programmed to emit signals Monday – Saturday for 8 hours/day. The collars were fitted with Televilt 1D battery packs. According to manufacturer specifications, the collars should have lasted for 348 – 450 days and collected 10,438 – 13,498 locations. These estimates were based on an average yearly temperature close to 0°C. Once the study period was over a remote-release mechanism caused functioning collars to fall from the deer.

Once the collars were recollected, I used the Televilt Tellus® TPM Project Manager software (Televilt/TVP Positioning AB, Lindesberg, Sweden) to download data. Fix rates were determined and any failures were noted. Locations with dilution of precision (DOP) values > 6 were filtered out. Because the collars failed to collect the needed satellite information, data could not be differentially corrected.

I deployed a test collar for 1-2 days at four locations at Chesapeake Farms during the spring of 2008. The locations simulated the four main types of cover at the two study sites: Open field, sparse deciduous, dense deciduous, and dense evergreen. Each location was pinpointed from a high-resolution aerial photograph. Six buffer regions (10, 20, 30, 50, 75, 100 m) were created around the true location and the percentage of data falling within each buffer was determined. Locations with DOP values > 6 were also filtered out from the test collar data.

RESULTS

Significant collar failure was experienced during the study. Three collars failed pre-deployment and were returned to the manufacturer for repairs. Five collars performed for the entire study period; however, only two responded to the remote-release signal. I recollected the three other collars by lethal harvest. These five collars collected 45,641 data locations ($\bar{x}$ = 9,128.2 locations, Range = 7,024 – 11,117 locations, SD = 1,574.7) and performed for an average of 359.8 days (Range = 343 – 394 days, SD = 20.3) (Figure 2.1). I obtained 15 other collars through lethal harvests. Two of these collars sustained water damage and did not contain any data. Thirteen of the collars experienced failures due to faulty wiring that caused batteries to drain faster than expected. These collars lasted an average of 144.5 days (Range = 9 – 269 days, SD = 78.4, N = 13) yielding partial datasets and 37,237 locations ($\bar{x}$ = 2,864.4 locations, Range = 249 – 7,459 locations, SD = 2,115.6). Seven other collars malfunctioned for unknown reasons and were not retrieved. During the time period when collars were functioning, all of those that I retrieved reliably collected data. There was an average fix rate of 91.9% (SD = 2.7%, N = 18) after filtering out positions with DOP values > 6 (Figure 2.1).

The test collar had a fix rate > 93.3% at all four habitat types (Table 2.2). However, the accuracy of the test collar was relatively low as only 59 – 78% of the data fell within 30 m of the true location. On average, approximately 90% and 95% of the data fell within 75 m and 100 m, respectively.

DISCUSSION

Accuracy of the Televilt Tellus® Basic GPS collars was less than expected, although comparable to some reports on GPS collars. Rempel et al. (1995) reported average errors between 46 – 64 m on open habitat and 56 – 70 m in a boreal forest. Ron et al. (1996) reported 50% and 95% of their data fell within 32 m and 77 m, respectively. These results closely mirror my results. However, Hansen and Riggs (2008) reported average errors of 2.7 m on an open hill top and 49.5 m in a forested ravine. The accuracy obtained during this study was below the upper limits of GPS technology. Nonetheless, these GPS collars collected more data, and more accurate data than traditional radio-telemetry data (Springer 1979, Lee et al. 1985). The degree of accuracy in these data is unlikely to have significant effects on home range analyses, the primary goals of this research. The accuracy would have greater effects on fine-scale movement or habitat analyses or perhaps when working with species that have small-confined home ranges.

Throughout the study period, Televilt was very cooperative and assisted as much as possible. The company has refurbished all of the collars that malfunctioned and replaced their battery packs without charge.

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Table 2.1 Performance of Televilt Tellus® Basic GPS collars during 2006-2007 at Chesapeake Farms, Maryland and the Great Cypress Swamp, Delaware

Collar ID	Operational Days	Number of Fix Attempts	Number of Data Points	Number of Data Points (DOP < 6)	Fix Rate (%)
1	361	10,615	9,255	8,346	90.2%
2	347	7,915	7,024	6,360	90.6%
3	181	5,293	4,924	4,528	92.0%
4	9	304	249	216	86.8%
5	343	9,513	8,251	7,386	89.5%
6	54	1,637	1,379	1,194	86.6%
7	28	912	820	720	87.8%
8	394	11,622	11,117	10,300	92.7%
9	90	2,374	2,233	2,100	94.0%
10	46	1,219	1,109	1,053	95.0%
11	354	10,449	9,994	9,267	92.7%
12	269	7,649	7,459	6,989	93.7%
13	123	3,476	3,333	3,144	94.3%
14	204	2,388	2,301	2,167	94.2%
15	69	1,902	1,822	1,684	92.4%
16	95	2,648	2,571	2,406	93.6%
17	200	5,762	5,596	5,203	93.0%
18	121	3,477	3,441	3,247	94.4%
19-20	WATER DAMAGE				
21-27	UNRETRIEVED				

Table 2.2 Accuracy results (% of locations falling within a buffered radius) of a test collar deployment at Chesapeake Farms, Kent County, Maryland in Spring 2008.

		Buffer Radius						
Cover Type	Fix Rate	10 m	20 m	30 m	50 m	75 m	100 m	> 100 m
Open Field	97.4	29.9	61.5	77.5	89.2	94.8	96.1	3.9
Sparse Deciduous	98.6	38.6	62.9	75.7	90.0	95.7	98.6	1.4
Dense Deciduous	95.2	22.6	44.6	59.3	77.5	89.2	93.1	6.9
Dense Evergreen	93.3	30.6	56.0	70.1	80.9	89.8	94.3	5.7

CHAPTER 3

THE EFFECTS OF HIGH-INTENSITY SAMPLING REGIMES ON HOME RANGE ANALYSES

Kolodzinski, J. J, K. V. Miller, L. V. Tannenbaum, D. A. Osborn, M. C. Conner, and W. M. Ford.
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ABSTRACT

The two most common methods for determining home ranges, minimum convex polygon (MCP) and kernel analyses, can be affected by sampling intensity. Despite prior research, it remains unclear how high-intensity sampling regimes affect home range estimations. We used datasets from 14 GPS-collared, white-tailed deer (*Odocoileus virginianus*) to describe the accuracy and associated errors of home range analyses based on differing sampling. We compared monthly home range estimates from seven sub-samples (480, 360, 180, 90, 60, 30, and 15 locations) to the range estimates of the full datasets (720 locations). Minimum convex polygon (MCP) home range estimates increased as sampling rate increased; although, MCP areas calculated from datasets with > 180 locations did not differ ($P<0.05$). Areas calculated with 60-90 locations may underestimate MCP size by 50% or more. Sampling regimes with ≥ 360 locations are needed to reduce underestimation errors below 20%. Kernel home range analyses accurately estimated home range size for all sampling regimes. Error associated with the sampling regimes was lower in kernel analyses. Sampling regimes collecting 480 and 360 locations had less than 10% relative error. Intensive sampling regimes are becoming more necessary as analyses focus on fine-scale movement and habitat selection. Researchers should employ intensive sampling regimes whenever possible, as these higher sampling rates allow home ranges to be described more precisely. Higher error rates associated with the low-intensity sampling regimes of many previously published radio-telemetry studies may make their results questionable.

INTRODUCTION

GPS technology has increased the accuracy and precision of animal locations estimates and has allowed researchers to generate more frequent and larger datasets that are useful for home range analyses. In many cases, sampling rates may be compromised to ensure battery longevity for the duration of the study. Considerations of trade-offs between sampling rate and study duration necessitate an understanding of the effects of sample size on the accuracy and precision of home range estimations.

The two most common methods for determining home ranges, minimum convex polygon (MCP) and kernel analyses, are both affected by changes in sampling regime (Silverman 1986, Harris et al. 1990, Seaman et al. 1999, Powell 2000, Girard et al. 2002). Generally, ≥ 100 locations are required to accurately describe a MCP area, with < 100 locations resulting in underestimations (Harris et al. 1990, White and Garrot 1990, Seaman et al 1999, Powell 2000, Girard et al. 2002). However, kernel analyses are less sensitive to sampling rates than MCP estimators (Boulanger and White 1990, Worton 1995, Seaman and Powell 1996, Hansteen et al. 1997, Kenward 2001). Nevertheless, Seaman et al. (1999) and Girard et al. (2002) reported that smaller datasets tend to overestimate kernel home range size.

Given the nonparametric nature of kernel range calculations, the number of locations needed to accurately describe a home range cannot be easily calculated, although the topic has been explored in depth without a consensus (Silverman 1986, Seaman et al. 1999, Girard et al. 2002). Under several restrictions, Silverman (1986) concluded that only 19 locations were necessary, whereas Girard et al. (2002) concluded that as many as 300 locations were needed.

Recent improvements in battery life allow GPS devices to collect ≥ 24 locations per day for an entire year. Despite prior research on this topic, it remains unclear how high-intensity sampling regimes affect home range estimations. Whether greater sampling rates improve the accuracy of home range estimates has received little research attention.

Herein, we used datasets collected from GPS-collared white-tailed deer (*Odocoileus virginianus*) to describe the accuracy of home range analyses based on differing sampling regimes and quantified the associated errors.

STUDY SITES

Our study was conducted at Chesapeake Farms (CF) in Kent County, Maryland and the Great Cypress Swamp (GCS) in Sussex County, Delaware. Chesapeake Farms is 13.4 km^2 of fragmented forest/agricultural habitat, whereas, the GCS is a 44.5 km^2 unfragmented forested habitat surrounded by productive agricultural land.

The forested habitat at both studies sites contains tree species common to southern forests, including *Acer rubrum, Diospyros virginiana, Ilex opaca, Liquidambar styraciflua, Liriodendron tulipifera, Pinus taeda, Quercus alba,* and *Q. nigr*a. The GCS also contains several stands of *Pinus taeda, Chamaecyparis thyoides, and Taxodium distichum*. The understories of CF and GCS are mostly composed of *Clethra alnifoia, Smilax* spp*.,* and *Vaccinium corymbosum*. The understory at CF is considerable more dense than at GCS.

The agricultural activities surrounding CF and GCS are almost exclusively tied to corn (*Zea mays*) and soybeans (*Glycine max*). Both study sites plant wildlife food crops such as *Lolium multiflorum, Sorghum biocolor, Trifolim* spp., and *Triticum aestivum*

Both study sites support deer densities between 30-40 deer/km^2 and are intensively managed by selective harvest guidelines to promote healthy deer herds with balanced sex-ratios. Shaw (2005) determined the CF preharvest deer density to be 33 deer/km^2. In 2006, the CF deer population had a sex ratio around 1:1.5 (M.C. Conner, Chesapeake Farms, unpublished data). In 2005, the GCS area was determined to support around 36 deer/km^2 (DNREC 2006). A camera survey in 2006 determined the GCS deer sex ratio to be near 1:1.

METHODS

We fitted 14 adult female deer (≥ 1.5 years old) with Televilt Tellus® Basic, 5H1D GPS collars (Televilt/TVP Positioning AB, Lindesberg, Sweden) between Feb 2006 and Aug 2007. Four deer were collared at GCS and 10 were collared at CF. We captured deer with a combination of free-darting and rocket nets. We used 3-ml transmitter darts (Pneu-dart Inc., Williamsport, Pennsylvania, USA) with a 7.0 mg/kg Telazol® (Fort Dodge Animal Health, Fort Dodge, Iowa, USA)/ 6.5 mg/kg xylazine hydrochloride (Cervizine®, Wildlife Laboratories, Inc., Fort Collins, Colorado, USA) mixture to immobilize animals. Deer captured in rocket nets were immobilized with a 10.7 mg/kg ketamine hydrochloride (Ketaset®, Fort Dodge Animal Health, Fort Dodge, Iowa, USA)/ 2.2 mg/kg xylazine hydrochloride injection. We calculated dosages assuming an average weight of 70 kg at GCS and 45 kg at CF. During immobilization, we monitored vital signs, treated minor injuries, lubricated eyes, and blindfolded each deer. After 90 minutes, we administered a 400 mg injection of tolazoline hydrochloride (Tolazoline®, Lloyd Laboratories, Shenandoah, Iowa, USA) to reverse the effects of the immobilization agent to all deer captured through darting. We administered a similar injection to deer immobilized with a ketamine/xylazine injection after 30 minutes. We monitored all deer until they were ambulatory. Animal handling procedures were approved by the University of Georgia Institutional Animal Care and Use Committee (#A3437-01).

We programmed GPS collars to collect and store GPS locations in the form of X, Y coordinates on their nonvolatile memory. The collars were programmed to collect 24 locations/day at equal intervals during the study period. At the end of the study, activation of a remote-release mechanism caused functioning collars to fall from the animal. Because the release mechanism failed on some collars (n=12), we retrieved these collars via lethal methods (gunshot). Once the collars were collected, the Televilt Tellus® TPM Project Manager software (Televilt/TVP Positioning AB, Lindesberg, Sweden) was used to download the data.

We selected only data collected during August, September, February, and March for our analysis. Other months were excluded to eliminate data that might be biased by activities related to breeding and parturition (D'Angelo et al. 2004, Tomberlin 2007). There were 33 months of data among the 14 deer (23 from CF and 10 from GCS). The 33 months were analyzed independently or each other.

Eight datasets were derived from each month of data to simulate eight sampling regimes (24, 16, 12, 6, 3, 2, 1, and 0.5 locations/day). We structured the original datasets into time blocks based on the average number of hours between sampling points for each regime (i.e., for the 12 locations/day regime the data were structured into 2-hour time blocks). One representative data point was randomly selected from each time block to create the seven simulated datasets. The eighth data set (24 locations/day) contained all of the collected locations. Non-fix locations and locations with dilution of precision (DOP) values > 6 were filtered out, yielding an average fix rate of 92%.

We used Home Range Tools for ArcGIS extension (Rodgers et al. 2007) to calculate a 95% kernel home range for each data set. We calculated the *accepted* home ranges using the sampling rate of 24 locations/day (720 locations) and the s*imulated* home ranges from the seven simulated datasets. We also calculated accepted and simulated MCP home ranges with Hawth's Analysis Tools for ArcGIS (Beyer 2006).

We compared simulated home ranges to the accepted ranges and determined areas of error (under- or overestimation, Figure 3.1). We expressed the area of error as a percentage of the simulated home range size. We examined the changes in home range size and error for each of the sampling rates. We determined statistical differences by the non-overlap of 95% confidence interval.

RESULTS

For MCP methods, home range size increased as sampling rate increased (Figure 3.2a); although, MCP areas calculated from datasets with sampling rates > 6 locations/day (> 180 locations) were not different (95% confidence intervals overlapped). The MCP area increased more than five times between the least and the most intensive sampling regimes. All errors in MCP ranges were the result of underestimations of home range size. Error rates increased as sampling rates decreased (Figure 3.3a). We observed errors as high as 80% for our least-intensive sampling regime.

Kernel home range sizes were slightly larger with lower sampling rates, although they did not differ statistically (Figure 3.2b). Mean differences were less than ± 0.4 km^2. However, overall errors in kernel area increased as sampling rates decreased (Figure 3.3b). The shape of kernel home ranges became less stable as sampling rates decreased, resulting in higher errors. Most of the error was a result of overestimations, but as sampling rates dropped, the destabilization of home range shape resulted in increased ratio of underestimation errors (Figure 3.4). Sampling regimes collecting 16 and 12 locations/day (480 and 360 locations) had less than

10% error relative to the accepted home range, whereas errors greater than 40% were observed in the least intensive sampling regime.

DISCUSSION

The number of points needed to accurately describe an animal's home range is undoubtedly linked to the behaviors of individual species. Regardless, as sampling regimes become less intensive (i.e., smaller datasets) important areas of use may be excluded from home range estimates.

With MCP analyses, sampling regimes collecting at least six locations/day (180 data points) were necessary to accurately assess home range size. Our results question the validity of analyses in prior studies because MCP areas calculated with 2-3 locations/day (60-90 locations) may underestimate MCP areas by 50% or more. Sampling regimes of > 12 locations/day (360 locations) are needed to reduce errors below 20%.

In contrast, even the least intensive regime resulted in an accurate kernel home range size estimate. Error associated with the sampling regimes also was lower in kernel analyses. The 12 and 16 locations/day regimes had errors less than 10%. Prior studies, using sampling rates of 2-3 locations/day, may have misrepresented home ranges by 20-30%. These errors are largely a result of overestimations.

Whereas most errors in kernel analyses were the result of overestimations, all the errors in MCP analyses were the result of underestimations. Underestimations of home range size likely have greater consequences, and further identify the limitations of MCP analyses.

Intensive sampling regimes are becoming more necessary as analyses focus on fine-scale movement and habitat selection. Because of the large error rates associated with infrequent sampling, error in home range estimations could result in erroneous inferences.

Researchers should employ intensive sampling regimes whenever possible, as these higher sampling rates allow home ranges to be described more precisely. Higher error rates associated with many previously published radio-telemetry studies may make the results of these studies questionable.

ACKNOWLEDGEMENTS

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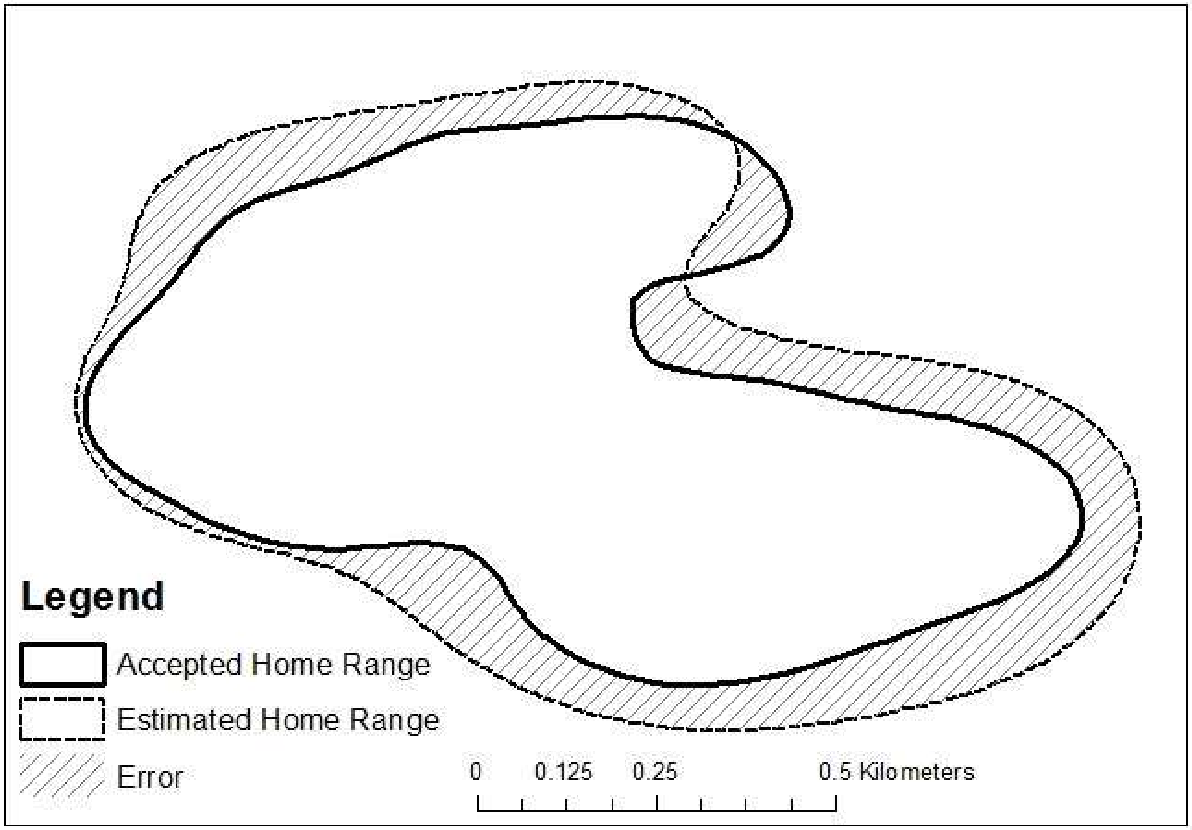

Figure 3.1 Example of accepted (720 location) and simulated (360 location) monthly home ranges and the resultant errors in home range estimations for an adult female deer at Chesapeake Farms, Maryland in 2006.

