ABSTRACT

TOMBERLIN, JAMES WEATHERMAN. Movement, Activity, and Habitat Use of Adult Male White-Tailed Deer at Chesapeake Farms, Maryland. (Under the direction of Richard Angelo Lancia.)

Despite extensive research on white-tailed deer (*Odocoileus virginianus*) specific research on the impacts of seasonal changes and climatic factors on movement, activity, and habitat use of adult males managed under a Quality Deer Management (QDM) philosophy is lacking. This research focused on movement, activity, and habitat use of adult male white-tailed deer on a privately owned 1,330-ha agricultural/wildlife research farm under QDM since 1994. Eighteen adult males were fitted with global positioning system (GPS) radio telemetry collars that provided detailed data of movement, activity, and habitat use in relation to seasonal changes and climatic factors. I looked for changes in seasonal patterns of adult males during four 3-week intervals between September and December. Seasonal changes focused primarily on pre-breed, breed, and post-breed periods predetermined by fawning data. Impacts of climatic factors focused on precipitation, barometric pressure, temperature, and lunar cycles and were analyzed using multiple regression (PROC MIXED, SAS, 2001) with repeated measures and random effects. Habitat selection was determined from GPS positional data overlaid on geographic information system (GIS) maps of Chesapeake Farms and calculated using compositional analysis (Aebischer *et al*. 1993).

Mean home range was 299.6 ha with breed (298.6 ha, $F_{6, 80} = 3.95$, $P = 0.006$) and pre-breed2 (285.5 ha, $F_{6, 80} = 3.95$, $P = 0.007$) ranges being significantly larger than summer (114.7 ha). Breed (46.9 ha, $F_{6, 80} = 4.15$, $P = 0.014$) and pre-breed2 (46.7 ha, $F_{6, 80} = 3.95$, $P = 0.008$) core areas were also significantly larger than summer (13.8 ha). Intensity of use ranged from 12% during summer to 16.7% during post-breed with a mean of 14.8%. Adult males increased movement and activity from summer to the breed season with a subsequent decrease during post-breed. Average daily movement during the breed season (4 km ± .25 km) was significantly higher than during pre-breed1 ($F_{6,485} = 40.32$, $P < 0.001$). Relative activity during the breed season was significantly higher than during pre-breed1 and post-breed ($F_{6,487} = 15.22$, $P < 0.001$). Period of day and temperature were the most consistent predictors of adult male movement and activity across all seasons. Diel movement and activity fluctuated across seasons, but was generally lowest during daytime. Adult male movement and activity was inversely related to temperature. Cultivated vegetation was the predominant cover type used during August and September. Use of cultivated vegetation decreased post-harvest with woodlands more selected through December. Adult males selected closed habitats during the day and open habitats at night. Crop phenology influenced movement in addition to breeding. Behavior of adult males will vary across the landscape with the onset of rutting behavior and seasonal changes in habitat availability. Understanding this behavior is the foundation for understanding how to address issues (i.e., human-deer conflicts and harvest strategies) surrounding the sustainable use of deer populations.

MOVEMENT, ACTIVITY, AND HABITAT USE OF ADULT MALE WHITE-TAILED DEER AT CHESAPEAKE FARMS, MARYLAND

By

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DEDICATION

I dedicate this work to the memory of my grandparents, Daddy Vic and Granny Lou and Mama Brown and Brown. They were such a big part of my childhood and continue to influence my life. I was truly blessed to know them and have them in my life.

BIOGRAPHY

James Weatherman Tomberlin was born in Kingsport, Tennessee on April 10, 1980. He grew up in Granite Falls, North Carolina and attended South Caldwell High School where he graduated in May 1998. He began his undergraduate career at North Carolina State University in August of 1998. He spent the spring semester of 2002 working on a yearling white-tailed deer dispersal project at Chesapeake Farms and graduated with a Bachelor of Science in wildlife science in December of 2002. After touring the United States for 3 months he worked as a summer technician on an elk reintroduction project in the Great Smoky Mountains National Park in 2003. He began his graduate research at North Carolina State University in the summer of 2004 and obtained a Master of Science in wildlife and fisheries science in May of 2007. He plans to pursue a career in wildlife management with emphasis on game species.

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The Fisheries and Wildlife Program at North Carolina State University and DuPont Crop Protection provided funding and support for this research. I give credit for the organization of this research to my major advisor, Dr. Richard Lancia and my field advisor Dr. Mark Conner. I consider myself fortunate to have been given the opportunity to work with these professionals, and value the opportunity to know them on a professional and personal level. They both made themselves accessible in spite of their busy schedules whether it pertained to research or college football. Dr. Conner provided untold hours of assistance in deer capture and processing not because he had too, but because he enjoyed being out in the deer woods as much as I did. They provided me with an independent environment to grow in, guidance when needed, and were instrumental in my professional development.

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I consider the opportunity to be a graduate student at Chesapeake Farms a special one. It was an opportunity of a lifetime and I will always cherish it. I want to thank the entire staff for their assistance in this research and hospitality as the farm became my home away from home. I thank Steve Demchyk for his help and for the "rock" fishing trips. George Fahrman provided technical assistance throughout my field work, introduced me to oystering and crabbing, included me in goose, duck, and deer hunting, and kept the "caddy" running, he is truly a jack-of-all-trades. Bobbi Pippin greeted me with a smile every time I walked into the office and dealt with the headache of mailing hazardous materials across the U.S. border so I did not have to. David Startt allowed me to beef up my resume with a variety of activities and provided assistance in deer processing if needed. A special thanks to the ladies in the kitchen, Malinda, Judy, Tina, and Terri for their hospitality and delicious fare.

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I am grateful to my predecessor of the NCSU/Chesapeake Farms program, Dr. Jon Shaw, for providing me an opportunity to get my feet wet while interning on his research and for helping to get this project off the ground. Jon has been a valuable resource over the past several years and most importantly, a good friend. Kent Adams, a former Chesapeake Farms graduate student under Dr. Muller, was a great resource for darting queries and I am very appreciative of his assistance in getting this project off the ground. Ryan Williamson, field technician from the University of Tennessee, provided invaluable assistance in deploying collars and enhanced the enjoyment of field work. His persistence and patience were essential in an endeavor of this nature. I also thank my fellow Turner House colleagues, Chris Ayers, Neil Chartier, Kate Golden, Stan Hutchens, Liz Jones, Andrea Kleist, Tim Langer, Charlotte Matthews, Aimee Rockhill, Mark Sandfoss, Amelia Savage, and Jennifer Thompson for candid conversations and distractions when needed. Special thanks to Cindy Burke, Turner House administrative assistant and surrogate mother, for handling diverse requests and being the glue that held the house together.

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INTRODUCTION

White-tailed deer (*Odocoileus virginianus*) are the most popular big game animal in the United States, with deer hunters greatly outnumbering other big game hunters (Conover 1997, Leonard 2004). Despite extensive research on movement, activity, habitat use, and survival of adult female, yearling male, and fawn white-tailed deer (Ozoga and Verme 1975, Rosenberry et al. 1999, DePerno et al. 2000 and 2002, Brinkman et al. 2004, Vreeland et al. 2004, Shaw et al. 2006), specific research on the impacts of seasonal changes and weather on movement, activity, and habitat use of adult males managed under a Quality Deer Management (QDM) philosophy is lacking. Quality Deer Management is a popular management practice on private landholdings and is becoming widely established in the eastern United States (Hamilton et al. 1995). This management philosophy promotes sustainable use of deer populations by uniting landowners, hunters, and managers in a common goal of producing biologically and socially balanced deer herds within existing environmental, social, and legal constraints (Miller et al. 1995). It encourages restraint in harvesting young males, while harvesting an appropriate number of antlerless deer (i.e., females and non-antlered males) to maintain a healthy population in balance with the habitat (Hamilton et al. 1995). An appropriate harvest number for antlerless deer will vary across the white-tailed deer's range and will depend on existing population parameters and desired goals. The QDM program at Chesapeake Farms attempts to maintain a healthy deer herd and habitat, reduced crop damage by deer, and quality hunting experiences for hunters (Dr. Conner, Manager, Chesapeake Farms, personal communication). At Chesapeake Farms, research is vital in determining population management strategies and through the years

(Wickham 1993, Rosenberry 1997, Tardiff 1999, Adams 2003, Shaw 2005) has been essential in development and implementation of QDM.

A common question regarding QDM is: What scale of land is needed to implement a successful QDM program (Hamilton et al. 1995)? The answer is complex and many variables need to be evaluated including: land cover, soil quality, habitat diversity, degree of land access (public and private), shape of the property, habitat quality, and method of hunting (Hamilton et al. 1995). Seasonal movements and home ranges vary over the white-tailed deer's geographic range (Marchinton and Hirth 1984, Tierson et al. 1985) making it difficult to determine the minimum size of land needed for a QDM program. Therefore, region specific empirical information is needed to effectively manage white-tailed deer populations (Brinkman et al. 2005), especially under a QDM philosophy. Obtaining knowledge of movement, activity, and habitat use of adult males at Chesapeake Farms, coupled with knowledge gained from previous studies of yearling male dispersal (Rosenberry et al. 1999, Shaw et al. 2006), will enable managers to quantify the area required to implement a successful QDM program in mid-Atlantic agricultural areas.

Knowledge of nocturnal and diurnal movement, activity, and habitat use in relation to seasonal changes and climatic factors is the foundation for understanding how to manage human-deer conflicts and regulate harvests of white-tailed deer populations. Therefore, the purpose of this research is to evaluate movement, activity, and habitat use of adult male white-tailed deer on a privately owned 1,330-ha agricultural/wildlife research farm under QDM since 1994

LITERATURE REVIEW

Global Positioning System Collars

Since the 1960s, very high frequency (VHF) radio telemetry systems have been the preferred method for tracking movement of medium- and large-sized mammals (Heezen and Tester 1967, White and Garrott 1990). Early telemetry methods involving triangulation were time-consuming, costly, and varied in accuracy. Measurement error limited the ability to detect fine-scale movements and habitat selection (Rosenberry 1997). Also, time and effort required in the field to track animals with triangulation telemetry methods also limited sampling intensity. Consequently, fine-scale movements were often overlooked because an excessive amount of effort was required to collect animal locations and accuracy was limited.

Beier and McCullough (1990) conducted a deer activity study on the George Reserve in southern Michigan using motion-sensitive radio collars with a mercury tip-switch. The switch indicated whether the deer had "head up" or "down" by producing differing pulse intervals. Despite the ingenuity of Beier and McCullough's (1990) research and the usefulness in understanding when deer were feeding, they still did not know with confidence which habitat types deer were using, or how deer were moving throughout the landscape.

Global positioning system (GPS) radio telemetry is the integration of a GPS antenna and receiver into the traditional VHF radio transmitter collar. The GPS unit communicates with satellites orbiting the Earth and records location coordinates at time of communication. Recent advances in GPS technology allow collection of detailed movements of deer on a fine and more accurate scale. They are capable of acquiring positional data at short intervals, at specified times, and can store up to 21,000 locations. This data collection tool allows detailed study of habitat selection at short temporal and fine spatial scales that are not feasible with traditional telemetry methods (Dussault et al. 2001). Global positioning system telemetry is better suited than conventional radio telemetry to estimate home-range size precisely and accurately (Girard et al. 2002), and is gaining popularity in wildlife research (Rodgers et al. 1996) because it reduces many of the limitations associated with conventional telemetry (Girard et al. 2002). Adams (2003) stated GPS telemetry collars are ideal for studying habitat use by white-tailed deer in the Mid-Atlantic Coastal Plain.

Currently, GPS radio telemetry is in its early years as a data collection technique due to unknown and unquantified sources of error and bias in collected location data including radiocollar malfunction, location errors, and fix-rate biases (Rempel et al. 1995, Moen et al. 1996, D'Eon et al. 2002). Fix rate bias is the "inverse of fix success rate or observation rate, which is the likelihood of obtaining a GPS fix given a multitude of environmental factors including terrain, habitat, and animal behavior" (D'Eon et al. 2003:858). Terrain and habitat, especially thick forest, have proven to affect fix success rate, consequently imposing biases in the collected data (Rempel et al. 1995, Dussault et al. 2001, D'Eon et al. 2002). These biases are important omissions in the collected GPS data and can lead to wrong conclusions, especially in habitat selection studies (D'Eon et al. 2003). Also, animal behavior can introduce bias as Bowman et al. (2000) had less success obtaining fixes from bedded deer, consequently biasing data towards active locations. However, D'Eon et al. (2003) demonstrated that biases accounting for <10% data loss, related to overall numbers of locations, did not alter habitat selection conclusions.

D'Eon and Serrouya (2005) stated that GPS tracking increases animal sampling intensity and hence, accuracy of individual parameter estimates. Increased sampling intensity provides a closer approximation of the individual's trajectory throughout the landscape, thus providing more precise estimates of proportional habitat use and diel movement distances, even though it increases autocorrelation (Aebischer et al. 1993). Swihart and Slade (1985) stated that autocorrelated data violate the assumption of statistical independence and should not be used for estimating spatial use parameters. However, the issue of autocorrelation with radio telemetry data is negated if the analysis technique (1) uses the individual animal as the replicate for testing statistical significance of important parameter estimates (White and Garrott 1990, Aebischer et al. 1993, D'Eon and Serrouya 2005) and (2) samples animal locations systematically through time (White and Garrott 1990, McNay et al. 1994). Statistically independent data should not be used to compare diel movement distance estimates because statistically independent sequential data (i.e., normally distributed) were significantly different from actual diel movements (Reynolds and Laundre 1990, McNay et al. 1994).