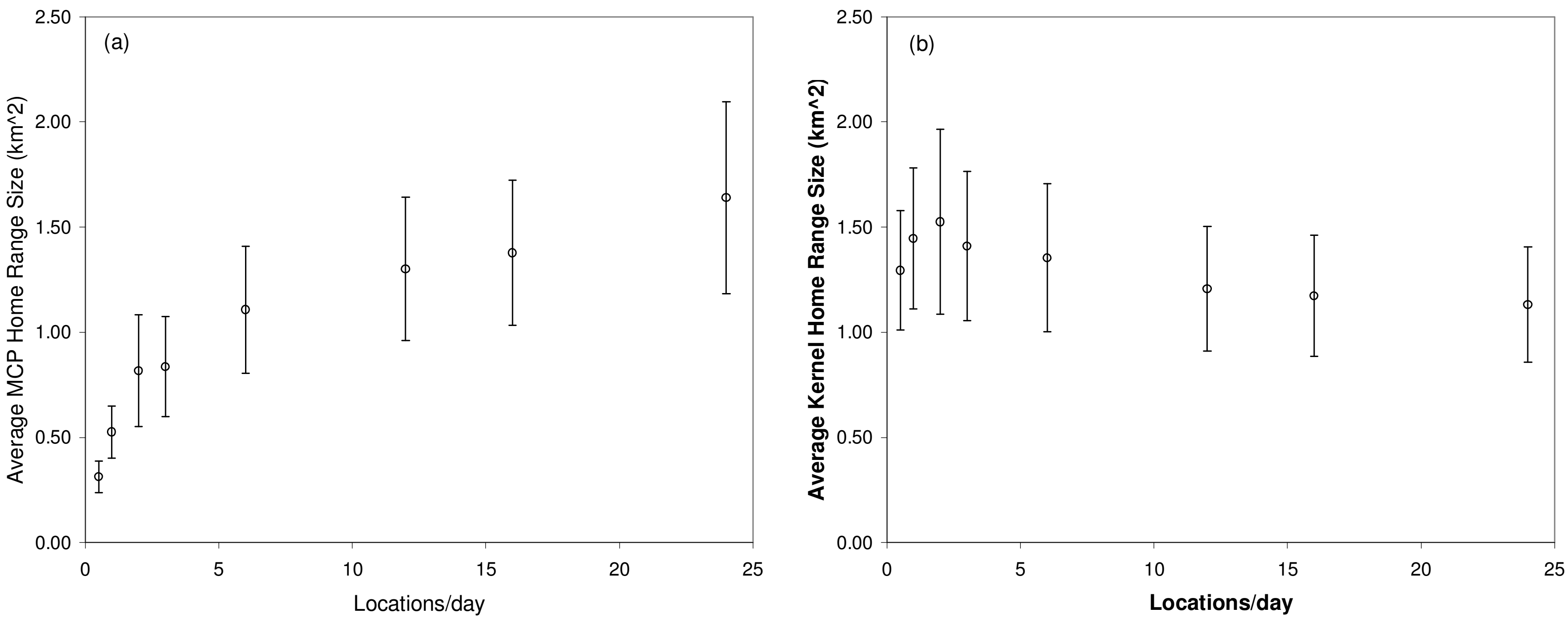

Figure 3.2 (a) Average MCP home range size estimates and (b) average kernel home range size estimates according to sampling regime at Chesapeake Farms, Maryland and the Great Cypress Swamp, Delaware during 2006-2007.

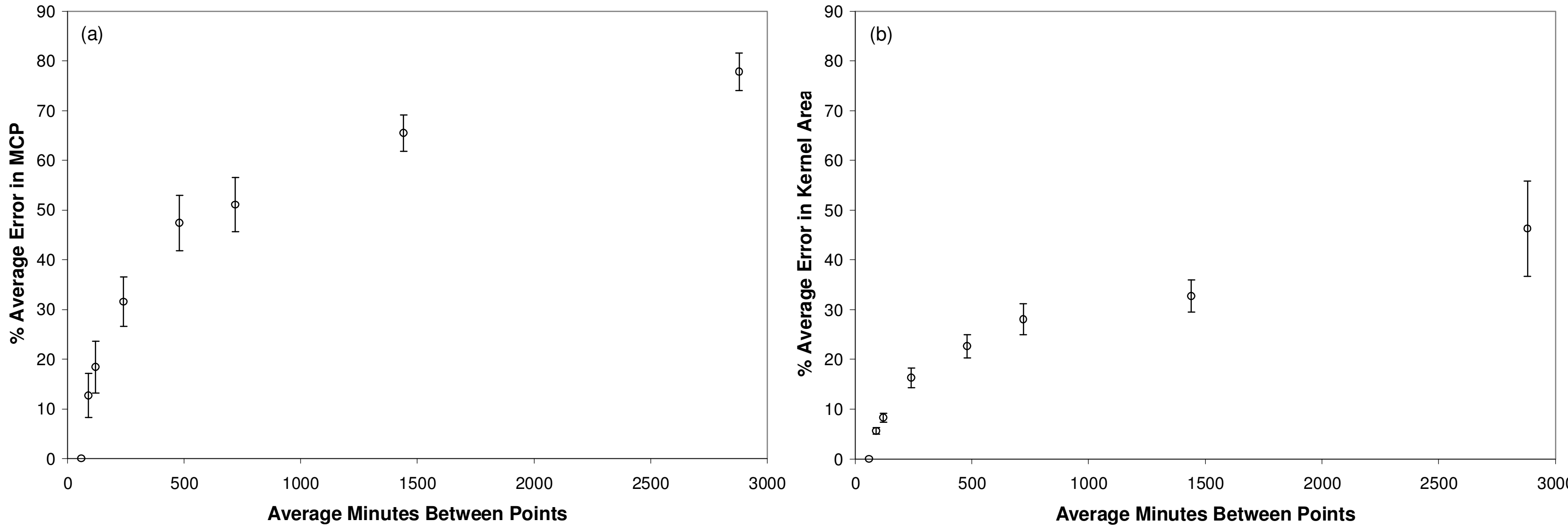

Figure 3.3 Errors in (a) MCP home range estimates and (b) kernel home range estimates according to sampling regime at Chesapeake Farms, Maryland and the Great Cypress Swamp, Delaware during 2006-2007.

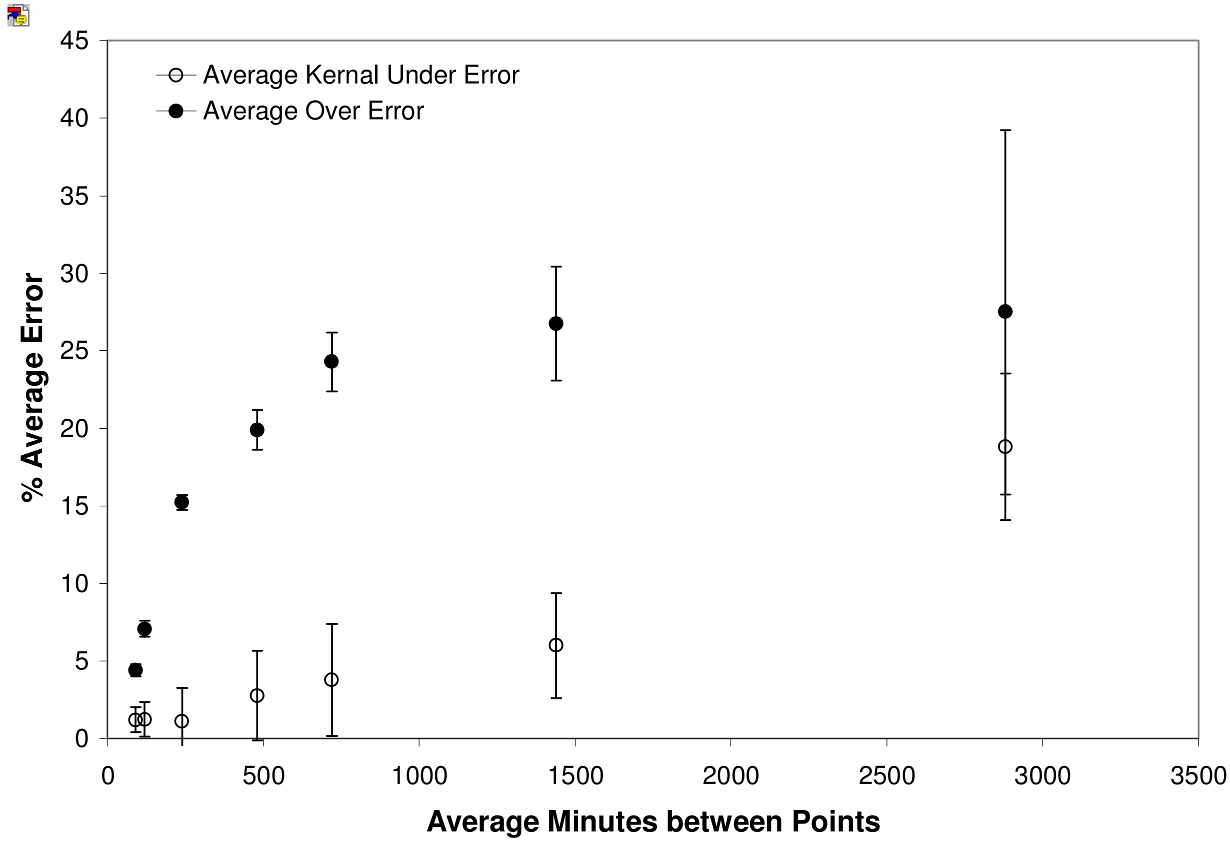

Figure 3.4 Changes in under- and overestimation error rates for kernel home range estimates as sampling rates increase at Chesapeake Farms, Maryland and the Great Cypress Swamp, Delaware during 2006-2007.

CHAPTER 4

EXCURSIVE BEHAVIORS BY FEMALE WHITE-TAILED DEER DURING ESTRUS[1]

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[1] Kolodzinski, J. J, K. V. Miller, L. V. Tannenbaum, L. I. Muller, D. A. Osborn, K. A. Adams, M. C. Conner, and W. M. Ford. To be submitted to the American Midland Naturalist.

ABSTRACT

Current research suggests that female white-tailed deer (*Odocoileus virginianus*) will adopt sedentary breeding strategies in populations with an abundance of males and a more active mate-searching strategy in low-density or unbalanced herds. We used GPS collars to document the movements of 10 female deer during the breeding season at Chesapeake Farms, Maryland and the Great Cypress Swamp, Delaware, that both support high high-density herds with nearly equal sex ratios. We calculated 95% and 50% seasonal and weekly kernel home ranges and the daily percentage of points located outside of the seasonal home range. Peaks in weekly home range and in the percentage of points located outside of the seasonal home range occurred between Nov. 7 and Dec. 9 ($\bar{x}$ = Nov. 22) for eight of the 10 deer. Past data from Chesapeake Farms have indicated that most breeding activity occurs from Nov. 5 – 25. Peaks in the percentage of points outside of the seasonal home range that we recorded corresponded to brief ($\bar{x}$ = 24.0 hrs, SD = 18.2 hrs; range 8-68 hrs) excursions from the seasonal home range. On peak days, we observed that 46-100% ($\bar{x}$ = 68.3 %, SD = 17.1%) of data points were located outside of the seasonal home range. No other significant excursions were observed during the study period. Our results suggest that female deer may travel outside of their home range during the breeding season even when presented with an abundance of potential mates. We believe that this provides some evidence to suggest females are engaging in a discrete form of mate selection.

INTRODUCTION

Conventional beliefs suggest that female white-tailed deer (*Odocoileus virginianus*) likely play a passive role in mate selection. However, Ozoga and Verme (1975) reported increased activity among penned females just prior to conception, providing the first evidence that females may play a more active role in breeding activities. Subsequent research has reported increased activity or home range expansion among females during the rut (Ivey and Causey 1981, Labisky and Fritzen 1998, D'Angelo et al. 2004), including large excursions outside of their home range at the estimated time of conception (Holzenbein and Schwede 1989, Sawyer et al. 1989, Labisky and Fritzen 1998, D'Angelo et al. 2004). Presumably, these excursions are efforts by females to find suitable mates. In contrast, other studies have reported decreased activity and constricted home ranges among females during rut (Ivey and Causey 1981, Holzenbein and Schwede 1989, Beier and McCullough 1990).

Changes in activity levels at the time of estrus may be related to the presence or absence of suitable mates. In areas of high deer density or when presented with an abundance of mature males, females would be expected to use their core areas more frequently during estrus to be predictably found by males (Holzenbein and Schwede 1989). However, in low-density populations or when relatively few mature males are present, females may actively search for prospective mates to ensure successful breeding (Labisky and Fritzen 1998, D'Angelo et al. 2004).

Many deer populations have female-biased sex ratios due to greater male mortality rates from hunting and natural causes. Under these conditions, females may need to invest significant energy in mate-searching behaviors. In contrast, recent deer management efforts to promote more-balanced herds with mature male age structures should result in more sedentary breeding behaviors among females. However, even with a nearly equal sex ratio, D'Angelo et al. (2004) reported excursive behaviors among females at the purported time of estrus in a South Carolina deer herd, perhaps due to the low deer density (~5 deer/km^2) on the study area.

Although the suggestion that female deer will use the most energy-efficient strategy to breed has support, Sawyer et al. (1989) documented large excursions by three female deer in an unhunted, high-density Georgia deer population. Holzenbien and Schwede (1989) also observed a large excursion by a single female under high-density conditions on a Virginia study site. The sex ratio and male age structure on their study sites, however, were not reported. Therefore, the breeding activity of adult female deer in populations with an abundance of adult males remains unclear. To help better understand the breeding behavior of female deer, we designed our study to investigate rut-related movements of adult female deer in two moderate-high density, managed (hunted) deer populations with an abundance of adult males.

STUDY SITES

Our study was conducted at Chesapeake Farms (CF) in Kent County, Maryland and the Great Cypress Swamp (GCS) in Sussex County, Delaware. Chesapeake Farms is a 13.4-km^2 research and demonstration property owned by Dupont Agricultural Enterprise. Tomberlin (2007) characterized CF as 50% forested (primarily oak/hardwood), 33% agricultural fields (primarily soybean and corn), 14% managed wildlife habitat, and 3% impoundments. The GCS, owned by Delaware Wild Lands Incorporated, is a 44.5-km^2 unfragmented, low-lying, mixed hardwood forest containing sizeable stands of loblolly pine (Pinus taeda), surrounded by rich agricultural lands.

Both study sites support deer densities between 30-40 deer/km^2 and are intensively managed by selective harvest guidelines to promote deer herds with nearly equal sex ratios and mature male age structures. Shaw (2005) determined the CF preharvest deer density to be 33 deer/km^2. In 2006, the CF deer population had a sex ratio near 1:1.5 (M.C. Conner, Chesapeake Farms, unpublished data). In 2005, the GCS area was determined to have one of the highest deer densities in Delaware, approximately 36 deer/km^2 (DNREC 2006) and a camera survey in 2006 estimated the sex ratio to be near 1:1.

The 2006 hunting season at CF opened on Sept. 15 and concluded on Dec. 29; however, hunting at the Farm was focused between Nov. 24 and Dec 8. Hunting seasons at GCS spans from Sept. 1 – Jan. 31, although shotguns and or muzzleloaders are only permitted Oct. 6 – 30, Nov. 10 – 18, Dec. 9 – 16, and Jan. 13 – 27.

METHODS

We captured adult female deer (≥ 1.5 years old) at GCS from Feb-April 2006 and at CF from June-Aug 2006 using a combination of free-darting and rocket nets. We used 3-ml transmitter darts (Pneu-dart Inc., Williamsport, Pennsylvania, USA) with a 7.0 mg/kg Telazol® (Fort Dodge Animal Health, Fort Dodge, Iowa, USA)/ 6.5 mg/kg xylazine hydrochloride (Cervizine®, Wildlife Laboratories, Inc., Fort Collins, Colorado, USA) mixture to immobilize animals. Deer captured in rocket nets were immobilized with a 10.7 mg/kg ketamine hydrochloride (Ketaset®, Fort Dodge Animal Health, Fort Dodge, Iowa, USA)/ 2.2 mg/kg xylazine hydrochloride injection. Dosages were calculated assuming an average weight of 70 kg at GCS and 45 kg at CF. During immobilization we monitored heart and respiration rates, treated minor injuries, lubricated eyes, and blindfolded deer. We estimated deer ages based on dental eruption and wear (Severinghaus 1949). We fitted deer with activated, Televilt Tellus® Basic, 5H1D GPS collars (Televilt/TVP Positioning AB, Lindesberg, Sweden). After being immobilized for 90 minutes all deer captured through darting received a 400 mg injection of tolazoline hydrochloride (Tolazoline®, Lloyd Laboratories, Shenandoah, Iowa, USA) to reverse the effects of the immobilization agent. Deer immobilized with a ketamine/xylazine were reversed with a similar injection after 30 minutes. We monitored all deer until they were fully ambulatory. Animal handling procedures were approved by the University of Georgia Institutional Animal Care and Use Committee (#A3437-01).

Collars were programmed to collect and store 3D GPS locations in the form of X, Y coordinates on their nonvolatile memory. The collars were programmed to collect 32 locations per day at equal intervals during the study period. The GPS collars were equipped with a VHF beacon which allowed regular mortality checks. At the end of the study period, activation of a remote-release mechanism caused functioning collars to fall from the animal. The Televilt Tellus® TPM Project Manager software (Televilt/TVP Positioning AB, Lindesberg, Sweden) was used to download the data.

We included two additional datasets from adult does previously collared at CF (Muller et al. 2006) in our analyses. These deer were collared with Lotek GPS-2200 GPS Collars (Lotek Engineering, Ontario, Canada). One dataset, from 2001, collected data locations at 4-hour intervals, whereas the other dataset, from 2002, collected locations every 2 hours.

We were able to obtain eight useable datasets spanning the Fall 2006 breeding season (five from CF and three from GCS). Most datasets contained 17 weeks of data from Oct. 1, 2006 to Jan. 27, 2007. One data set contained data from Oct. 1 – Dec. 11, 2006. The datasets from 2001 and 2002 span from Oct. 1 – Nov. 22 and Oct. 1 – Nov. 30, respectively.

Locations with dilution of precision (DOP) values >6 were filtered resulting in an average fix rate of 92%. Because the collars failed to collect the needed satellite information, data could not be differentially corrected. However, it is unlikely that differential correction would have significantly affected the data (Dussault et al. 2001).

We assessed the accuracy of our data by placing an unused GPS collar at four locations of different habitat type and allowed it to collect data for 1-2 days. We filtered the data as described above. Our results indicated that 70% of the data was within 30 m of the true location and 92% of the data were within 75 m.

We calculated 95% and 50% seasonal kernel areas using the Home Range Tools for ArcGIS extension (Rodgers et al. 2007). We used all locations collected between Oct. 1 and Jan. 27 to calculate seasonal home ranges. We also calculated kernel ranges for each of the 17 weeks. For each 24-hour period, we inspected the data to identify obvious excursions outside of the seasonal home range. We also calculated the percentage of points located outside of the seasonal home range for each week and day. Because of the less-frequent sampling rate in 2001, points collected during that deer's excursion were not included in seasonal home range analyses.

In early 2008, five adult female deer were harvested at CF and fetal measurements (Hamilton et al. 1985) indicated that conception had occurred between Nov. 6 and 23 with an average conception date of Nov. 15. At CF, Tomberlin (2007) had previously determined the peak of breeding activity to occur between Nov. 5 and 25, noting that 82% of neonate captures (N = 139) at CF occurred between May 24 and June 8.

RESULTS

Nine of the 10 does we monitored showed discernable peaks in weekly home range and core area size (Figure 1), corresponding to peaks in the percentage of weekly points located outside of the seasonal home range (Figure 2). Eight of the nine peaks occurred between Nov. 7 and Dec. 9 ($\bar{x}$ = Nov 22) whereas the peak for the other doe (1.5 years old) occurred on Dec. 30. Our analyses indicated that these peaks in the percentage of points outside of the seasonal home range occurred over a 1-4-day period (Figure 2). On these days, 46-100% ($\bar{x}$ = 68.3 %, SD = 17.1%) of data points were located outside of the seasonal home range. The locations outside of the seasonal home ranges corresponded with relatively brief ($\bar{x}$ = 24.0 hrs, SD = 18.2 hrs; range 8-68 hrs) excursions from the seasonal home range. Seven of 10 deer made a single excursion. One deer did not make any notable excursions. The two remaining deer made excursions lasting approximately 14 hrs, returned to their home ranges and then repeated these excursions the following night to the same area. We observed both long and short-distance excursions (Figure 3).

Four deer were observed to make long-distance travels (2.36 – 4.78 km, $\bar{x}$ = 3.23, SD = 1.11 km). These movements occurred in a straight line over a few hours. Each deer occupied a new area for several hours and then returned to their normal seasonal home ranges. Two deer made long-distance excursions that crossed a 100-150 m wide embayment of the Chesapeake Bay. Short-distance travels (0.57 – 1.05 km, $\bar{x}$ = 0.86 km, SD = 0.20 km) were observed in the remaining five individuals. These movements were characterized by travels to areas adjacent to the seasonal home range. Deer also remained in these locations for a few hours and then returned to their normal home range area. No other significant excursions outside of the seasonal home ranges were observed for any deer over the study period.

DISCUSSION

Our data mimic those previously collected from low-density and/or unbalanced herds (Ozoga and Verme 1975, Ivey and Causey 1981, Holzenbein and Schwede 1989, D'Angelo et al. 2004). However, if females used the most energy-efficient strategy to breed, then the high densities and balanced sex ratios of our study sites would have suggested that females would adopt a more sedentary breeding strategy (Ivey and Causey 1981, Holzenbein and Schwede 1989, Beier and McCullough 1990). In contrast to expectations, we observed that most females made a single excursion outside of their home range during a time when conception might have occurred. Eight of the nine excursions occurred in mid- to late November during the time of intense breeding activity. The exception came from the only yearling female in the study, who did not conduct an excursion until late December. Delayed conception, and hence late excursions, could be associated with a deer of that age (Ozoga and Verme 1982).

Accordingly, we posit three hypotheses may explain these movements: 1) increased harassment by rutting males during tending, 2) movements associated with hunting pressure, 3) mate selection by females.

Because these excursions were relatively rare and ubiquitous among the females, we believe that harassment or disturbances associated with hunting pressure is an unlikely cause. Hunting-related excursions might be expected to occur over the entire hunting season. In addition, several of these excursions occurred before any major hunting activity and Sawyer et al. (1989) documented similar excursions in a non-hunted population in Georgia.

Harassment by males outside of the tending phase of courtship similarly would be expected to occur on multiple occasions and to span most of the breeding season. Rather, these one-time excursions reliably correspond to the peak of the breeding season and the timing of conception. Although we cannot directly tie these events to the formation of tending bonds, it appears likely that conception occurred around the time of these movements. Unfortunately, our data do not let us definitively evaluate whether the excursions are a result of tending behaviors between the sexes and selection for isolated breeding areas, or active searching for a suitable male by the does. However, the fact that these excursions tend to be relatively straight-line travels of several kilometers outside of the does normal home range suggest that active searching by the female is the plausible explanation.

Even in high-density herds with balanced sex-ratios, females might still need to search for prospective mates since the relative abundance of mature males to reproductively mature females may be low. If most males are preoccupied with receptive females, then females entering estrus may be forced to engage in mate-searching behaviors. However, the fact that all of the does in our study displayed excursive behavior suggests that females may be engaging in discrete selection for the most reproductively fit breeding partner.

Although some previous studies have not reported similar movements (Ivey and Causey 1981, Holzenbein and Schwede 1989, Beier and McCullough 1990), the relatively infrequent sampling schedules associated with traditional radio-telemetry may have failed to document these relatively brief movements. Our study using GPS technology suggests that excursive movements associated with breeding behaviors of female deer may be more common that previously reported.

Clearly, female deer in our study traveled outside of their home range around the time of conception. Both male and female deer have a vested interest in finding the best possible mate. While males commonly compete for breeding rights, we suggest that the movements observed in our study are the result of a more discrete form of mate selection by female deer.

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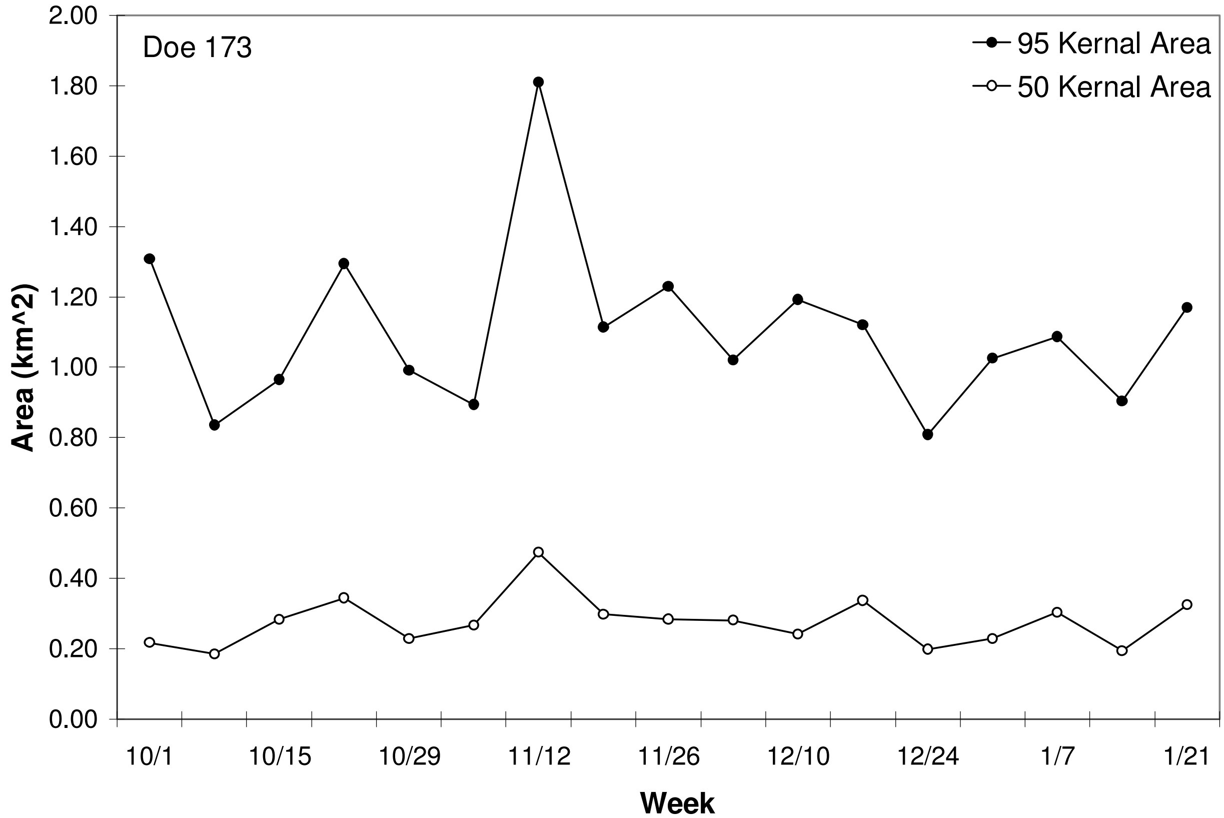

Figure 4.1 Example of weekly home range sizes (95% and 50% kernel) over the 17 week study period (244 locations/week) for Doe 173 at the Great Cypress Swamp, Delaware, 2006.

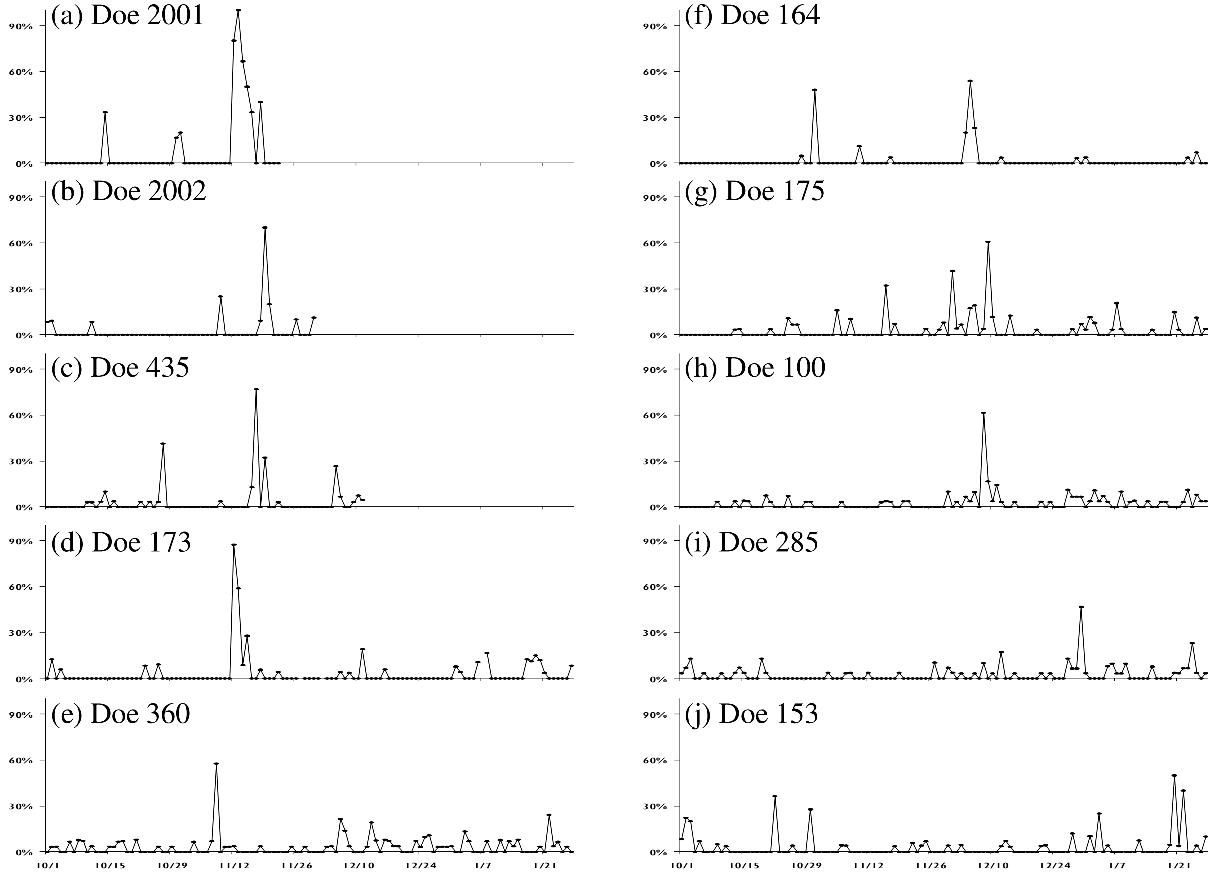

Figure 4.2 Percentage of locations outside of each adult female white-tailed deer's season home range per day at Chesapeake Farms, Kent County, Maryland during 2001 (a), 2002 (b), and 2006 (c, e, g-i) and the Great Cypress Swamp, Sussex County, Delaware during 2006 (d, f, j). No significant excursion was identified for deer (j). Subfigure (i) represent data collected from a yearling doe on Chesapeake Farms.

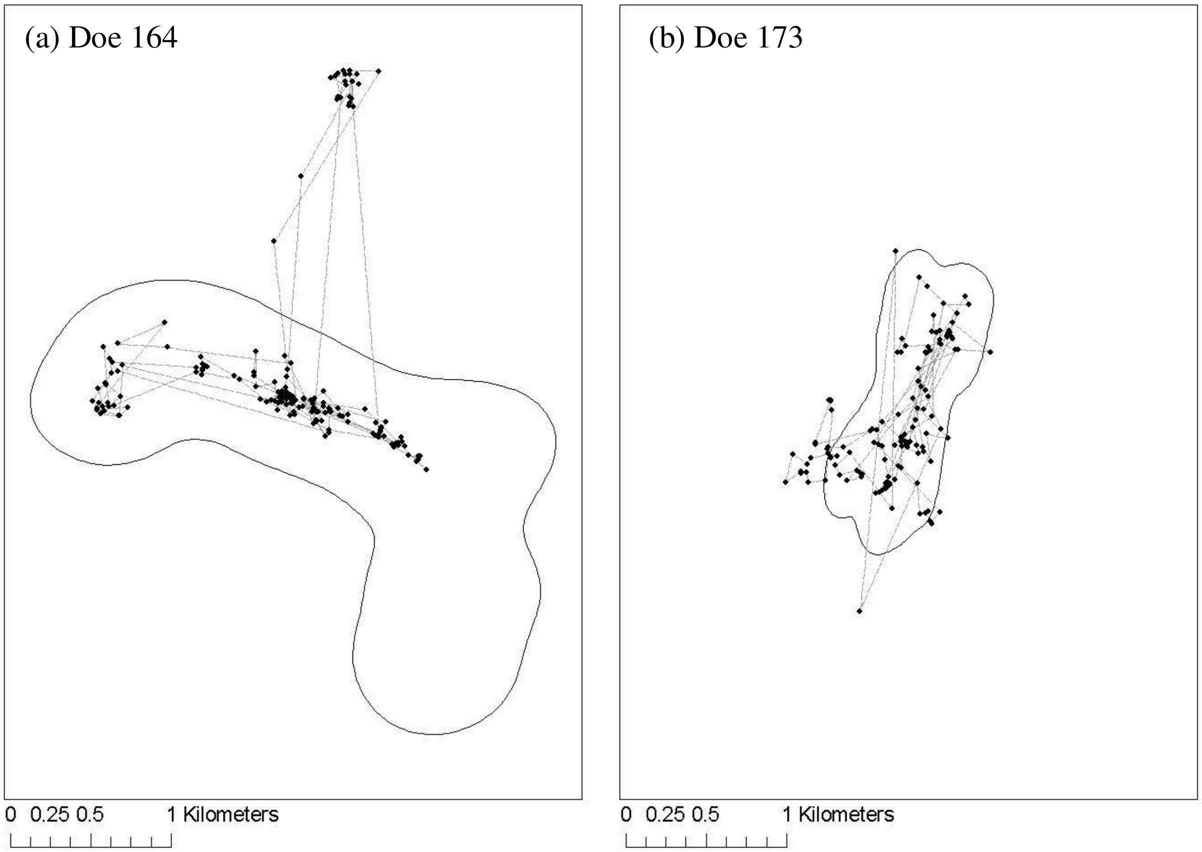

Figure 4.3 Examples of (a) long and (b) short-distance excursions outside of the seasonal 95% kernel area (solid black line) of two adult female white-tailed deer at the Great Cypress Swamp, Sussex County, Delaware during the 2006 breeding season. Individual data points represent observations during the week in which the excursion occurred.

CHAPTER 5

RHYTHMIC SHIFTS IN DAILY MOVEMENTS BY FEMALE WHITE TAILED DEER

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To be submitted to the Journal of Wildlife Management.

ABSTRACT

Activity patterns of white-tailed deer (*Odocoileus virginianus*) are at least partially affected by seasonality, weather or climatic conditions, and moon phase or position. Herein we report on variations in the daily movement patterns of female white-tailed deer that are unexplained by previously reported factors and are suggestive of endogenous rhythms in movement patterns.

INTRODUCTION

Activity patterns of white-tailed deer (*Odocoileus virginianus*) are at least partially affected by seasonality (Kammermeyer and Marchinton 1977, Tomberlin 2007), weather or climatic conditions (Progulske and Duerre 1964, Thomas 1966, Hawkins and Klimstra 1970, Michael 1970, Cartwright 1975, Marchinton and Hirth 1984, Beier and McCullough 1990), and moon phase or position (Buss and Harbert 1950, Thomas 1966, Michael 1970, Carbaugh et al. 1975, Kammermeyer 1975, Tomberlin 2007). In most cases, the aforementioned studies attribute the differences in activity patterns among white-tailed deer to feeding patterns and predator avoidance strategies. Seasonal differences in activity have been linked to changes in metabolic demands whereas temperature and precipitation can have positive or negative effects on feeding rates (Beier and McCullough 1990). Higher activity levels associated with grazing have also been reported on moonlit nights, that may allow deer to see predators (Buss and Harbert 1950). Herein we report on variations in the daily movements of female white-tailed deer that are unexplained by previously reported factors and are suggestive of endogenous rhythms in movement periodicity.

METHODS

We conducted our study at Chesapeake Farms (CF) in Kent County, Maryland and the Great Cypress Swamp (GCS) in Sussex County, Delaware. Chesapeake Farms is 13.4-km^2 of fragmented forest/agricultural land. The GCS is 44.5-km^2 of unfragmented forested habitat surrounded by productive agricultural land.

We deployed Televilt Tellus® Basic GPS collars on 15 adult female white-tailed deer (N = 10 at CF, N = 5 at GCS). We programmed the collars to collect 24 locations/day at equal intervals during February, March, August, and September and 32 locations/day during the other months. Animal handling procedures were approved by the University of Georgia Institutional Animal Care and Use Committee (#A3437-01).

We filtered out non-fix locations and locations with dilution of precision (DOP) values > 6, yielding an average fix rate of 92%. Because collars failed to collect the needed satellite information, we could not differentially correct the data; however, it is unlikely that differential correction would have had a significant effect on the data (Dussault et al. 2001). Data from a test collar revealed that 70% and 92% of filtered data were within 30 m and 75 m of the true locations, respectively.