Global positioning system technology increases sampling intensity for individuals, but due to cost of equipment and battery life (D'Eon and Serrouya 2005), potentially decreases the number of individuals sampled. However, this technology maximizes the amount of information obtained from each individual, so that even a relatively small number of individuals can increase knowledge and understanding (Adams 2003). This is particularly germane for adult males because in most populations they are not abundant and are difficult to capture and radio collar. Detailed data at fine temporal and spatial scales can provide valuable insight, particularly for refining population and habitat management strategies (Adams 2003), and will undoubtedly be the preferred research tool in the future for researchers studying animal movement, activity, and habitat use. Global positioning system collars can be used cost-effectively and collect precise and accurate locations with little operator or equipment error (Bowman et al. 2000). The cost of GPS collars makes them an expensive investment initially. However, compared to the time, effort, and costs of manpower to collect data with radio telemetry, GPS collars can be more cost-effective than conventional telemetry (Girard et al. 2002). Furthermore, cost likely will decline as GPS collar technology advances and becomes more efficient.

Home Range

Burt (1943) termed home range as the area traversed by an individual in its normal activities of food gathering, mating, and rearing young. However, differential use of the home range has been reported (Favreau 2005). Utilization distributions (UD; Favreau 2005), calculated by home range estimators, index the differential use of home ranges and are often reported as 50% (core area) and 95% (home range) UD. Intensity of use (Favreau 2005) is another measure of differential use of home range, and is the ratio between 50% and 95% adaptive kernel UD's (Lent and Fike 2003).

Kernel density estimation is widely viewed as the most reliable technique for estimating home ranges in ecology (Kernohan et al. 2001). Worton (1995) recommended that use of kernel density estimators in home range data analysis, but with careful selection of the smoothing parameter and level of smoothing. The smoothing parameter (h) determines the spread of the kernel that is centered over each observation (Rodgers and Carr 2002) and is the most important factor in developing a kernel density estimator (Worton 1989). The h_reference method (h_{ref}) may result in oversmoothed estimates if the data are clumped (Worton 1995). Seaman et al. (1999) recommended home range studies using kernel estimates use the Least Squares Cross Validation (LSCV) method to determine amount of smoothing. However, LSCV has the tendency to undersmooth data (Sain et al. 1994).

Hemson et al. (2005) stated that LSCV will fail to estimate the UD due to identical points or points that are very close to each other and cautioned against the use of LSCV with large datasets such as those generated by GPS collars. Rodgers and Carr (2002) stated Biased Cross Validation (BCV) may present a balance between the oversmoothing of h_{ref} and undersmoothing of LSCV in estimating UD's (Rodgers and Carr 2002). Sain et al. (1994) reported that simulation studies showed BCV performed quite well and with reasonable variability in comparison to LSCV and h_{ref} methods.

Utilization distributions of adult male white-tailed deer estimated from GPS collar data can provide a detailed look at range use. Although kernel home range estimates can vary depending on the type of smoothing approach, smoothing parameter, and level of smoothing, temporal shifts and changes in range size can provide insight into seasonal changes in range use.

Seasonal and Diel Movements

Home ranges of white-tailed deer vary among sex, age, habitat, and seasons, ranging from 43 ha to 6,033 ha (Tierson et al. 1985, Smith et al. 1996, Nelson and Mech 1999, Kilpatrick and Spohr 2000, Lesage et al. 2000*b*). Uniformly distributed habitats with a "mix" of food, cover, and water are associated with smaller home ranges (Marchinton and Hirth 1984). Generally, annual and seasonal home range sizes of females are approximately $1/3^{rd}$ as large as males (Beier and McCullough 1990, Nelson and Mech 1981). However, Beier and McCullough's (1990) study at the George Reserve, Michigan, was fenced, potentially limiting movement of adult males, which would result in decreased home range size. Fall has been documented as the period with the largest ranges for adult males, likely due to the onset of breeding behavior (Moore and Marchinton 1974, Marchinton and Hirth

1984, Beier and McCullough 1990). Ivey and Causey (1984) showed that females increased activity during breeding while movement distances decreased, but average male movements in both summer and autumn are likely to be greater than those of females (Kammermeyer and Marchinton 1977). Marchinton and Hirth (1984) stated that seasonal shifts in activity centers are usually related to food availability, but are not significant enough to cause changes in home range boundaries.

Diel movements of white-tailed deer are dependent on interspersion of food, cover, water, and human activity (Marchinton and Hirth 1984). Daily movement is highest during Autumn (Pledger 1975) with males increasing their movements at the onset of breeding (Kammermeyer and Marchinton 1977). Marchinton and Hirth (1984) stated that different portions of a deer's home range are used during night and day. Further, white-tailed deer activity and movement have been reported to peak at dawn and dusk (Montgomery 1963, Kammermeyer and Marchinton 1977, Rouleau et al. 2002, Coulombe et al. 2006), but will fluctuate during breeding (Marchinton and Hirth 1984).

Weather and Lunar Cycles

The relationships between deer activity and climatic factors vary (Marchinton and Hirth 1984). Thomas (1966) determined that reduced activity resulted from a change in barometric pressure and greatest activity occurred at moderate pressures. Cartwright (1975) stated deer were most active at low relative humidity. The effect of precipitation (i.e., rainfall) is not as conclusive (Marchinton and Hirth 1984). Hawkins and Klimstra (1970) reported rain in northern areas depressed activity, whereas in Texas, light rains increased summer activity and heavy rains decreased summer activity (Michael 1970). Thomas (1966) noted that low velocity winds had little effect on white-tailed deer, but high velocity winds reduced movement. In warm temperature climates deer were likely to exhibit the highest activity levels during the coolest parts of the day (Marchinton and Hirth 1984). Progulske and Duerre (1964) stated combinations of temperature, precipitation, relative humidity, wind speed, and cloud cover probably impact deer activity more than any single meteorological factor. Deer responses to lunar cycles range from no relationship (Michael 1970, Carbaugh et al. 1975) to increased nocturnal activity during light phases (Thomas 1966, Kammermeyer 1975), however, further research is needed (Marchinton and Hirth 1984). Beier and McCullough (1990) stated climatic effects on George Reserve deer reflected adjustments to food availability and the thermal environment.

Combining fine-scale movement and activity data with fine-scale weather data will determine if and how adult males respond to different environmental pressures and changes in photoperiod. This will allow further illumination of inconsistencies and false positives and provide insight into individual variation between adult males.

Habitat Selection

Previously, wildlife habitat use was estimated from radio telemetry point relocation data and bias might result if the research design did not consider the sampling strategy and associated location error (Kernohan et al. 1998). Furthermore, a sampling strategy that did not represent the circadian activity of a species might introduce bias and render management recommendations from these data ineffective or incomplete (Beyer and Haufler 1994). Also, topography can affect error in GPS locations. However, the topography of the Mid-Atlantic is relatively flat and provides the best possible conditions for 2-dimensional (2-D) locations (Adams 2003).