We calculated the daily sum of distances between consecutive points using Hawth's Analysis Tools for ArcGIS (Beyer 2006). The average distance between consecutive points was determined by dividing the daily sum of distances between consecutive points by the difference of the number of points collected and the number of paths. A path was defined as a string of consecutive points. This method ensured that missing data points did not contribute to daily distance travel. Instead, the average distance traveled per day was calculated by multiplying the average distance between consecutive points by the maximum number of points collected per day minus one (either 23 or 31 depending on the sampling rate). The resulting trend was plotted and compared among deer. Although we examined data collected from all 15 deer, comparisons and regression analyses among deer were made between data from nine deer at Chesapeake Farms collected between 15 Aug. and 14 Sept. 2006 to eliminate movement variations caused by season or study site. This was the largest block of consecutive data from a single study site.

OBSERVATIONS AND DISCUSSION

Overall, the deer we monitored traveled an average of 3.36 km/day (Range 0.26 – 19.11 km/day, SD = 1.40 km/day, N = 2,950). The average minimum and maximum distance traveled per day among the deer was and 1.04 km/day (Range 0.26 – 1.95 km/day, SD = 0.46 km/day, N = 15) and 9.38 km/day (Range 4.78 – 19.11 km/day, SD = 3.98 km/day, N = 15), respectively.

Each deer showed an oscillating trend in daily distance traveled (i.e., Figure 5.1). Generally, deer movements showed peaks and nadirs occurring 3 – 5 times every two weeks. Distances traveled on peaks were about 2 -3 times greater than distances traveled during nadirs. The periodicity of the cycle appeared unpredictable. The distance traveled during peak and nadir days varied by individual. Some deer traveled as little as 0.26 km/day on nadir days, while others traveled no less than 1.94 km/day. Some of the variability in movement rates may be due to the seasonal and local differences in the datasets.

When comparing data from deer at the same time and study site, movements varied among deer. For example, one of the nine deer traveled no less than 2.07 km/day whereas another deer traveled as little as 0.50 km/day during the same period. Dates of high and low movement for individual deer did not reliably correspond among deer (Figure 5.2). For example, on 21 Aug. 2006 three of the nine deer demonstrated high rates of movement, whereas movements for four other deer were low. Also, regression analysis comparing rates of movement among these deer resulted in $R^2 < 0.01$.

This rhythmic-like movement of white-tailed deer is an undescribed behavior. Because the peaks in movements do not correspond among deer it seems unlikely that this behavior is the result of common external stimuli, such as moon phase or weather conditions. The observation that the period of these movements is not constant also questions whether this is a behavior innately ingrained in the species.

These movements may be the result of feeding cyclicity. However, these events may be the result of a combination of behavioral cycles and external stimuli occurring on an individual basis. For example, changes in movement rates may be associated with feeding patterns; and these patterns may be influenced by changes in dietary needs or preferences, predator avoidance strategies, intraspecific competition, or other factors. A highly controlled experiment, one in which animals could be monitored constantly, would be required to help shed light on the exact nature of these rhythmic patterns.

ACKNOWLEDGEMENTS

We thank the Department of Defense, U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM), and the U.S. Forest Service, Northern Research Station for funding this research and Dr. Nate Niblink for help with data analyses. Chesapeake Farms and Delaware Wild Lands Inc. allowed us to conduct this study on their properties. Ralph Fleege, Ron Haas, Vanessa Lane and Family, Dustin Rutledge, Jenny Petersen, Blake Fountain provided help in the field and Michael T. Scuse and the Delaware Department of Agriculture provided use of a dart rifle.

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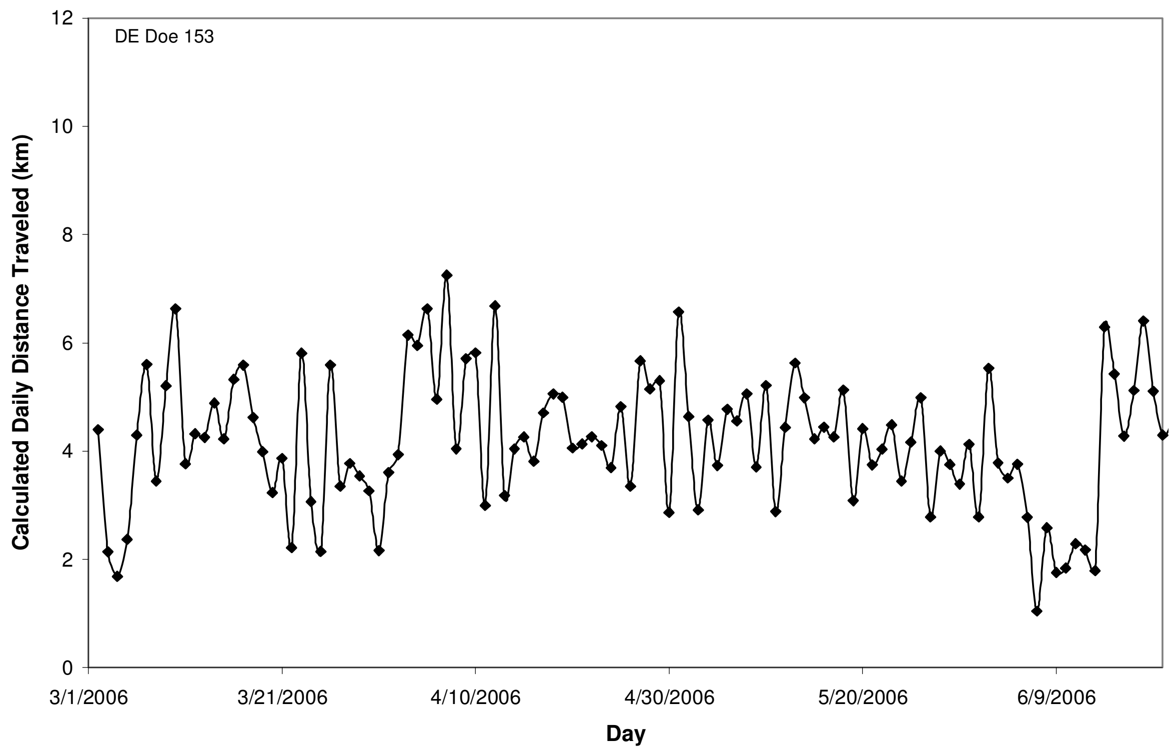

Figure 5.1 Daily distances traveled for one adult female deer at the Great Cypress Swamp, Sussex County, Delaware from March – June 2006.

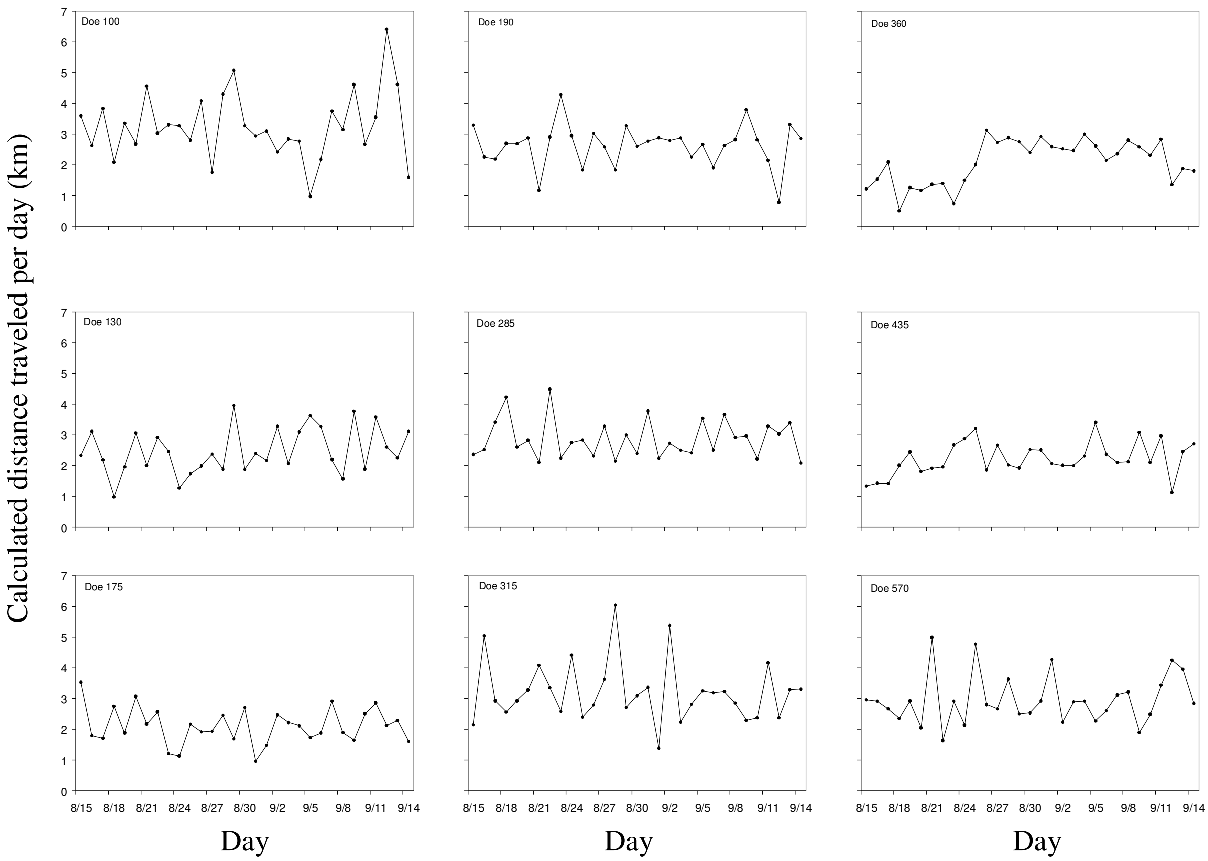

Figure 5.2 Daily distances traveled for nine adult female deer at the Chesapeake Farms, Kent County, Maryland from August 15 – Sept. 14, 2006 showing irregular frequencies in movement rates.

CHAPTER 6

SUMMARY AND MANAGEMENT IMPLICATIONS

SUMMARY

The usefulness of GPS technology in wildlife research is evident. Although my study experienced significant equipment failures, I still collected over 80,000 data locations. This wealth of data proved valuable to my analyses. My results showed that kernel home range size can be accurately predicted with as few as 15 data locations; however, many more locations are needed to correctly classify areas of use and nonuse. Ideally, an hourly sampling regime should be employed as larger datasets allow kernel areas to be described more precisely.

The intensive sampling regime also allowed me to report short-term excursions by female white-tailed deer during estrus. These excursions may not have been recorded had I used traditional radio collars. Although excursive movements by females during the rut have been commonly reported in low-density or unbalanced deer populations (Ivey and Causey 1981, Labisky and Fritzen 1998, D'Angelo et al. 2004), this study is one of the first to document movements in high-density, well-managed herds. This evidence is contrary to the current hypothesis on female breeding behavior, which suggests that females will only engage in mate-searching behavior when there are a limited number of suitable mates.

Finally, this research provides a humbling thought. Although white-tailed deer are one of the most researched animals in North America there is still a great deal that I have not discovered about their daily behaviors. Accurate GPS data and intensive sampling regimes helped reveal a rhythmic-like pattern in the daily-distance traveled by female deer. The cause for this pattern was not determined but opens the door for future research.

MANAGEMENT IMPLICATIONS

The applications of these data are diverse, as white-tailed deer are directly linked to humans and other species in many ways. White-tailed deer are a keystone species in many areas of the United States, drastically shaping habitats in which they exist. The effects deer populations have on humans range from recreational enjoyment to the monetary damages caused to landscaping and vehicles. Clearly, research on white-tailed deer is among the most tangible research in wildlife biology. Understanding how and why deer behave allows us to better manage deer population and meet management goals, whether they are to produce trophy animals or to prevent deer-vehicle collisions.

My results suggest that females may travel large distances from their normal home ranges to breed. This may have dramatic implications to deer management programs on small properties and stresses the importance of landowner collaboration to promote large-scale management efforts.

GPS technology has allowed researchers to collect larger datasets than past methods have allowed. Until this study, the way that these larger datasets affected home range analyses was not completely understood. Without intensive sampling regimes the conclusions reached in this research may not have been possible. My results outline the importance of high-intensity sampling designs for future home range studies.

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APPENDIX A.

EXCURSIONS OF FEMALE DEER FROM THEIR SEASONAL HOME RANGES OBSERVED DURING THE BREEDING SEASON AT CHESAPEAKE FARMS, KENT COUNTY, MARYLAND AND THE GREAT CYPRESS SWAMP, SUSSEX COUNTY, DELAWARE

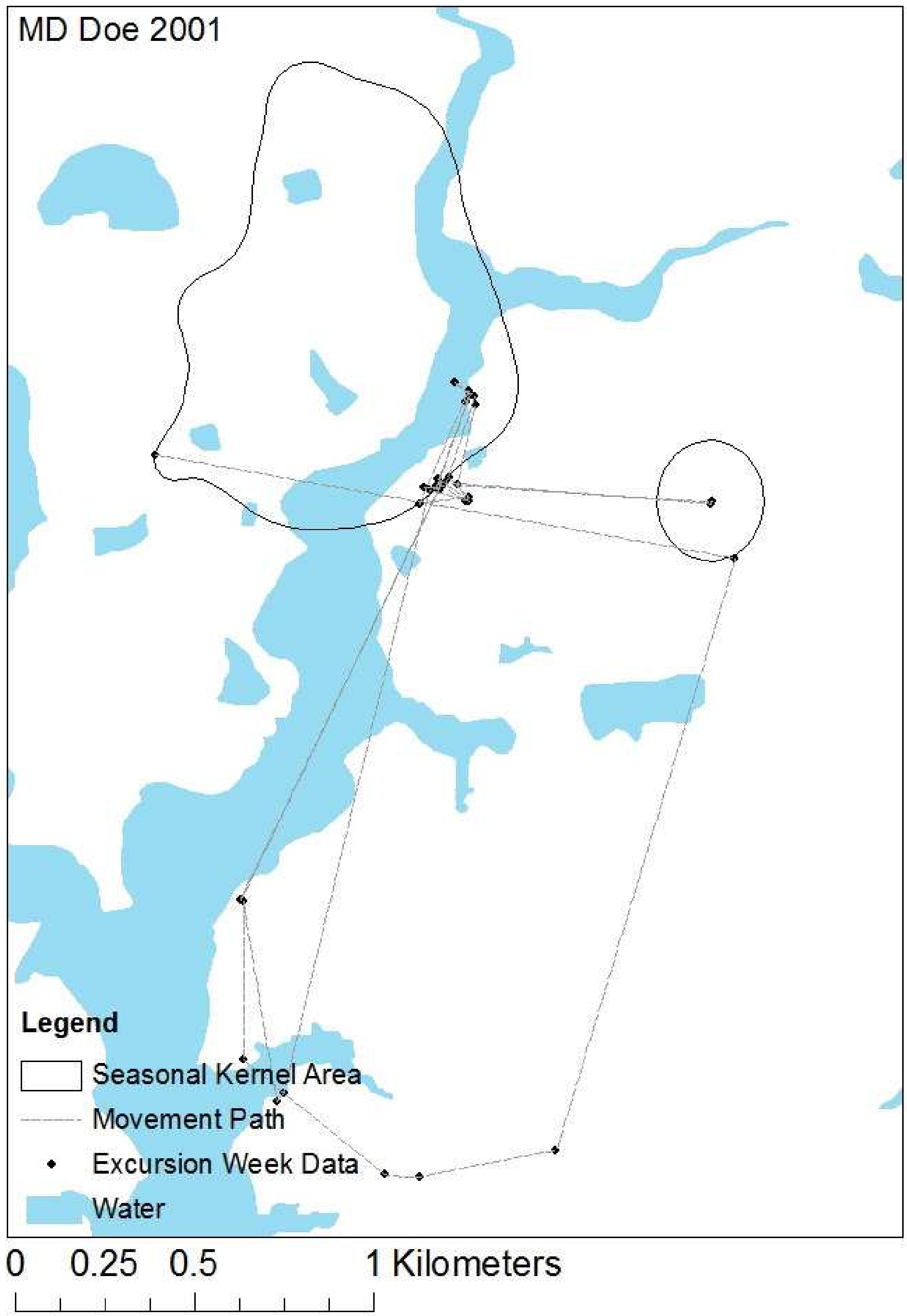


Figure 1. Seasonal home range and excursive movements of Doe 2001 at Chesapeake Farms, Kent County Maryland during 2001.

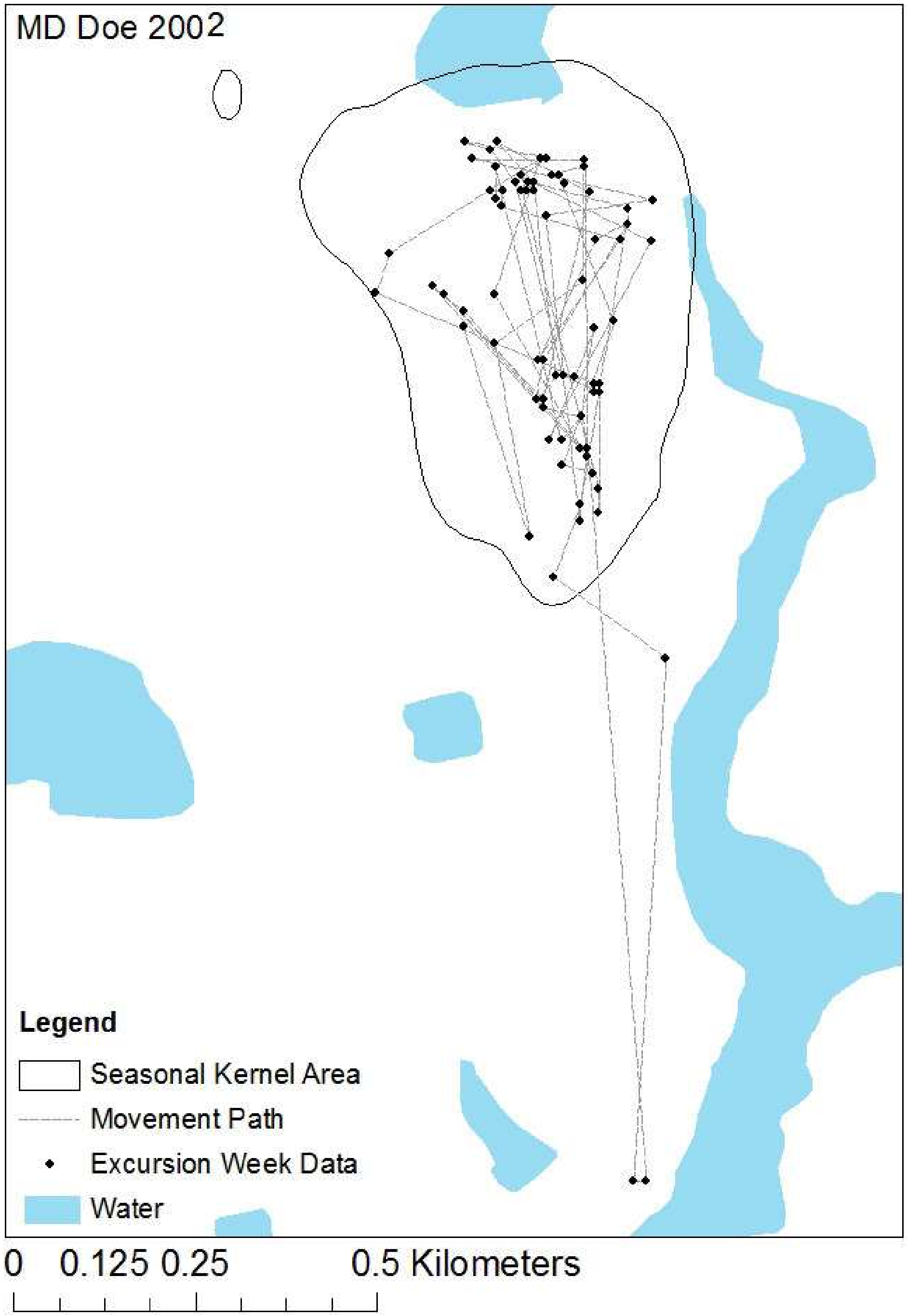


Figure 2. Seasonal home range and excursive movements of Doe 2002 at Chesapeake Farms, Kent County Maryland during 2002.

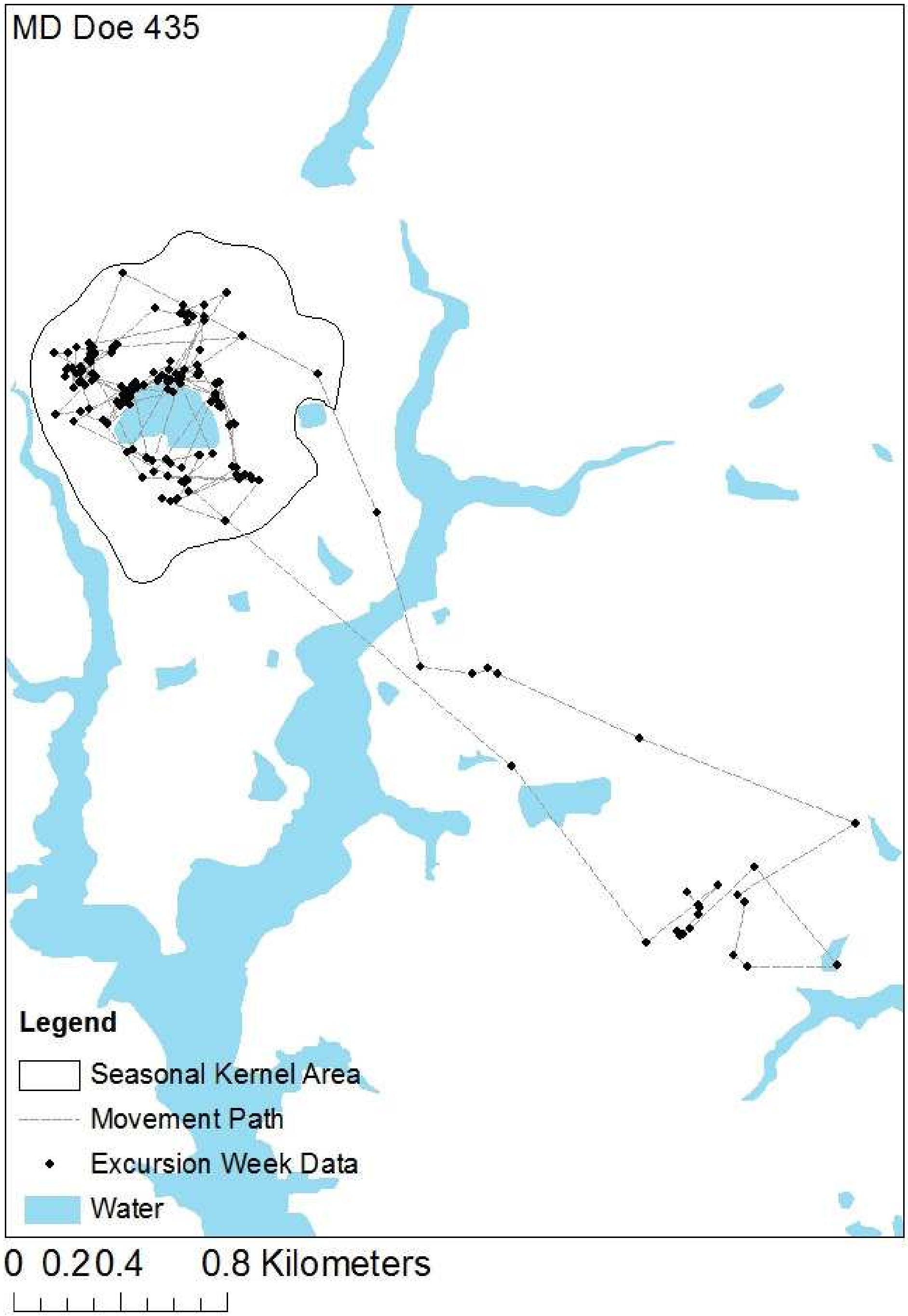


Figure 3. Seasonal home range and excursive movements of Doe 435 at Chesapeake Farms, Kent County Maryland during 2006.

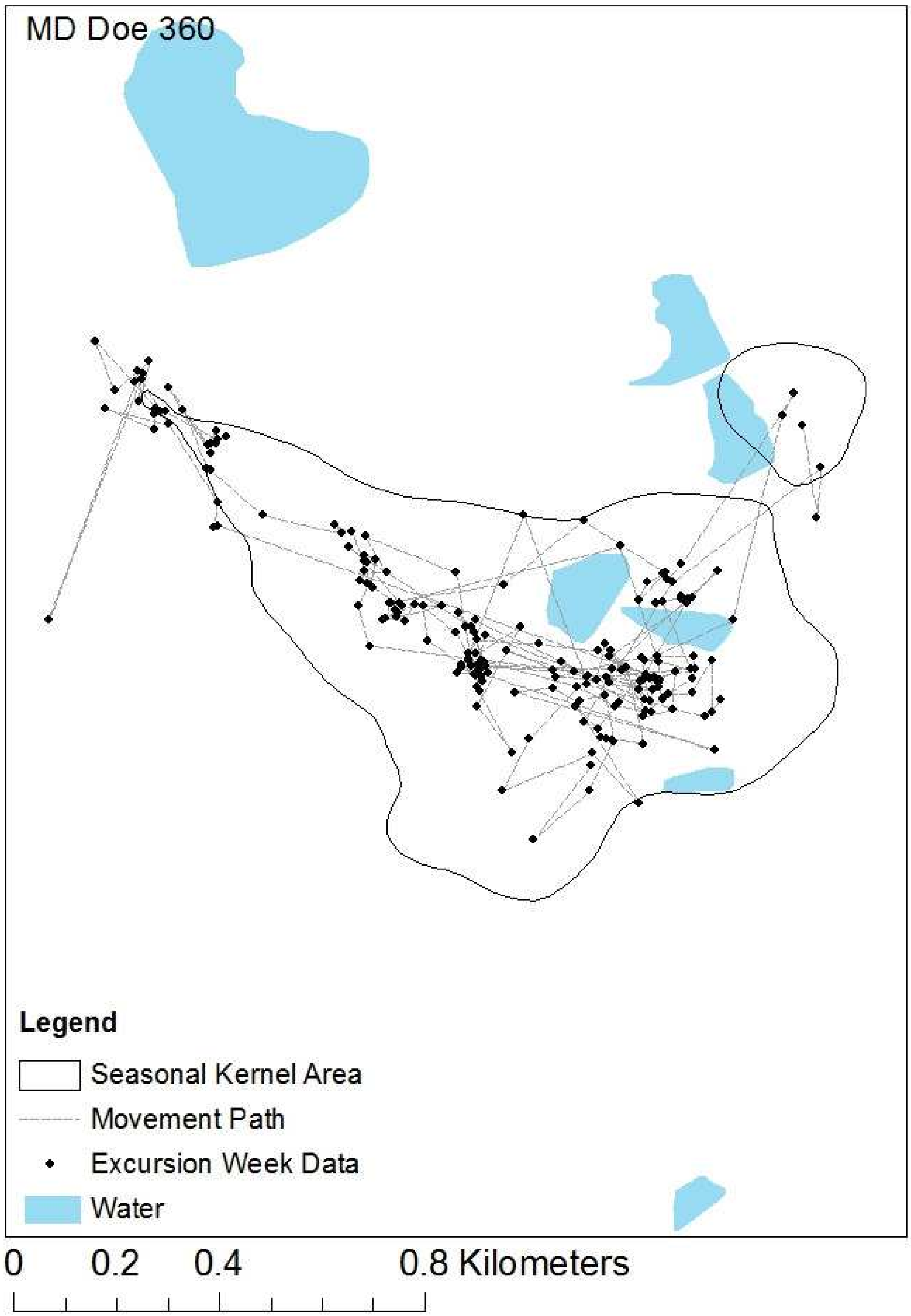


Figure 4. Seasonal home range and excursive movements of Doe 360 at Chesapeake Farms, Kent County Maryland during 2006.

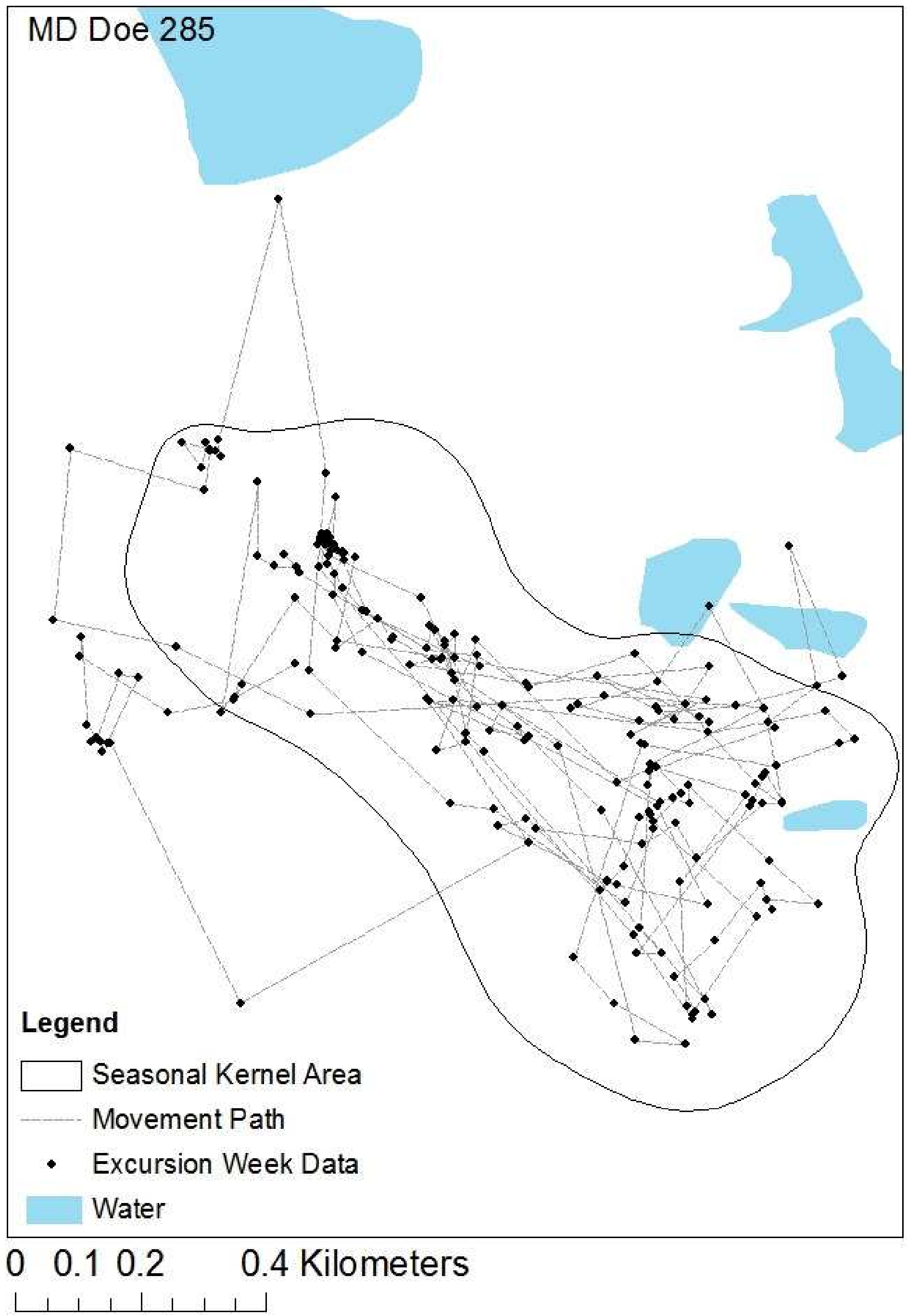


Figure 5. Seasonal home range and excursive movements of Doe 285 at Chesapeake Farms, Kent County Maryland during 2006.

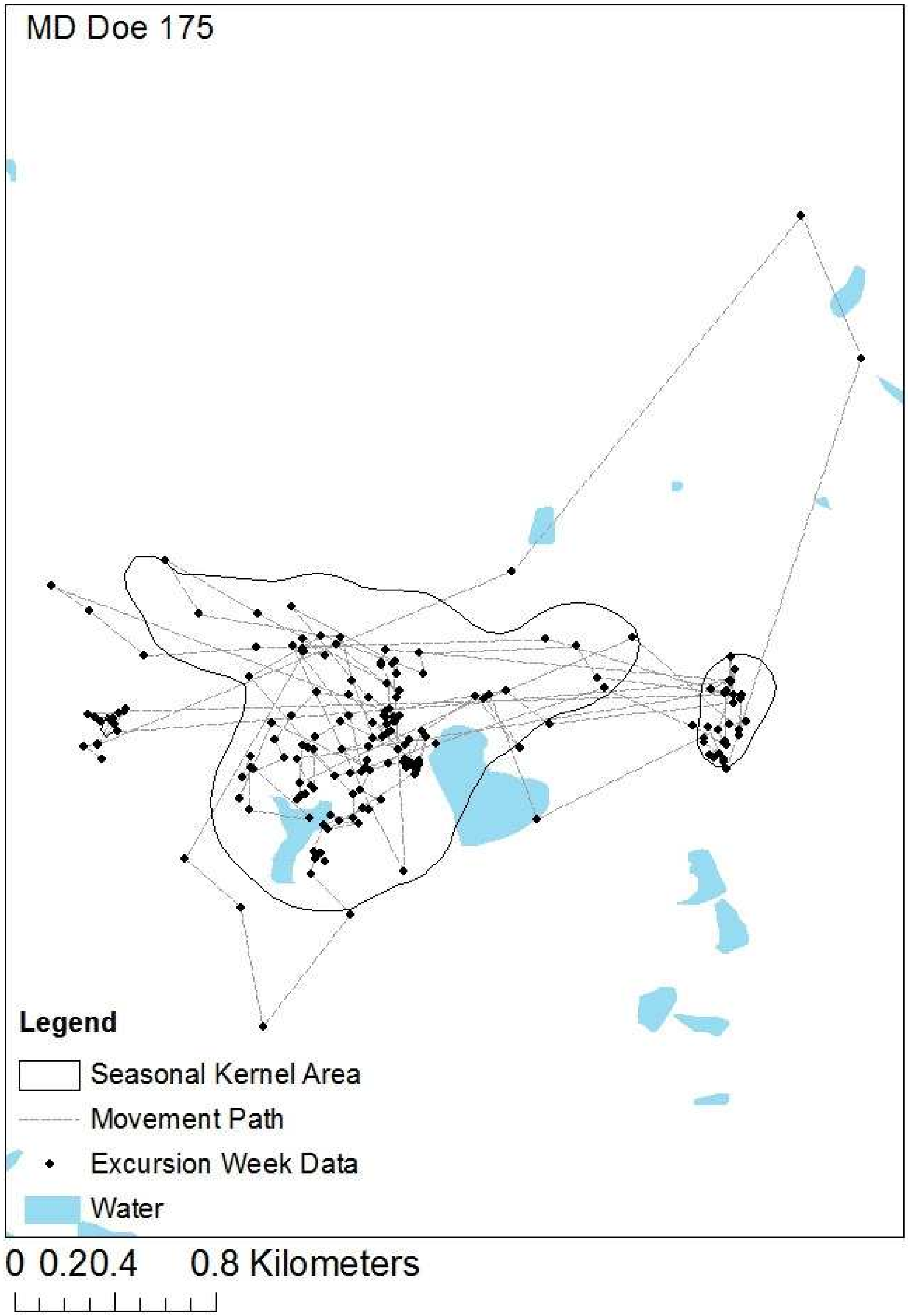


Figure 6. Seasonal home range and excursive movements of Doe 175 at Chesapeake Farms, Kent County Maryland during 2006.

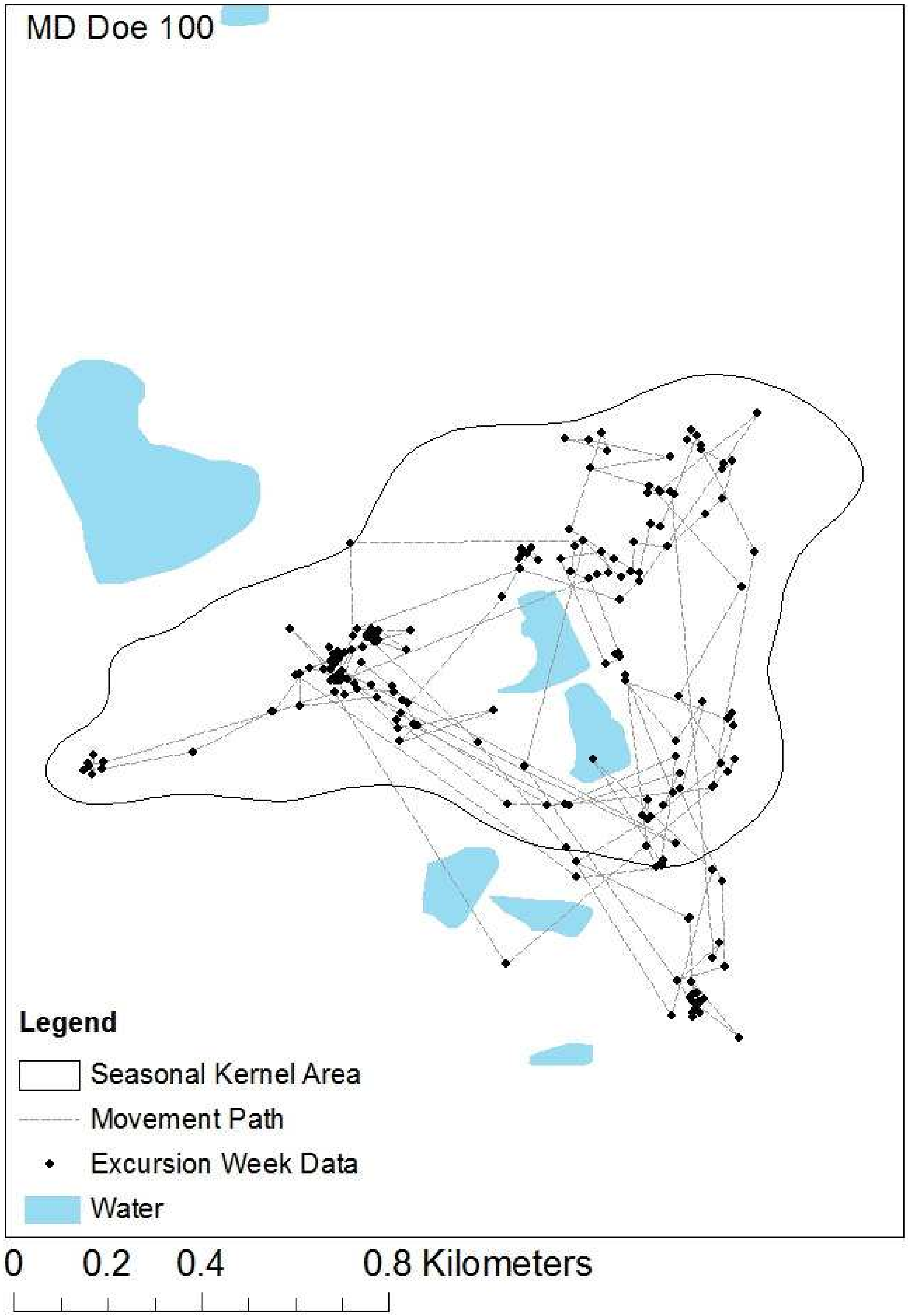


Figure 7. Seasonal home range and excursive movements of Doe 100 at Chesapeake Farms, Kent County Maryland during 2006.