Compositional analysis (CA, Aebischer et al. 1993) provides a statistically sound basis and flexible modeling capability for analyzing habitat use. Compositional analysis is closely related to Johnson's (1980) rank-based method; however, the difference is the switch from ranks to logarithms, which makes full use of all available information (Aebischer et al. 1993). Compositional Analysis (Aebischer et al. 1993) proposes ways of overcoming three problems in analyzing habitat use data. First, inappropriate sample size and pseudoreplication (Hurlbert 1984) from pooling data across individuals is remedied by using the individual animal as the sampling unit. Second, the unit-sum constraint (i.e., the proportions that describe habitat composition sum to one over all habitats) precludes statements of absolute preference or avoidance of habitats. Compositional analysis resolves this by analyzing whether or not habitat use is random or nonrandom, then ranks habitats by determining which are used more/less by chance, taking into account the use of other habitats (Aebischer et al. 1993). Third, differential use of habitats by groups of individuals may occur within a population due to sex, age, or season. Aebischer et al. (1993) states what is needed is a method similar to ANOVA where sample size is the number of individuals in each group and where between-group differences are tested by reference to within-group variation.

Delineation of habitat availability by researchers incurs some arbitrariness, but is vital because habitat use conclusions are based on what is considered available to the animal (Johnson 1980; Aebischer et al. 1993). Use of home range estimates is a useful method for utilization and avoids the serious consequences of an arbitrarily defined study area (Aebischer et al. 1993). Girard et al. (2002) stated that if the objective was to study use of habitat patches then the kernel home range estimator might prove valuable. Kernohan et al.

(1998) concluded the use of an adaptive kernel home range estimator is a viable alternative to traditional habitat use quantification. Johnson (1980) provided a hierarchical ordering of selection processes, which allows for delineating availability at different scales of selection. Second-order selection (i.e., population level) examines selection of an individual's home range within a geographical range and third-order selection (i.e., home range level) examines habitat selection within an individual's home range (Johnson 1980).

Adaptive kernel home ranges define availability at population and home range levels, which minimizes researcher subjectivity. Compositional analysis will reveal if habitat use occurs at random, rank habitat types in order of relative use, and determine variability of use between seasons (Aebischer et al. 1993).

Although much is known about deer movement, activity, and habitat use in general, very little is known about adult male movement during the breeding season. Knowledge of the breeding period combined with fine-scale movement and activity data can provide a detailed account of how adult male movement, activity, and habitat use fluctuate across biologically defined periods. Movement of adult males throughout their range in relation to seasonal and diel periods will provide insight into changes in amount and timing of movement. Concomitantly, activity data will clarify how adult male activity changes in relation to movement and habitat use. These data are essential to understand how movement of adult males can present limitations to management strategies, specifically QDM.

I hypothesize that adult males will increase movement and activity from the summer period up to the breed period with a subsequent decrease during the post-breed period resulting in smaller home ranges during the summer period and larger ranges during the breed period. Also, I hypothesize adult males will shift habitat use from summer to winter, using closed canopy habitats (i.e., woodlands) during diurnal periods and open canopy habitats (i.e., croplands and grasslands) during nocturnal periods, and diurnal and nocturnal habitat use will differ east and west of Maryland state highway 20 during the summer period.

STUDY AREA

Chesapeake Farms is a 1,330-ha agricultural and wildlife research and demonstration area located on the Eastern Shore of the Chesapeake Bay near Chestertown (39° 13' N, 76° 03' W) in Kent County, Maryland (Figure 1). Kent County ranges in elevation from sea level to 41.3 m. Chesapeake Farms is approximately 50% forested, 33% tillable, 14% managed wildlife habitat, and 3% impoundments. Forested habitats were mostly hardwoods consisting primarily of oaks (*Quercus palustris, Q. alba, Q. phellos, and Q. rubra*), sweetgum (*Liquidambar styraciflua*), black gum (*Nyssa sylvatica*), red maple (*Acer rubrum*), and tulip poplar (*Liriodendron tulipifera*) with a few stands mixed with loblolly pine (*Pinus taeda*). Forest understory consisted predominantly of multiflora rose (*Rosa multiflora*), greenbrier (*Smilax* spp.), highbush blueberry (*Vaccinium corymbosum*) (Rosenberry et al. 1999), and sweet pepperbush (*Clethra alnifolia*; M.C. Conner, Chesapeake Farms, personal communication).

Twenty percent of the farm is a cash grain farming operation consisting of corn (*Zea mays*) and soybeans (*Glycine max*). Thirteen percent of the land area consists of a variety of forage crops including clover (*Trifolium* spp.), sorghum (*Sorghum bicolor*), rye (*Lolium multiflorum*), winter wheat (*Triticum aestivum*), and Japanese millet (*Echinochloa frumentacea*). The 14% managed wildlife habitat consists of hedges, grasslands, and early successional areas and 80 ha of manmade water impoundments comprise the remaining 3% of land area (Rosenberry et al. 1999). Natural forages were promoted through mowing, burning, and herbicide use. Warm-season grasses included big bluestem (*Andropogon gerardii*), switchgrass (*Panicum virgatum*), little bluestem (*Schyzachyrium scoparius*), and indiangrass (*Sorghastrum nutans*). Fallow fields consisted of perennial cool-season grasses, such as tall fescue (*Festuca arundinacea*) orchardgrass (*Dactylis glomerata*), and various forbs (Adams 2003).

The antlered to antlerless ratio on Chesapeake Farms was about 1:1.6 in 2002 (J. C. Shaw, North Carolina State University, unpublished data) and about 1:1.5 in 2006 (M.C. Conner, Chesapeake Farms, unpublished data). Selective harvest criteria for males was implemented in 1994 ($\geq$ 7 points to harvest) and modified in 1997 ($\geq$ 40-cm outside antler spread to harvest). Pre-harvest deer density was 33 deer/km^2 (Shaw 2005), equivalent to a deer herd of approximately 440 individuals on Chesapeake Farms. Annual harvest varies between 90 and 130 individuals (M.C. Conner, Chesapeake Farms, personal communication) or 20% to 30% of the pre-harvest deer herd, respectively. Harvest occurred predominantly during Maryland's 2-week shotgun season during late November and early December. Age of harvested or deceased individuals was determined by tooth wear and replacement (Severinghaus 1949). A collection of known-age jaws from deer tagged as fawns at Chesapeake Farms complemented the Severinghaus (1949) technique.

METHODS

Animal Capture

I captured 18 adult males (i.e., > 24 months) between June and August of 2003 (n = 4), 2004 (n = 4), and 2005 (n = 10). Capture occurred during this time because of easy accessibility to adult males and because antler growth combined with body characteristics permitted sufficient aging in the field (Demarais et al. 2005). Adult males were captured with a CO_2 powered Dan-Inject (Dan-Inject, Inc., Fort Collins, Colorado, USA) JM Standard injection rifle (Adams 2003).