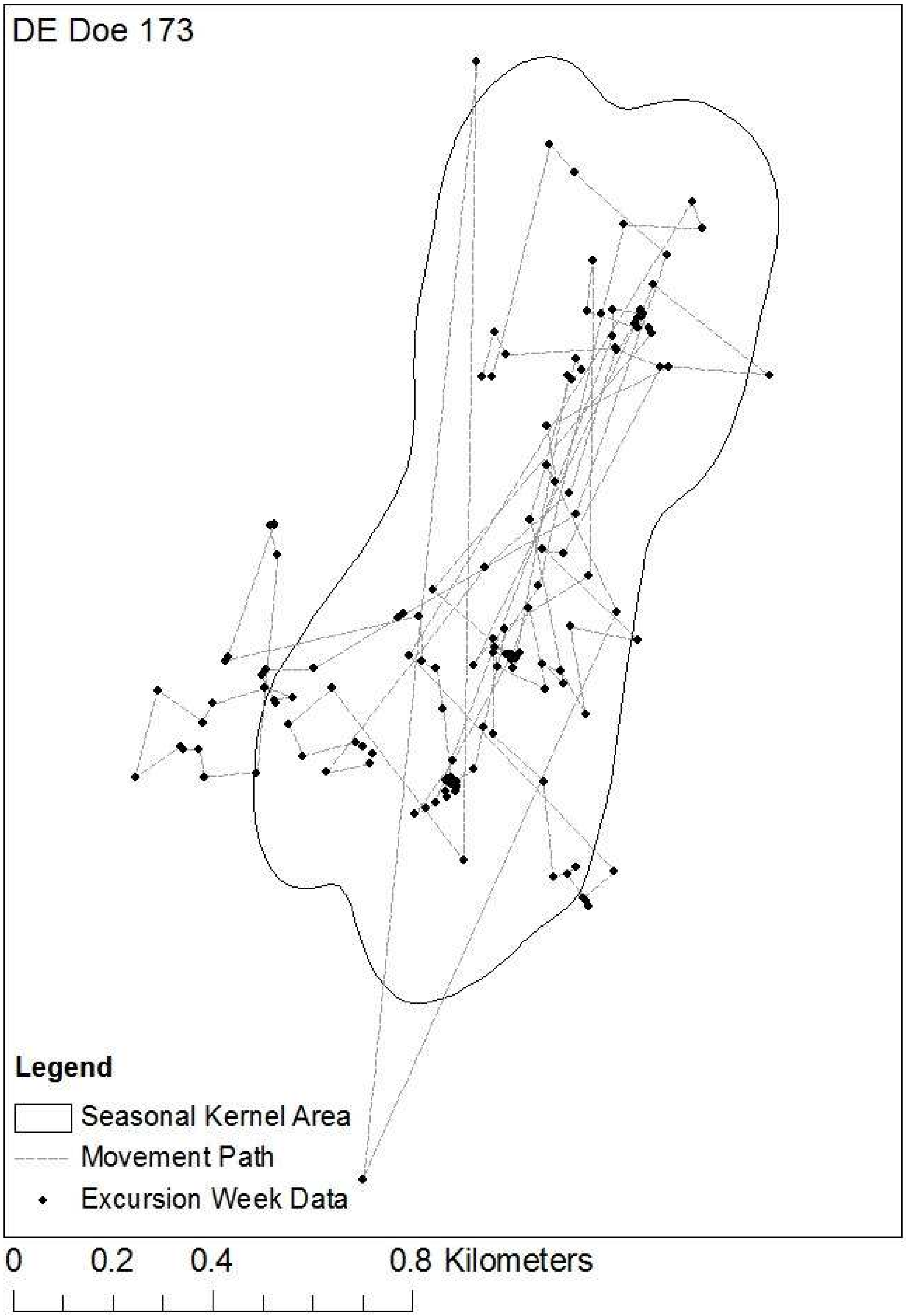


Figure 8. Seasonal home range and excursive movements of Doe 173 at the Great Cypress Swamp, Sussex County Delaware during 2006.

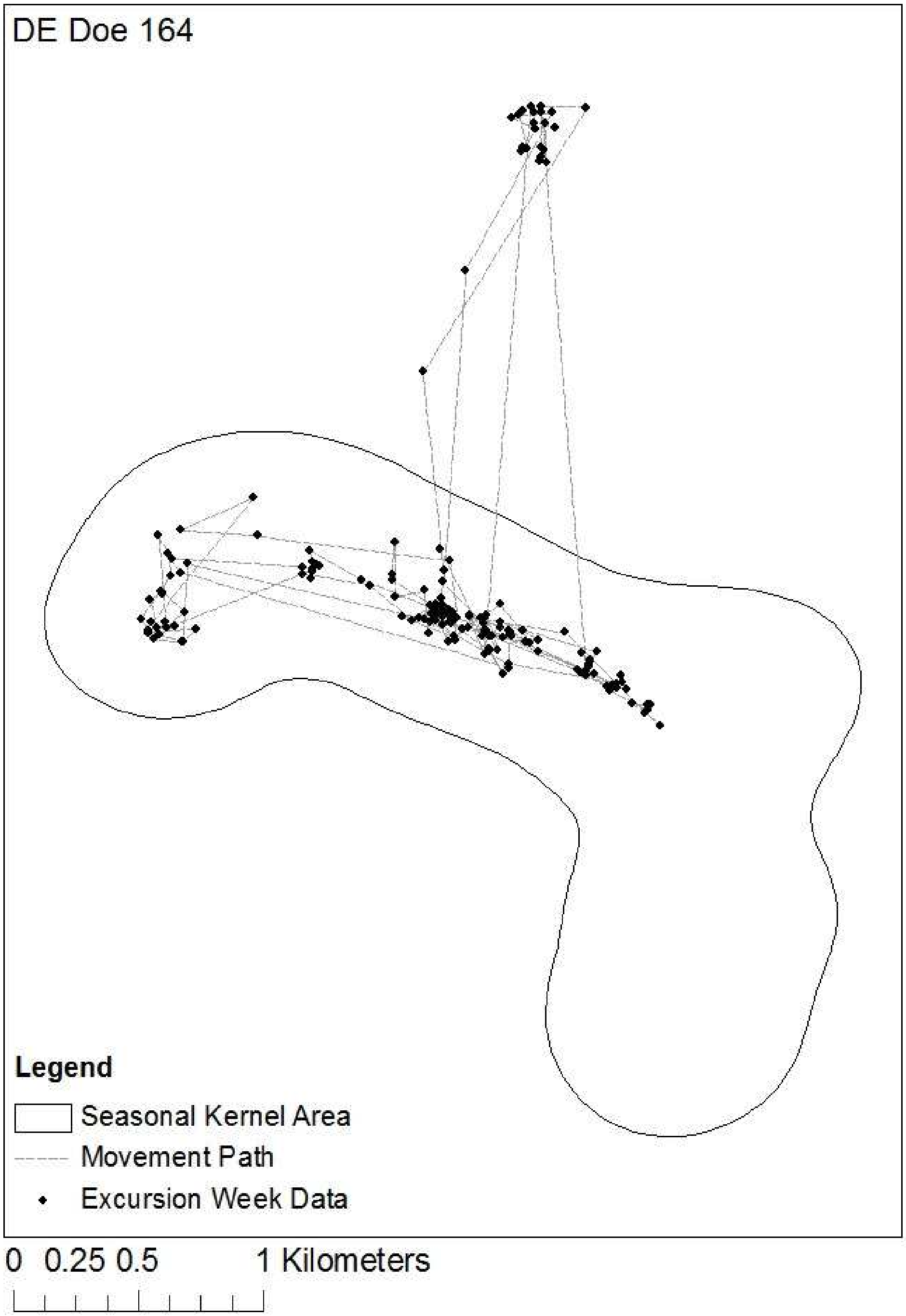
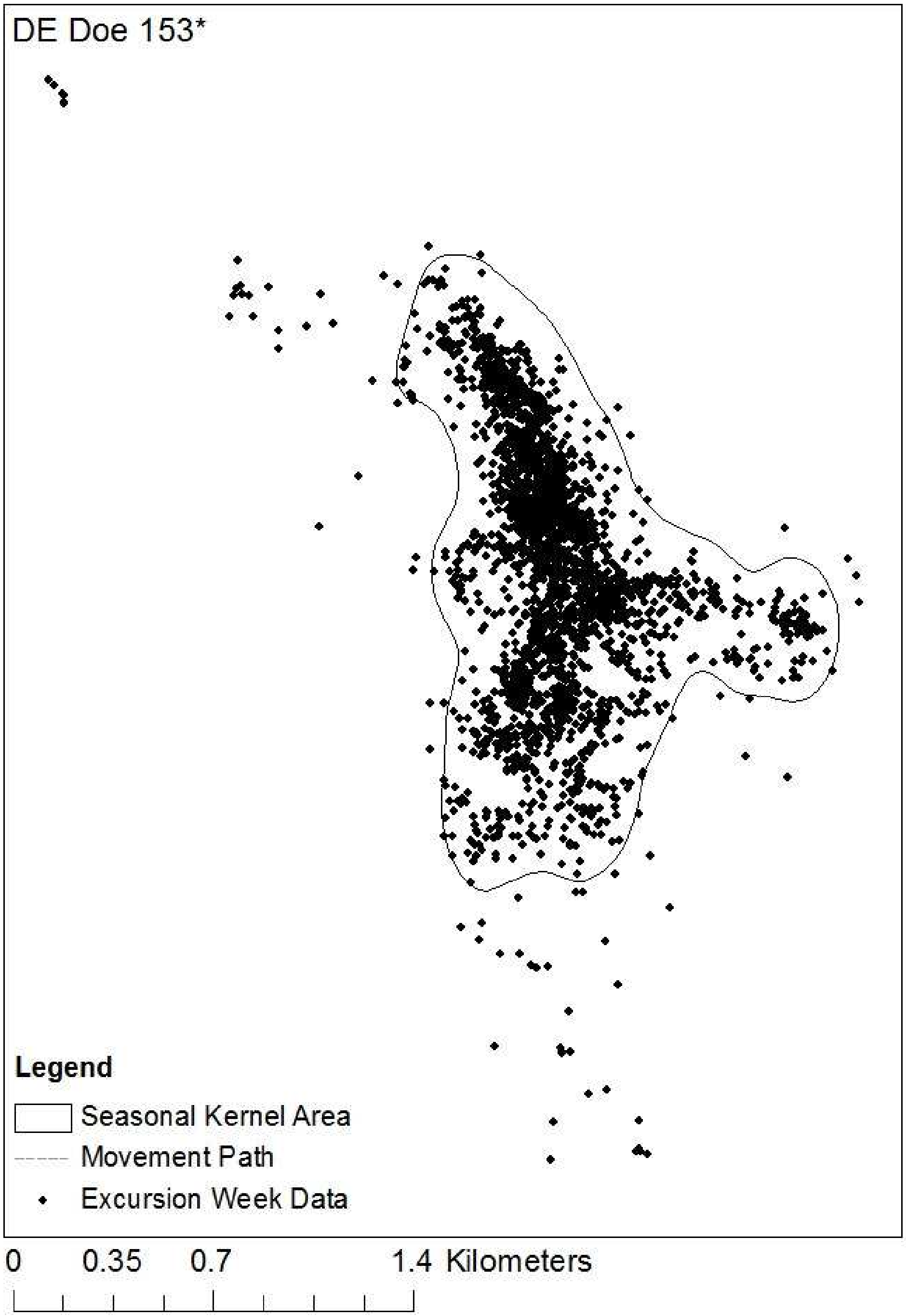


Figure 9. Seasonal home range and excursive movements of Doe 164 at the Great Cypress Swamp, Sussex County Delaware during 2006.


DE Doe 153*
Legend
Seasonal Kernel Area
Movement Path
Excursion Week Data
0
0.35
0.7
1.4 Kilometers

* This map displays data collected from Oct 1, 2006 – Jan 27, 2007 on DE Doe 153. No significant excursion during the predicted time of estrus was observed. The excursion located on the upper left part of the map occurred during between Oct 22 – Oct 28, much earlier than any breeding activity is expected to occur. The data points on the lower part of the map occurred sporadically over the study period and represent movements into an agricultural field.

Figure 10. Seasonal home range and excursive movements of Doe 153 at the Great Cypress Swamp, Sussex County Delaware during 2006.

APPENDIX B.

CHANGES IN THE DAILY MOVEMENT PATTERNS OF ADULT FEMALE DEER AT CHESAPEAKE FARMS, KENT COUNTY, MARYLAND AND THE GREAT CYPRESS SWAMP, SUSSEX COUNTY, DELAWARE

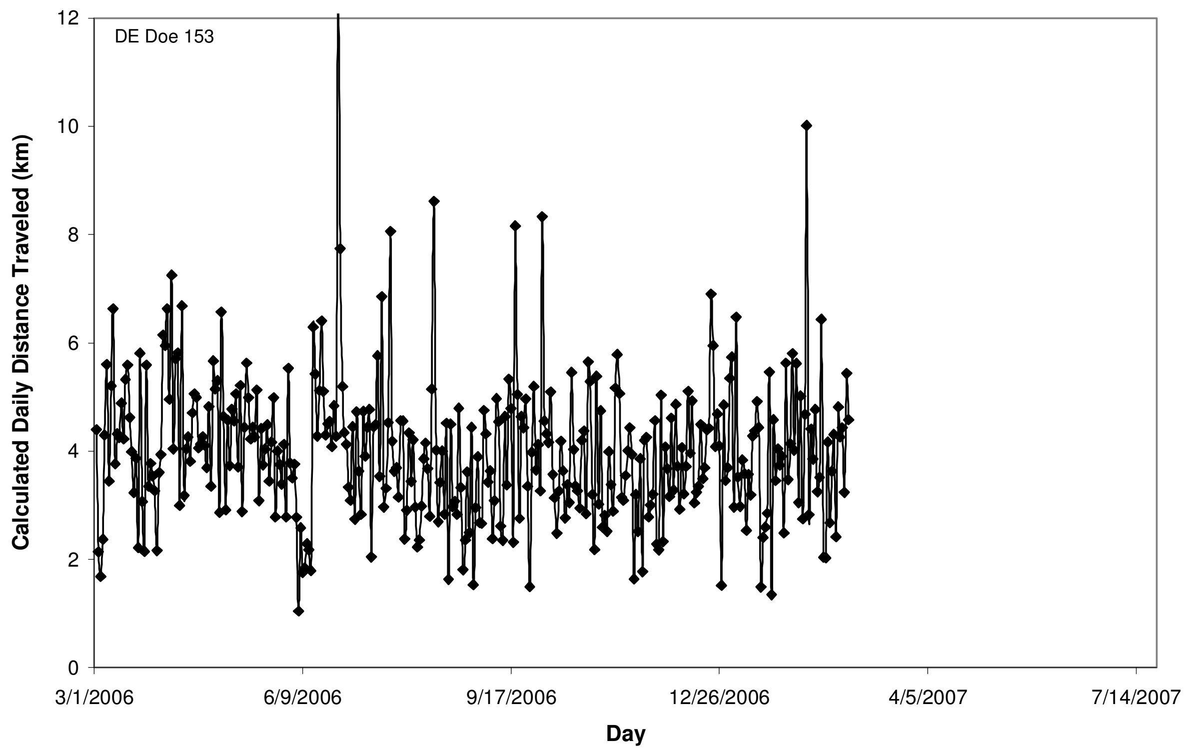


Figure 1. Daily distances traveled for Doe 153 at the Great Cypress Swamp, Sussex County, Delaware from 3/03/06 – 2/25/07.

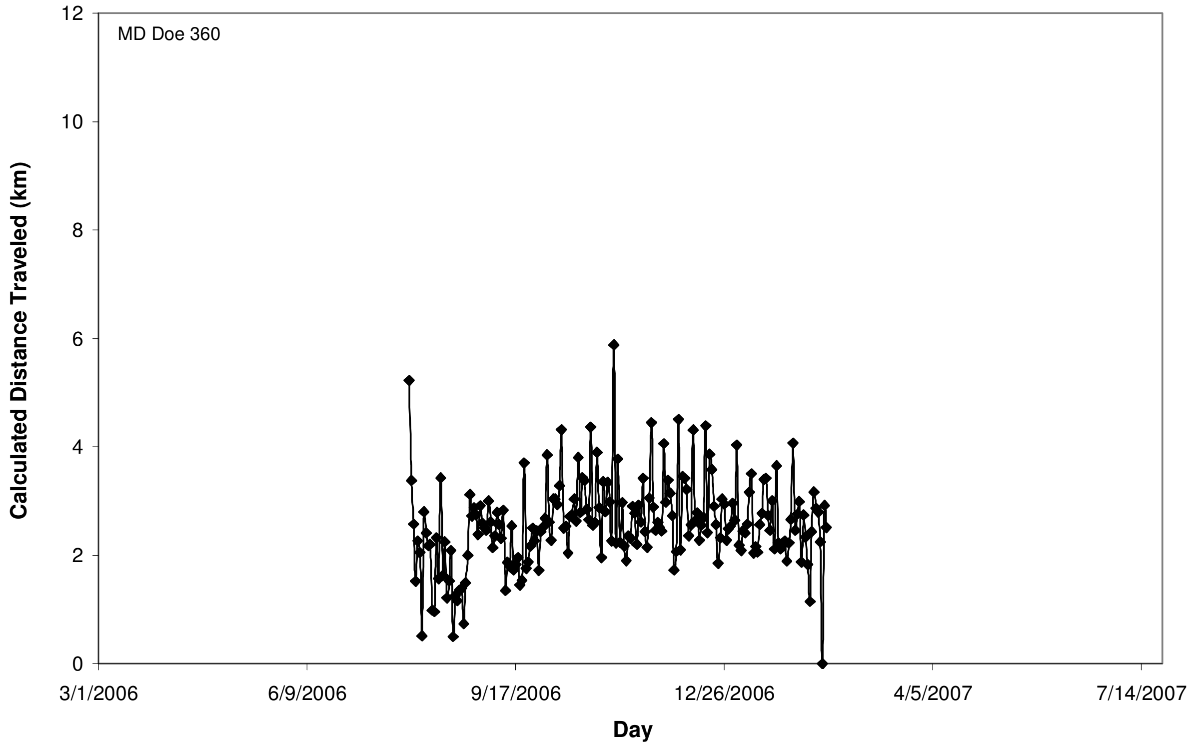


Figure 2. Daily distances traveled for Doe 360 at the Chesapeake Farms, Kent County, Maryland from 7/29/06 – 2/12/07.