I darted males with either a combination of 4.4 mg/kg tiletamine/zolazepam (100 mg/ml tiletamine and 100 mg/ml of zolazepam; 200 mg/ml total of Telazol®, Fort Dodge Animal Health, Fort Dodge, Iowa, USA) and 2.5 mg/kg xylazine (450 mg/ml Cervizine®, Wildlife Laboratories, Inc., Fort Collins, Colorado, USA) (XT) or 0.1 mg/kg medetomidine (20 mg/ml Dormitor®, Wildlife Laboratories, Inc., Fort Collins, Colorado, USA), 2.0 mg/kg ketamine (200 mg/ml Ketaset®, Fort Dodge Animal Health, Fort Dodge, Iowa, USA) and 2.8 mg/kg telazol (MKT) in a 3-ml telemetry dart (Pneu-dart Inc., Williamsport, Pennsylvania, USA). Darts were equipped with radio transmitters, which facilitated locating the sedated animal. If, upon approach, the deer was able to lift its head or was not fully sedated, I administered a 2.2 mg/kg intramuscular (IM) dose of ketamine to aid in sedation. Prior to release, I reversed deer darted with the XT drug combination with 3.0 mg/kg of tolazoline (100 mg/ml Tolazoline®, Lloyd Laboratories, Shenandoah, Iowa, USA) administered half intravascular (IV) and half IM. Similarly, I reversed individuals darted with the MKT combination with a 0.5 mg/kg IM dose of atipamezole (5 mg/ml Antisedan®, Pfizer Animal Health, Exton, Pennsylvania, USA).

Once sedated, eye ointment (Paralube, Pharmaderm, Melville, New York, USA) was applied to prevent corneal drying and a blindfold was placed over the deer's head to minimize stress. Deer were positioned either sternally or on the right side while fitting a GPS radio telemetry collar (Lotek 2200L and 3300L, Lotek Engineering, Ontario, Canada). In 2003 and 2004, each collar had a time delay release mechanism set to a 32-week time delay, which facilitated retrieval of the collar with no additional stress to the animal. In

2005, each collar was fitted with a remote-release mechanism to allow user-defined retrieval of collar in the field. To accommodate for neck swelling that accompanies breeding, collar circumferences were pre-determined based on maximum neck sizes of rutting adult males obtained from harvest data.

Heart rate, respiratory rate, and rectal temperature were checked upon approach and monitored every 15 minutes throughout processing. Numbered Monel tags (National Band and Tag Co., Newport, Kentucky, USA) were placed in both ears. To aid in field identification, deer received a duflex colored and numbered cattle ear tag (National Band and Tag Co., Newport, Kentucky, USA) corresponding to capture location, with even numbered tags placed in the right ear and odd numbers in the left. Also, a tissue sample (i.e., ear notch) was taken for genetic analysis. I allowed at least 70 minutes post-injection before administering corresponding antagonist drugs. This amount of time allowed the ketamine and/or telazol to begin to dissipate in the animals system and guarded against deer re-sedating after antagonist administration. All drug volumes were estimated for a 100-kg male based on previous harvest data. The research protocol was reviewed and approved by the Institutional Animal Care and Use Committee at North Carolina State University (NCSU IACUC #05-024-0).

<u>GPS Collars</u>

I programmed collars to attempt a location every hour. This sampling effort ensured sampling of circadian behavior and achieved a minimum number of locations during each season for home range estimation (Girard et al. 2002). Also, locations recorded at regular time intervals counteracted the effects of autocorrelation and provided an unbiased representation of the animal's trajectory (Aebischer et al. 1993, Otis and White 1999). Each collar contained a 2-axis activity sensor that recorded the number of times the vertical and horizontal position of the collar changed (i.e., broke a 15° plane) and recorded a number from 0-255. Zero represented no activity and 255 represented the maximum amount of activity recordable during the specified interval, indicating relative activity. Activity data from 2200L series collars deployed in 2003 were counts of changes in collar orientation during a 4-minute interval prior to attempting a fix. Activity data from 3300L series collars deployed in 2004 and 2005 collected counts of changes in collar orientation every 5 minutes regardless of fix schedule (W. Renaud, Lotek Inc., personal communication). For analysis purposes, activity data from 2004 and 2005 collars was the 5-minute interval preceding the scheduled hourly fix attempt. Active behaviors included feeding, moving or standing without feeding, and grooming; inactive behaviors were bedding and resting (Nawa 1972, Coulombe et al. 2006).

After retrieving collars, data were transferred to a computer using Lotek's download link and software (GPS Host, Lotek Engineering, Ontario, Canada). Each recorded GPS location had corresponding data consisting of the geographic coordinates, time of day, date, ambient temperature, status of fix, and a position dilution of precision (PDOP) value. Position dilution of precision was a 3D measure of GPS quality - as PDOP value increased, location error increased (D'Eon and Delparte 2005). To ensure location quality, 3-dimensional (3D) locations with PDOP >10, and 2-dimensional (2D) locations with PDOP >5 were screened from analysis (Moen et al. 1996; D'Eon et al. 2002; Adams 2003; D'Eon and Delparte 2005). Impossible data (i.e., locations with altitude values > 100-m or < -100-m), were omitted after PDOP screening to eliminate remaining outliers (D'Eon and Delparte

2005). Also, I inspected and removed GPS and activity data from collars that malfunctioned, indicated by VHF pulse rate or absence of VHF beacon.

Location Error

I estimated GPS location accuracy at Chesapeake Farms from stationary 3300L GPS tracking collars placed on poles 1-meter above the ground in 2 cover types (i.e., open field and woodland). Also, I placed a collar in leaf-on and leaf-off woodland cover types to determine seasonal differences of location accuracy. Collars attempted a fix every hour and were deployed ≥ 3 days. Collar data were screened according to PDOP and altitude value to remove outliers (D'Eon and Delparte 2005). I estimated "true" locations of test sites using the geometric mean of *x,y* locations of all successful, screened locations, instead of using a location from a hand-held unit, which is an approximation (G. Catts, N.C. State University, personal communication). Using the geometric mean is a more robust approach, because locations from multiple days and times of day represent more satellite configurations and the mean from these should be more accurate when at least 20 locations are used (G. Catts, N.C. State University, personal communication). Error distances between the geometric mean and individual test locations were calculated by calculating the square root of the sum of the squared *x,y* coordinate differences,

$$\text{Error Distance} = \sqrt{\left(x_i - \bar{x}\right)^2 + \left(y_i - \bar{y}\right)^2}$$

Positional data were not differentially corrected because the increase in accuracy would be insignificant for most wildlife applications (Dussault et al. 2001). Graves and Waller (2006) reported differential correction decreased mean error in locations by 0.99-m and only 5% of locations were corrected by more than 8 m. Fix rates for all error test sites were 100% and I was unable to detect any influence of satellite availability, time of day, terrain, or canopy cover on fix rate (Moen et al. 1997, D'Eon et al. 2002). Location error was largest in leaf-on woodlands and smallest in open field (Appendix 1); however, a higher percentage of leaf-off woodland locations were omitted based on screening criteria. Data screening resulted in 8.6% and 23.5% data omission in 3D and 2D locations, respectively, and 9.4% data omission overall for error test sites.

Data Analysis

The study period began 1 August and ended 6 January in 2003, 2004, and 2005. Breeding periods were based on dates and ages of fawns captured at Chesapeake Farms. Eighty two percent of neonate captures from 1999-2005 (n = 139) occurred between 24 May and 8 June. Parturition of 14 of 15 females occurred between 20 May and 3 June (J. L. Bowman, Dept. of Entomology and Applied Ecology at the University of Delaware, unpublished data). Using these fawning data and an average gestation time for white-tailed deer of ~200 days (Plotka et al. 1982), I established a breeding period and analogous periods before and after breeding (Appendix 2). The summer period represented GPS locations between 1 August and 2 September. The early fall period represented locations between 3 September and 23 September. To determine if any changes occur due to breaking up of bachelor groups, intra-sexual aggression, and courtship behavior (Hirth 1977, Marchinton and Hirth 1984), I defined 2 pre-breeding periods; pre-breed1 and pre-breed2 from 24 September to 14 October and 15 October to 4 November, respectively. The breed period occurred between 5 November and 25 November. To quantify movement and activity after breeding, I established a post-breeding period between 26 November and 16 December, which included Maryland's 2-week shotgun season. The winter period represented GPS locations between 17 December and 6 January.

Home Range - Data consisted of GPS locations and associated activity data from 7-days post capture until January 6th or until the collar stopped recording data. The post-capture delay allowed acclamation to wearing the collar and for overcoming any residual physiological effects of capture. I imported individual collar data into ArcGis® 9.1 (Environmental Systems Research, Inc., Redlands, California, USA) and used the Home Range Tools (HRT; Rodgers et al. 2005) extension to calculate adaptive kernel core area (50% volume) and home range (95% volume) utilization distributions for each individual. I used the unit variance method to standardize GPS data (Seaman and Powell 1996), which rescales each x and y coordinate by dividing them by their respective standard deviations (Rodgers and Carr 2002), and BCV to determine *h* (Sain et al. 1994, Rodgers and Carr 2002). Home ranges and core areas of each individual were calculated for the study period and each season. Unbalanced analysis of variance (SAS Institute, Cary, North Carolina, USA) with the Tukey adjustment for pairwise difference comparison (Cody and Smith 2006) was applied to test significance between years and seasons. Intensity of use (Favreau 2005) was calculated as the core area to home range ratio (Lent and Fike 2003). Statistical test were considered significant at $P < 0.05$.

We estimated a home range based on GPS data from 8 males that were captured < 0.5 km away from one another to quantify the minimum scale it would take to implement an effective QDM program in a mid-Atlantic agricultural landscape without formation of a management cooperative.

Movement and Activity - Individual animals were considered the experimental unit, thus avoiding pseudoreplication, inflated sample size problems, and type I error (i.e., increased chance of rejecting our null hypothesis when it was actually true) (Hurlbert 1984, Aebischer et al. 1993, Otis and White 1999) because my data consisted of multiple observations on a few number of individuals.

Movement step was the straight-line distance between successive locations (Favreau 2005) and was calculated using the animal movement extension ver. 2.0 (Hooge and Eichenlaub 2000) for ArcView® (version 3.3, ESRI, Redlands, California, USA). Instances where GPS locations were not obtained caused a gap in successive distance calculations and were omitted from analysis of movement step data. To aid in analysis involving missing data, I divided the 24-hour day into 4 periods; night, dawn, day, and dusk. Dawn consisted of the hour before sunrise, the hour in which sunrise occurred, and the hour after sunrise. Analogous periods were defined for dusk. Night represented the remaining hours between dusk and dawn, while day represented the remaining hours between dawn and dusk. I only used activity data from the vertical sensor "Y-activity" due to over-sensitivity of the horizontal sensor, which has been shown to log activity data when the animal was actually bedded (Coulombe et al. 2006).

To assess the relationship between deer behavior and climatic factors, movement step and relative activity were regressed against temperature, barometric pressure, relative humidity, wind speed, wind direction, and precipitation obtained from a continuously recording on-site weather station. Variables were generated to include the differences of wind speed, wind direction, barometric pressure, and precipitation at the n^{th} observation and n-1, and wind direction at n-1. These variables were created to determine if adult males respond to the change in these variables over a one-hour period. Moon phase was included in analysis to determine how adult male movement and activity respond to lunar cycles. Also, habitat type was included in analysis of activity data. A number of gaps, representing

13% of analysis days, were discovered from the onsite weather station, and were filled using weather data (WeatherBank Inc., Edmond, Oklahoma, USA) from Martin State Airport (39° 19’ N, 76° 25’ W) which is ~26 km NW of Chesapeake Farms in Baltimore County, Maryland.

Only observations during the four breeding periods (i.e., pre-breed1, pre-breed2, breed, and post-breed) were included in regression analyses because it increased data sensitivity by reducing noise introduced from data during summer, early fall, and winter. Also, dataset size from the entire study period was inordinately large, which made computation time unreasonable. Stepwise regression (StepAIC, MASS library of R, 2006) with Akaike’s Information Criteria (AIC) was used for model selection. Using StepAIC for selection did involve the wrong covariance structure for autocorrelated data, which can result in incorrect standard error estimates, but dataset size and computation duration necessitated this approach.

Multiple regression (PROC MIXED, SAS 2001) with random effects and repeated measures was used to regress movement and activity data. PROC MIXED uses a likelihood estimation method where PROC GLM uses a method of moments that requires complete data (Wolfinger and Chang 1995). Therefore, I could use all available data regardless of subjects with missing data, which was manifested due to unsuccessful acquisition of a GPS location. Movement step ($Z = 0.47$, $P = 0.3505$) and activity ($Z = 0.9$, $P = 0.185$) data showed no effect of year, so data were pooled across years. Variation of movement step ($Z = 2.39$, $P = 0.008$) and activity ($Z = 2.05$, $P = 0.02$) between males had a significant effect on parameter estimates, requiring use of individual males as a random effect in the models. Movement and activity data were log + 1 transformed due to nonnormal distribution of residuals. The serially autocorrelated nature of the data required the use of a first-order autoregressive process (i.e., AR(1) at $P < 0.001$) for accurate error estimation. Covariance parameters were estimated using restricted/residual maximum likelihood (REML) estimates of random effects.

Class variable estimates in regression analyses (i.e., period of day, moon phase, habitat type, and wind direction) were based on individual specified levels because these data were categorical. The specified level was chosen a posteriori based on when highest movement and activity occurred (Appendix 3).

Habitat selection - I evaluated habitat selection with positional data for each collared adult male combined with habitat classifications of Chesapeake Farms obtained by traversing habitat perimeters with a handheld GPS unit, which were transferred into a geographic information system (GIS). Gaps in habitat classifications were delineated in a GIS using U.S. Geological Survey 7.5-minute digital orthophoto quarter quadrangles (DOQQ) with 1-m resolution, and resource availabilities were treated as known quantities (Thomas and Taylor 1990).

Habitat delineation resulted in 4 classes; cropland, grassland, woodland, and other. Croplands consisted of cash grains (i.e., corn and soybeans) and forage crops (i.e., clover, Japanese millet, sorghum, winter wheat, and rye). These two habitats were lumped because sometimes forage crops were in strips within a field of unharvested crops left for migrating waterfowl and would be utilized by deer (Nixon et al. 1991). Grasslands consisted of warm and cool season grasses and early successional areas. Woodlands consisted of deciduous stands with some mixed deciduous/evergreen stands ranging in age from 15- to ~80- years old. Other consisted of buildings and grounds, marshes, ponds, roadways, and tidal waters. These land covers were grouped into one class because they were available but not utilized by all individuals or not available to all individuals (Figure 2; Aebischer et al. 1993). I consolidated habitat types because it avoided problems caused by missing habitats and decreased incidences of available habitats not being utilized. This consolidation decreased type I error rates (Thomas and Taylor 2006), and reduced incidences where a habitat was not available (Aebischer et al. 1993).