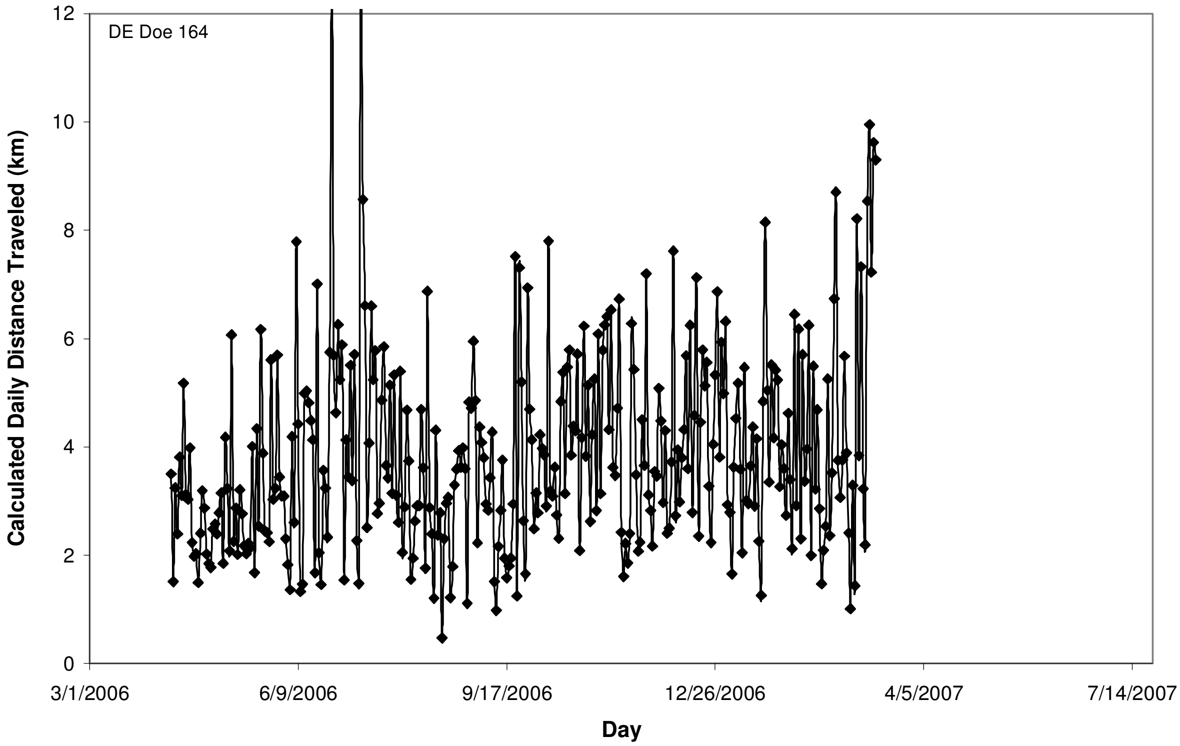


Figure 3. Daily distances traveled for Doe 164 at the Chesapeake Farms, Kent County, Maryland from 4/10/06 – 3/17/07.

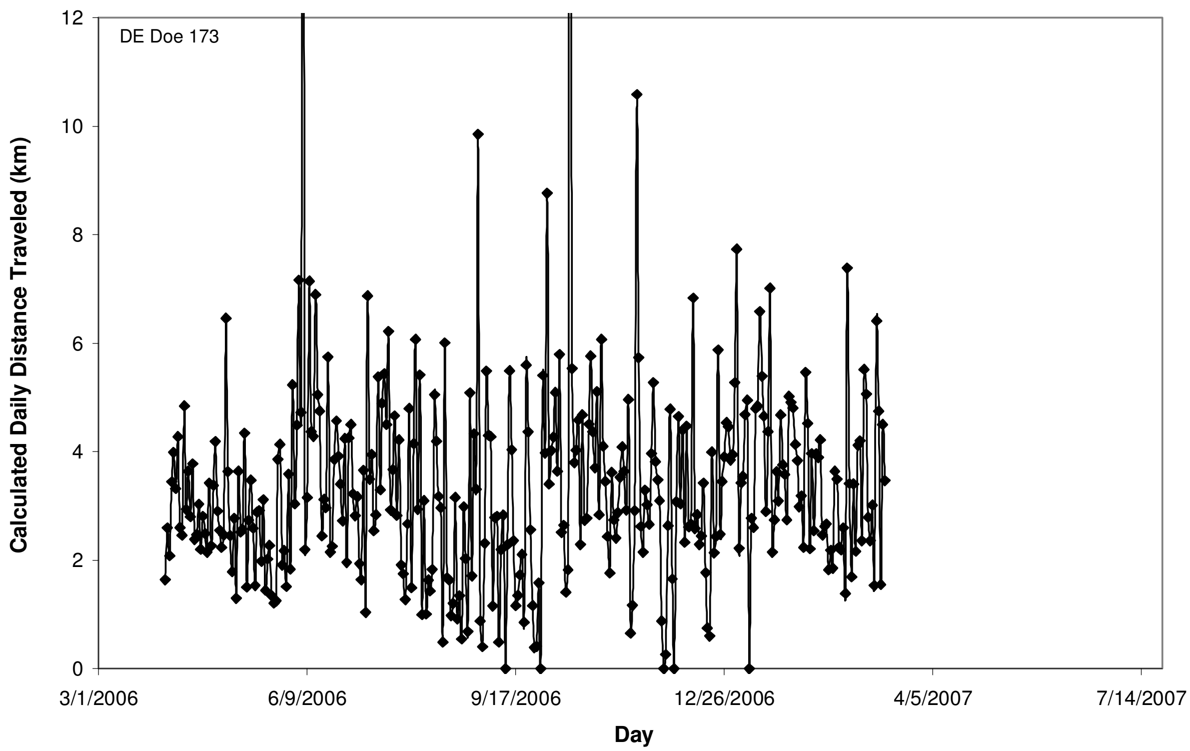


Figure 4. Daily distances traveled for Doe 173 at the Chesapeake Farms, Kent County, Maryland from 4/4/06 – 3/16/07.

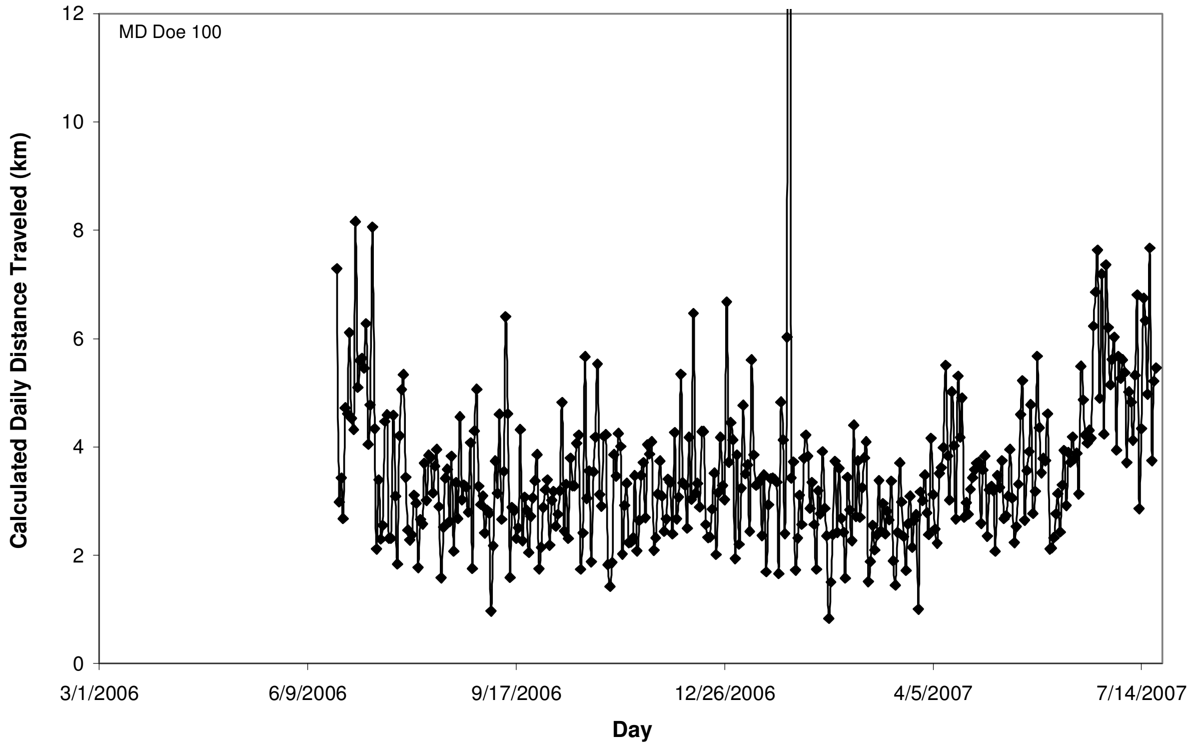


Figure 5. Daily distances traveled for Doe 100 at the Great Cypress Swamp, Sussex County, Delaware from 6/24/06 – 7/21/07.

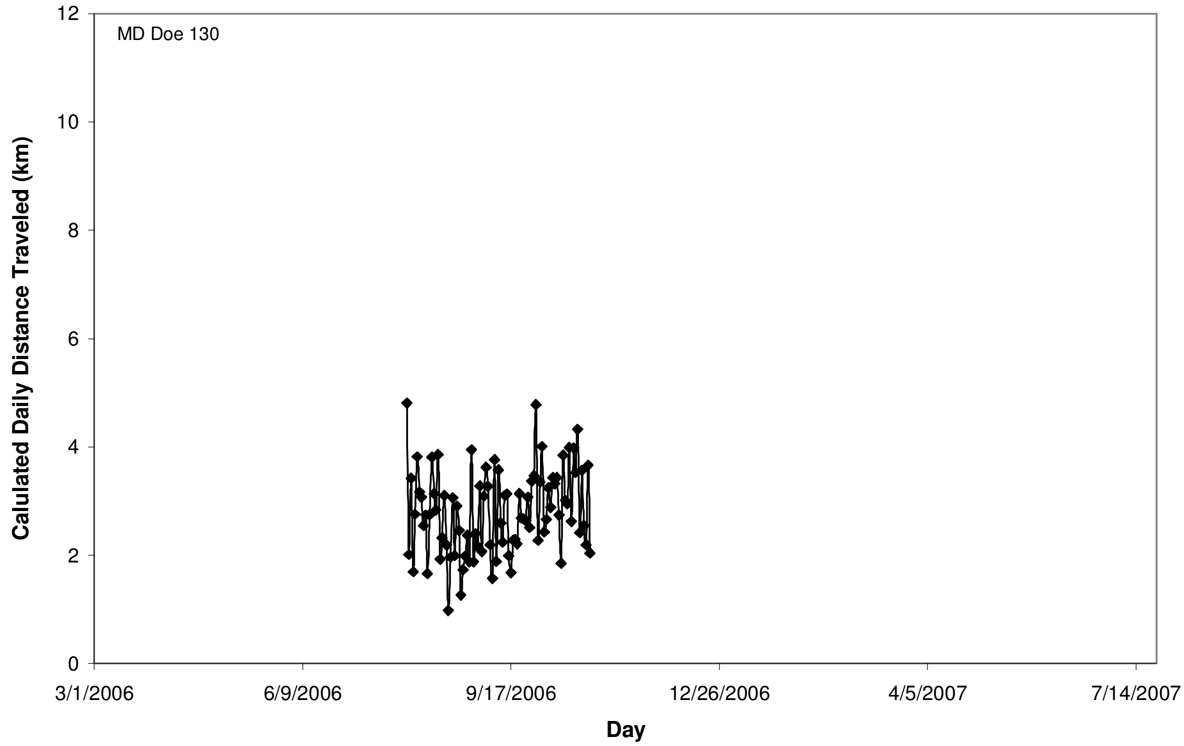


Figure 6. Daily distances traveled for Doe 130 at the Great Cypress Swamp, Sussex County, Delaware from 7/30/06 – 9/05/06.

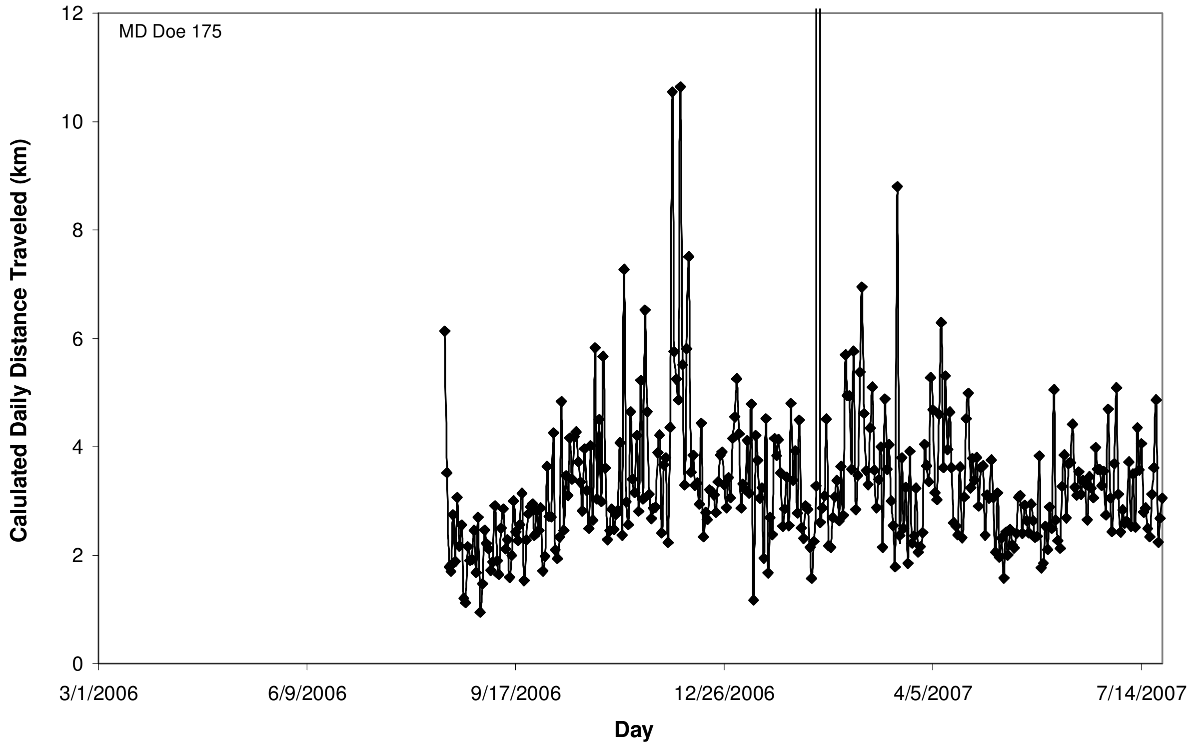


Figure 7. Daily distances traveled for Doe 175 at the Great Cypress Swamp, Sussex County, Delaware from 8/15/06 – 8/03/07.

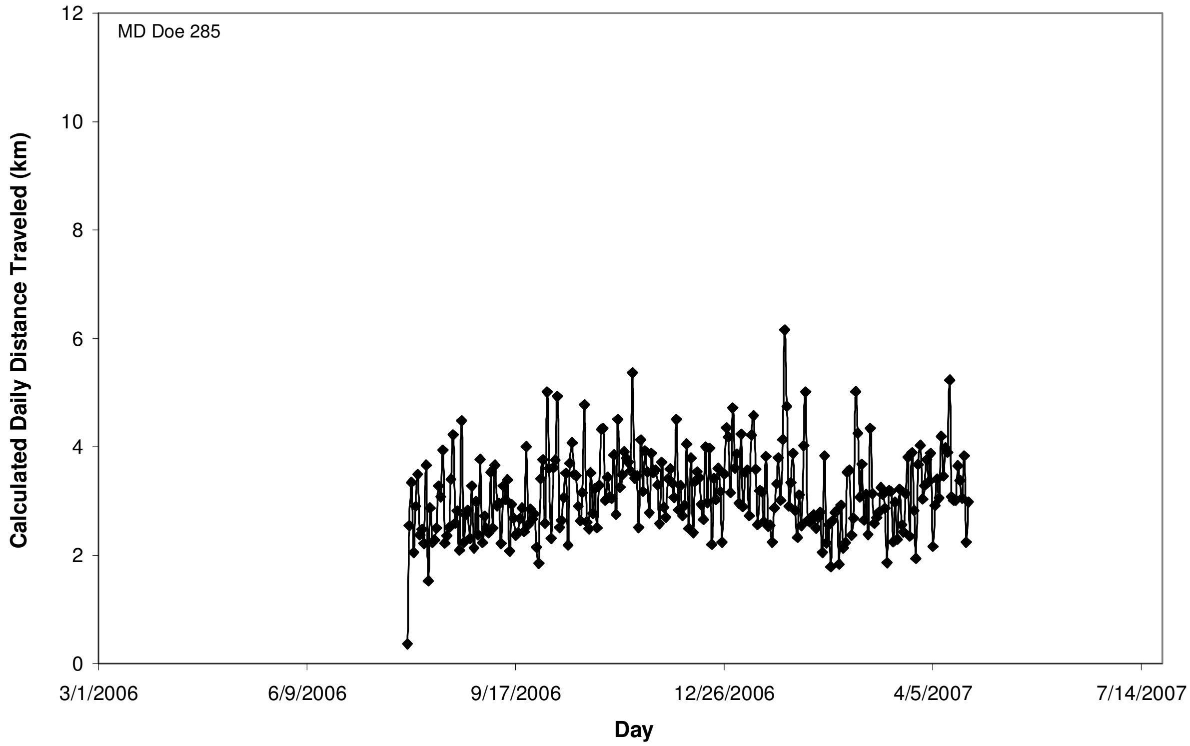


Figure 8. Daily distances traveled for Doe 285 at the Great Cypress Swamp, Sussex County, Delaware from 7/28/06 – 4/21/07.

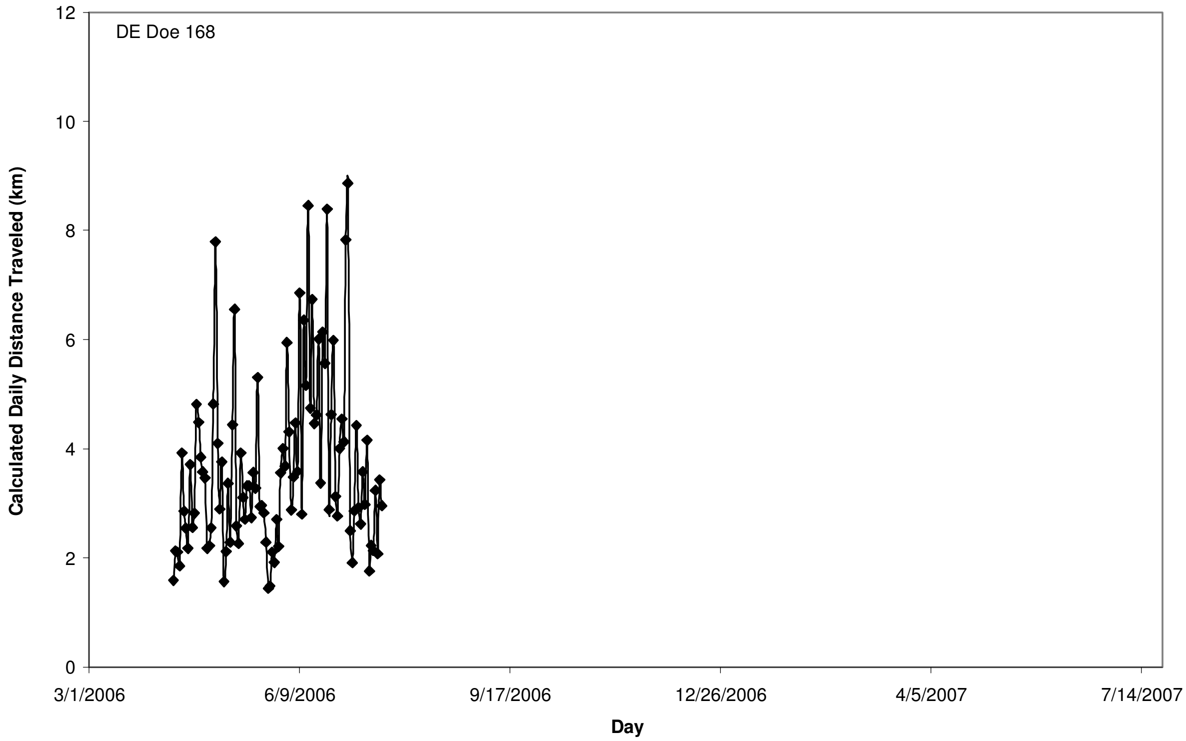


Figure 9. Daily distances traveled for Doe 168 at the Chesapeake Farms, Kent County, Maryland from 4/11/06 – 7/18/06.

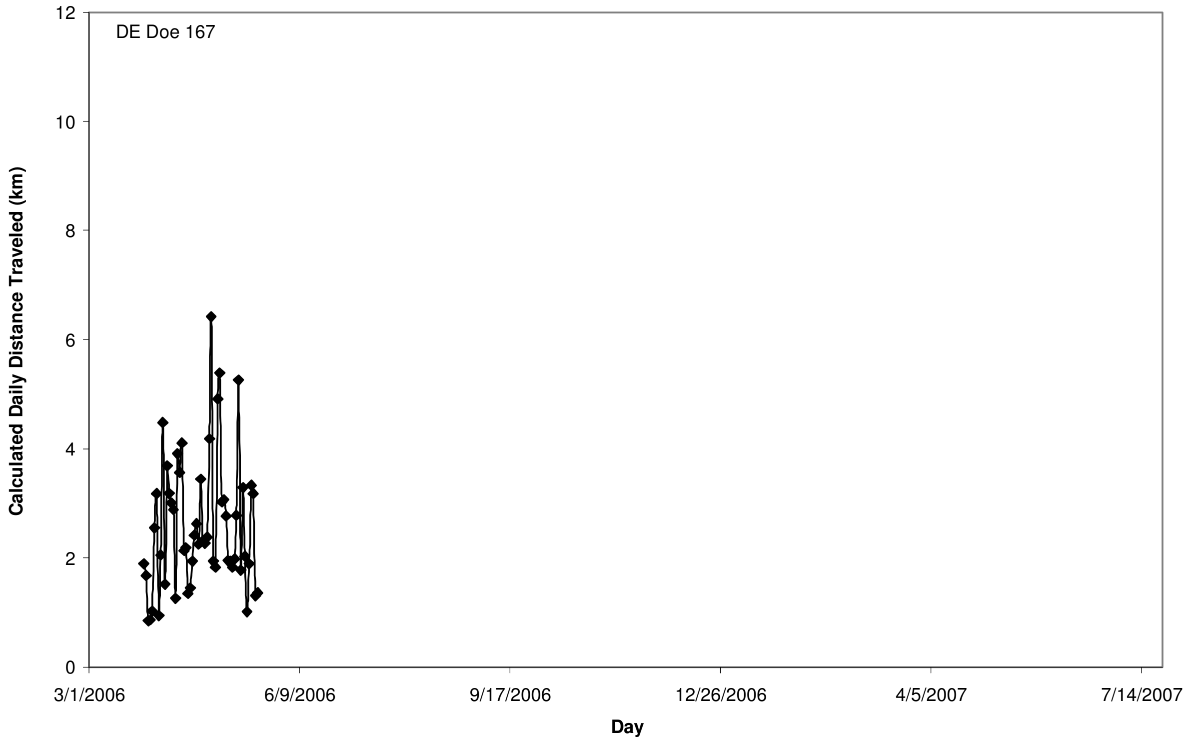


Figure 10. Daily distances traveled for Doe 167 at the Chesapeake Farms, Kent County, Maryland from 3/28/06 – 5/20/06.

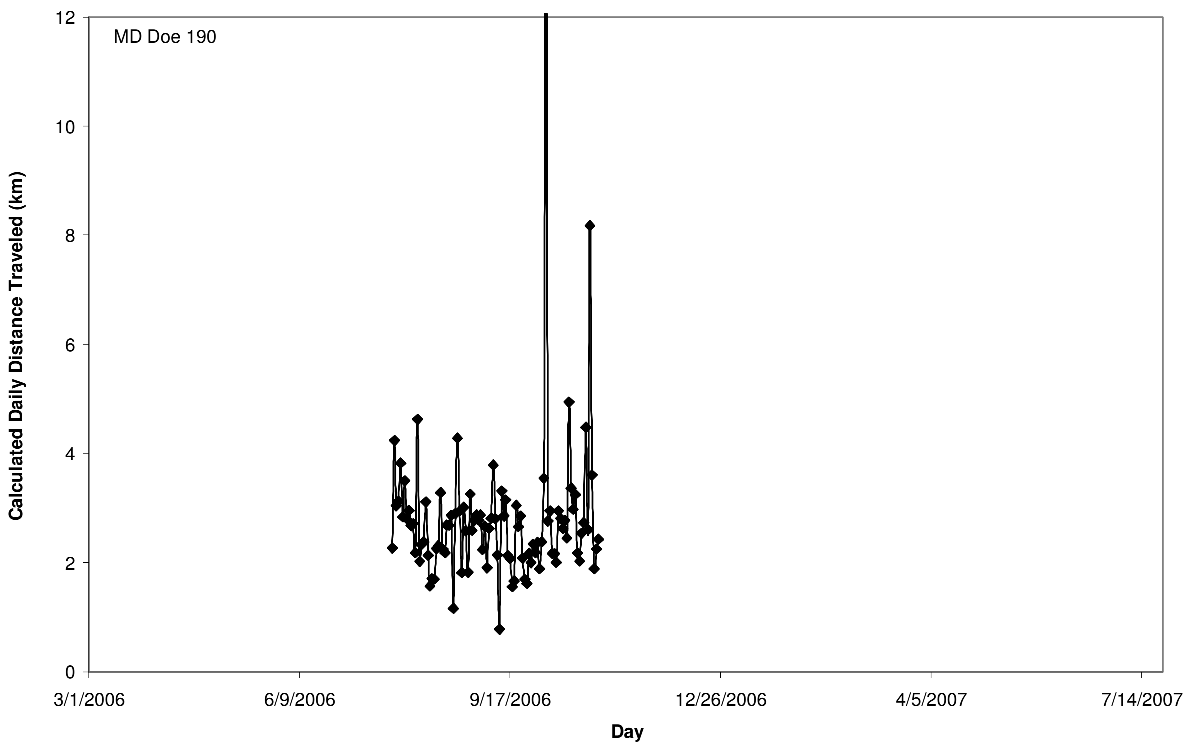


Figure 11. Daily distances traveled for Doe 190 at the Great Cypress Swamp, Sussex County, Delaware from 7/24/06 – 10/26/06.

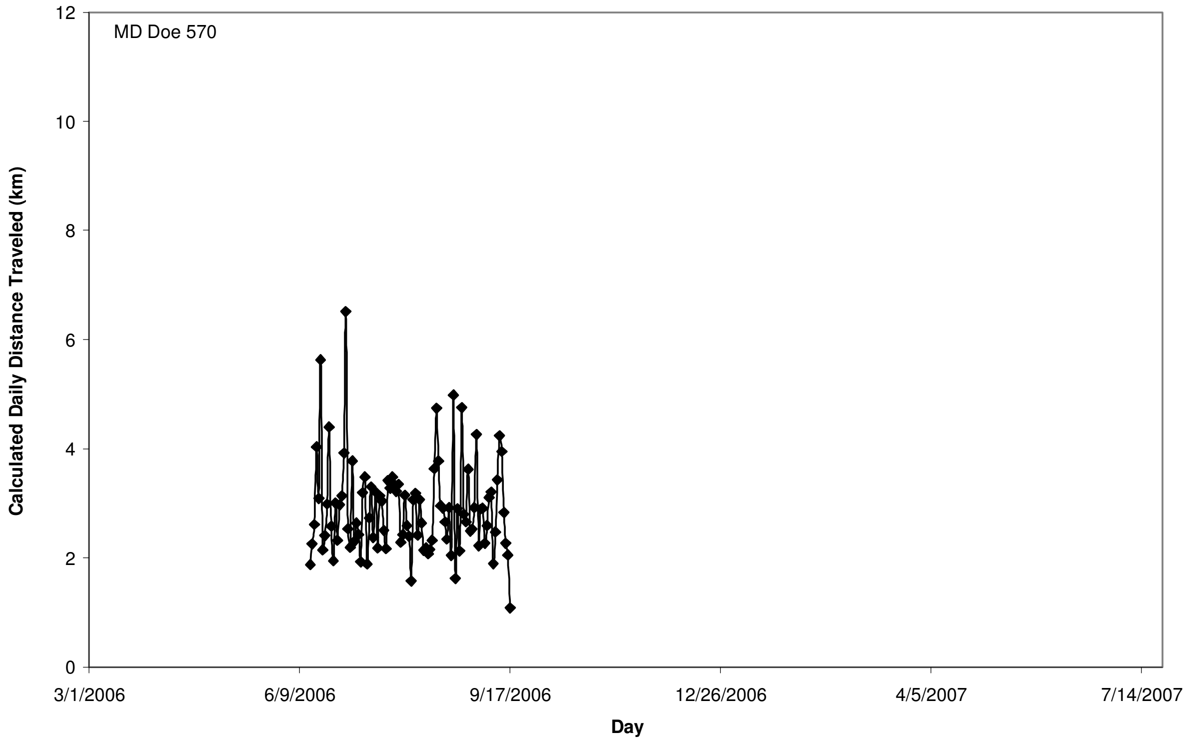


Figure 12. Daily distances traveled for Doe 570 at the Great Cypress Swamp, Sussex County, Delaware from 6/15/06 – 10/14/06.

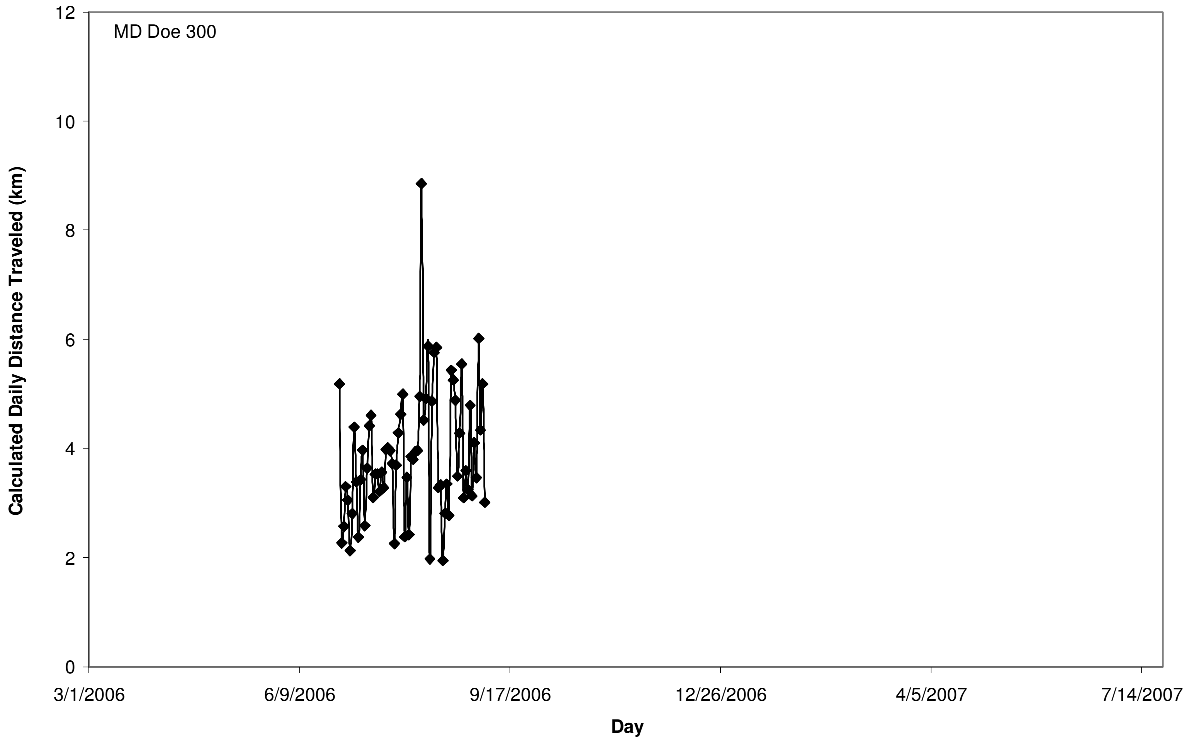


Figure 13. Daily distances traveled for Doe 300 at the Great Cypress Swamp, Sussex County, Delaware from 6/29/06 – 9/4/06.

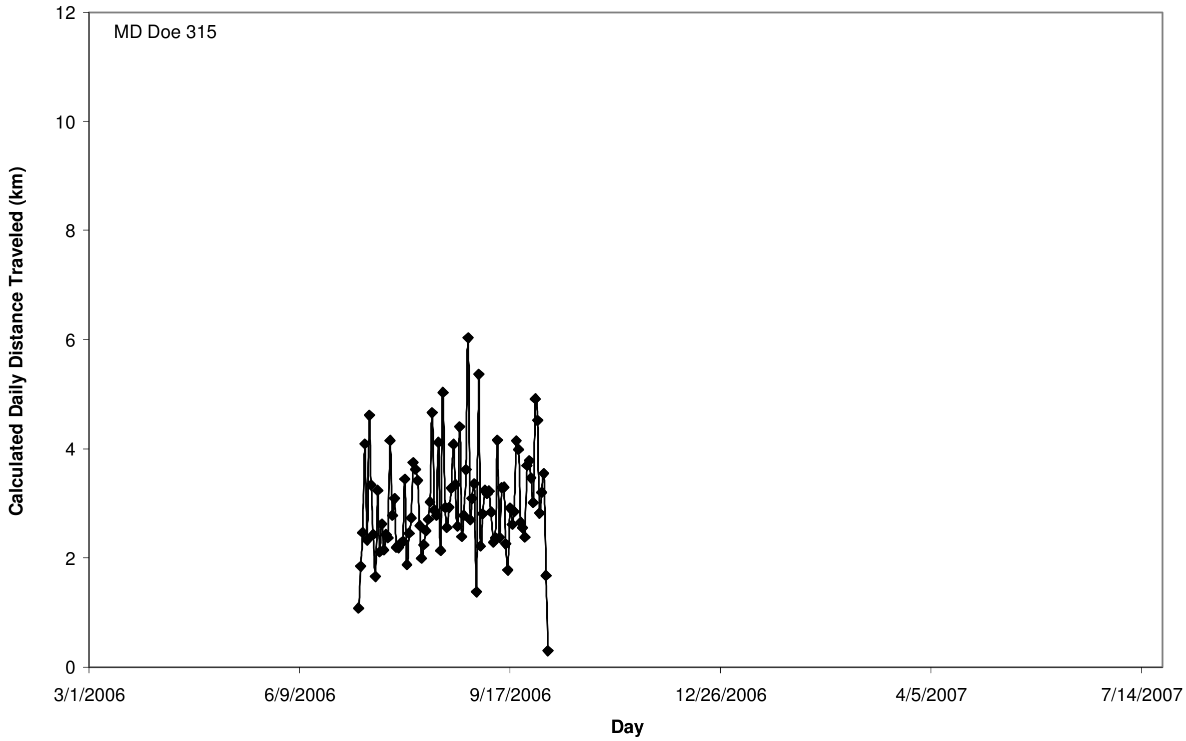


Figure 14. Daily distances traveled for Doe 315 at the Great Cypress Swamp, Sussex County, Delaware from 7/8/06 – 10/4/06.

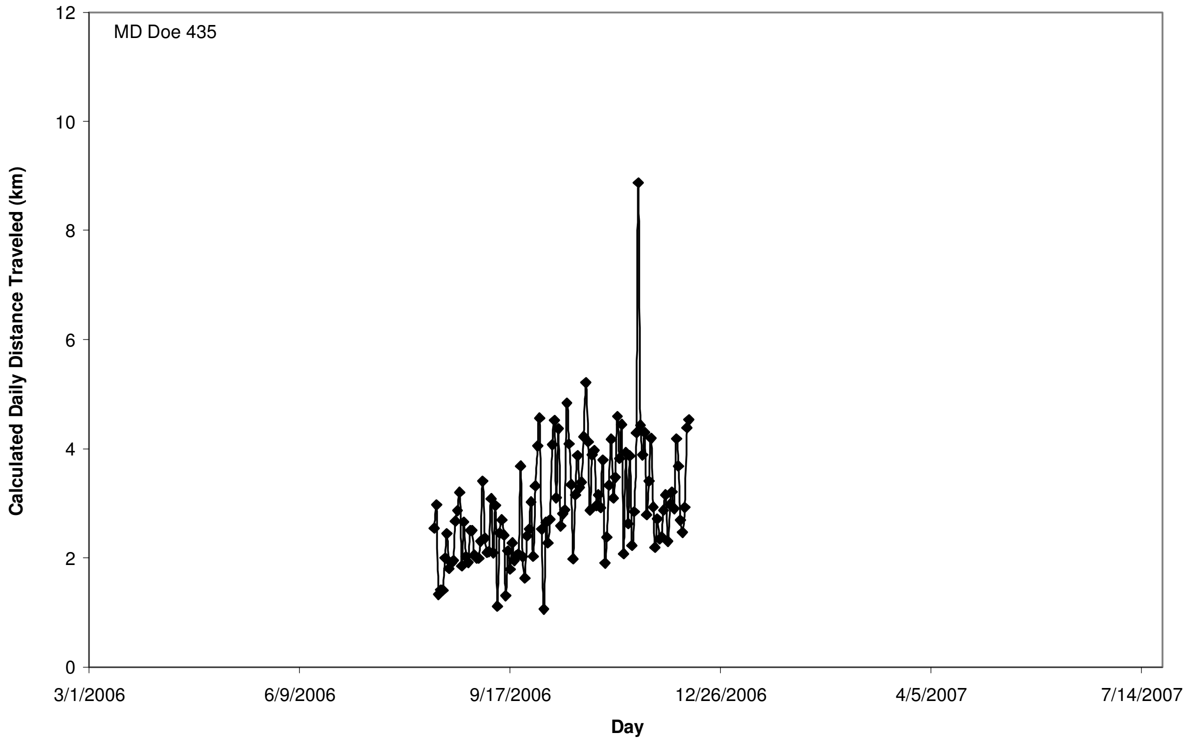


Figure 15. Daily distances traveled for Doe 435 at the Great Cypress Swamp, Sussex County, Delaware from 8/13/06 – 12/10/06.