I compared used habitats with available habitats at the population level (2^{nd} order selection, Johnson 1980) with habitat availability being the same for all individuals (i.e., design II [Thomas and Taylor 1990]) and at the home range level (3^{rd} order selection, Johnson 1980) with habitat availability being calculated for each individual (i.e., design III [Thomas and Taylor 1990]). Availability at the population level was estimated by calculating a home range of all locations from all individuals (Rouleau et al. 2002) and use was estimated by each individual's home range. Availability at the home range level was estimated using home ranges for each individual and use was estimated using each individual's positional data. Analyses were carried out using compositional analysis for the entire study period and seasonal periods (Aebischer et al. 1993).

Given D types of available resource units, an individual animal's proportional use of these resources is denoted by the composition $o_{u1}, o_{u2}, ..., o_{uD}$, where o_{ui} is the estimated proportion of resources used by the individual that are of type *i*, and the available proportions for the same individual are denoted by the composition $\pi_{a1}, \pi_{a2}, \ldots, \pi_{aD}$ (Manly et al. 2002). Any instance where a habitat was available but not utilized a value was entered that resulted in a proportion of use of 0.001%. Aebischer et al. (1993) showed this replacement value had little effect on significance levels and habitat rankings. Manly et al. (2002) stated that for any component o_j of a composition, the log ratio transformation produces variables that are linearly independent. As a result, the differences were calculated,

$$d_i = \log_e(o_{ui}/o_{uj}) - \log_e(\pi_{ai}/\pi_{aj})$$

for the i^{th} animal to represent the difference between relative use and availability of resources i and j. An overall test for selection entailed considering whether the vector of mean values of d_i was significantly different from a zero vector using Wilk's Lambda test (Manly et al. 2002). The significance of Wilk's Lambda and *t*-values was determined by randomization to overcome problems when non-normal multivariate distributions of log-ratio differences existed (Smith 2006). One thousand iterations were used for randomization tests based on Manly (1997) for tests of significance at the 0.05 level. If an overall test showed deviation from random, pairwise difference comparisons between matching log-ratios determined where use indicated selection (Aebischer et al. 1993). Analyses were carried out using program MACOMP (Ott and Hovey's 1997) in SAS (2001).

I compared diurnal and nocturnal locations at the home range level using MANOVA (PROC GLM; SAS, 2001). I tested the hypothesis of similar diurnal and nocturnal habitat use, which was concluded by paired *t*-tests to show diurnal or nocturnal selection of habitats (Rouleau et al. 2002). First, data were pooled across all years to test seasonal periods. Second, a separate analysis was performed based upon capture location of deer and only included the summer period. This approach served to quantify diurnal and nocturnal habitat use of adult males inhabiting two different landscapes, with emphasis on the influence of cultivated vegetation. For analysis purposes, these two landscapes were delimited by Maryland state highway 20, which runs north to south and dissects Chesapeake Farms.

Figure 2 displays the dichotomy of Chesapeake Farms habitat composition east and west of highway 20.

RESULTS

GPS Collar Performance

Four, 4, and 10 collars were deployed in 2003, 2004, and 2005, respectively. Three, 3, and 9 collars were collected and provided usable data in 2003, 2004, and 2005, respectively (Table 1). VHF contact was lost with one collar in 2003, but was found opportunistically in 2005 with no usable data. In 2004, one deer suffered capture related mortality (i.e., leg through the collar) and collar data were excluded from analysis. Two collars in 2004 malfunctioned due to water damage from a poor battery seal. Data collected before malfunction occurred were included in the analysis. Contact was lost with one collar in 2005 and was never located.

Fix success rates of 2200L models (2003, n = 3) ranged from 89.4% to 90.0% ($\overline{X}$ = 89.7% ± 0.3% SE; Appendix 4). Proportion of 3D fixes by collar ranged from 36.1% to 39.8% ($\overline{X}$ = 38% ± 1.8% SE). Total number of recorded fixes by collar ranged from 2,142 to 4,293 ($\overline{X}$ = 3680 ± 769.3 SE). Fix success rates of 3300L models (2004 and 2005, n = 12) ranged from 95.4% to 99.9% ($\overline{X}$ = 98.8% ± 0.4% SE; Appendix 4). Proportion of 3D fixes by collar ranged from 64.5% to 90.2% ($\overline{X}$ = 81.3% ± 2.2% SE). Total number of recorded fixes by collar ranged from 1,448 to 9,109 ($\overline{X}$ = 4142 ± 596.1 SE).

Study design called for collars to be deployed from August through December. After completion of collar recovery, only 6 of 18 collars deployed collected usable data for the expected study period (Table 1). Premature collar censoring was due to natural mortality

($n = 2$), capture related mortality ($n = 1$), vehicle collision ($n = 1$), collar malfunction ($n = 6$), and unknown ($n = 2$). All collars were retrieved for data collection throughout the study except one. Data screening resulted in omission of 10.2% of total observations across all years and individuals (Appendix 5).

Home Range

Home ranges (95%) and core areas (50%) were calculated for 3, 3, and 9 deer in 2003, 2004, and 2005, respectively. Mean home range and core area for all individuals over all years was 299.4 ha and 40.7 ha, respectively (Table 2). No significant differences were detected between years for mean home range ($F_{2, 12} = 0.63$, $P = 0.547$) and mean core area ($F_{2, 12} = 0.23$, $P = 0.799$). Thus, data were pooled across years to test seasonal differences (Figure 3). Breed (298.6 ha, $F_{6, 80} = 3.95$, $P = 0.006$) and pre-breed2 (285.5 ha, $F_{6, 80} = 3.95$, $P = 0.007$) home ranges were significantly larger than summer (114.7 ha). Breed (46.9 ha, $F_{6, 80} = 4.15$, $P = 0.014$) and pre-breed2 (46.7 ha, $F_{6, 80} = 3.95$, $P = 0.008$) core areas were significantly larger than summer (13.8 ha). Intensity of use ranged from 12% during summer to 16.7% during post-breed with a mean of 14.8% (Figure 4). Intensity of use for males east ($n = 5$) and west ($n = 10$) of highway 20 was 11% and 15.2%, respectively. The combined GPS locations of 8 males captured in close proximity yielded a home range of 390 ha.

Range Shifts – Male 40 orange occupied ranges in the D area and T area during summer and early fall, which were ~2 km apart (Figure 5). During summer 40 orange's core area was in the D area, but there were core areas in both ranges during early fall. By pre-breed1 the home range had shifted to the T area where he was originally captured.

Male 22 blue's core area and home range shifted during pre-breed2 from the Gould area to the Point (Figure 6). These two range centers were separated by ~2.75 km. Prior to the pre-breed1 season, the core area and home range was contained in the Gould area. During pre-breed1, 22 blue had a core area in the Gould area and on the Point. By pre-breed2, the only core area was on the Point, with the home range encompassing the point and parts of the Gould area. Breed and post-breed ranges were on the Point where he was originally captured.

Male 49 blue occupied two different ranges throughout the study period, Chesapeake Farms range (CFR) and Hitchingham range (HR), that were separated by ~6 km (Figure 7). During summer, pre-breed1, and post-breed, 49 blue's range was contained in CFR where he was captured. During early fall, pre-breed2, breed, and winter, 49 blue occupied both ranges. He moved between CFR and HR on three separate occasions. The first occurred on 7 September 2005 from CFR to HR, and back to CFR on 23 September. The second excursion occurred on 20 October from CFR to HR and back to CFR on 18 November. The third event was from CFR to HR on 27 December and back to CFR on 29 December.

<u>Regression Analysis</u>

Model selection of movement step (i.e., straight line distance between successive locations) and activity data consisted of few similarities and activity data selected a larger variety of independent variables (Appendix 6 and 7). Concurrently, regression analyses resulted in few similarities, and activity data had a larger variety of significant predictors (Appendix 8 and 9).

Movement Step – Period of day (Figure 8) and temperature were significant predictors of adult male movement in all and three of four seasons, respectively (Table 3). Movement step by period of day fluctuated by season, but, in relation to dusk, daytime generally had the least amount of movement (Appendix 10). Adult male movement step decreased at higher hourly temperatures and may be an artifact from period of day because adult males moved less during the daytime; the period of day with higher temperatures (Appendix 11). Moon phase was a significant predictor during pre-breed2 ($F_{3, 1282} = 3.28$, $P = 0.02$) and post-breed ($F_{3, 836} = 6.12$, $P < 0.001$) but the effect of moon phase on adult male movement was inconsistent between these two periods (Figure 9).

During Pre-breed1, 13% of collared adult males exhibited at least one instance of a strictly nocturnal, extensive movement out of their normal range into an area, or areas, not previously occupied. Forty percent of collared males exhibited similar movements during pre-breed2, but 30% either began or occurred diurnally. During breed, 58% of collared males performed these movements and 73% either began or occurred diurnally. Twenty percent of collared males exhibited these movements during post-breed and 30% either began or occurred diurnally. By the winter period only 17% performed an extensive movement.

Activity – Habitat type and difference in temperature were significant predictors of activity in three of four seasons. Period of day (Figure 10) and moon phase were significant in two of four seasons, while several predictors were only significant in one of four seasons (Table 4). Activity was consistently higher in open canopy habitats, specifically croplands, than woodland habitats (Figure 11). During pre-breed1 ($F_{1, 4431} = 6.73$, $P = 0.01$) and pre-breed2 ($F_{1, 3814} = 43.3$, $P < 0.001$), adult male activity decreased as the change in hourly temperature increased, but activity increased as the change in hourly temperature increased during post-breed ($F_{1, 2713} = 5.53$, $P = 0.02$). Also, temperature interacted with period of day during pre-breed1 ($F_{3, 3279} = 4.39$, $P = 0.004$) and slightly during pre-breed2 ($F_{3, 2545} = 2.33$, $P = 0.0539$) as male activity decreased with higher temperatures during the dawn period. Period of day was only significant during pre-breed1 ($F_{3, 3304} = 7.8$, $P < 0.001$) and pre-breed2 ($F_{3, 2956} = 4.39$, $P = 0.004$) periods (Appendix 12). Moon phase was a significant predictor during pre-breed2 ($F_{3, 1458} = 14.95$, $P < 0.001$) and breed ($F_{3, 1237} = 10.11$, $P < 0.001$) periods (Figure 12).

Period of day and temperature were consistent significant predictors between adult male movement and activity during pre-breed and post-breed periods, but not during the breed season (Table 5). This suggests male movement and activity were not related to photoperiod and environmental pressures when breeding was occurring. Moon phase was a consistent predictor during pre-breed2, with greater movement and activity occurring during the darker phases (i.e., new and last quarter). Although adult males could be responding to moon phase it was only consistently detected in one of the four seasons.

Habitat Selection

Population Level – Adult males showed greatest selection for croplands during summer and for woodlands during winter in proportion to their availability (Appendix 13 and 17). Habitats were used in proportion to their availability during early fall, pre-breed1, pre-breed2, breed, and post-breed periods.

Home Range Level – Habitat selection by adult males shifted across seasons (Table 6). Males exhibited greater selection of cropland during summer and pre-breed1 in proportion to its availability (Appendix 13 and 14). During breed, post-breed, and winter males showed greater selection for woodland habitats (Appendix 15-17). Habitats were used in proportion to their availability during early fall and pre-breed2.

Diel Habitat Use – Males did not select diurnal and nocturnal habitats similarly by period of day ($P < 0.001$; Appendix 18). Nearly half of diurnal locations during summer were in open canopy habitats (i.e., cropland and grassland), but woodland quickly became the predominant diurnal habitat type after summer (Figure 13). Open canopy habitats comprised the majority of nocturnal locations until the breed period (Figure 14). During the summer period, males east ($F_{6, 32} = 3.46$, $P = 0.01$) and west ($F_{6, 64} = 38.81$, $P < 0.001$) of highway 20 did not use habitats similarly during diurnal and nocturnal periods. However, paired t-tests of males east of highway 20 were unable to detect significant selection of diurnal habitats during summer (Table 7).

DISCUSSION

Animal behavior (e.g., bedding, foraging, and moving) is reported to have an impact on fix rates of GPS collars (D'Eon 2003, D'Eon and Delparte 2005, Graves and Waller 2006) and may be evident in this research because deployed GPS collar fix rates were <100%. Estimating potential bias incurred from unsuccessful attempts was difficult because fix rates from location error tests were 100%. Missing data (i.e., number of unsuccessful attempts and screened data) by time of day were used to determine whether missing data occurred at random or if their distribution was skewed towards certain times of day (Appendix 19). Interestingly, distribution of missing data was skewed toward periods of increased movement (i.e., dawn and dusk) and daytime inactivity (i.e., daytime). Deer using closed canopy habitats during the daytime for bedding and rumination (Beier and McCullough 1990, Nixon et al. 1991) will result in less success in obtaining GPS locations from bedded deer (Bowman et al. 2000). Another potential source of bias was males were captured during crepuscular periods. Therefore, results may be biased towards individuals that are most active during these periods. However, impacts of potential biases are considered minimal because our results were consistent with past research (Ivey and Causey 1984, Beier and McCullough 1990, Nixon et al. 1991, Rouleau et al. 2002, Coulombe et al. 2006). Potential bias could exist in activity data from GPS collars due to variations in collar tightening among individuals and seasons (Coulombe et al. 2006). However, diel and seasonal results of adult male activity on Chesapeake Farms are consistent with previous research (Ozoga and Verme 1970, Ivey and Causey 1984, Marchinton and Hirth 1984, Rouleau et al. 2002, Coulombe et al. 2006).

Home Range

Seaman and Powell (1996) noted that using the adaptive smoothing approach actually over-smoothed utilization distributions due to outlying areas of relatively low densities of locations. Therefore, home range and intensity of use results may be overestimated. However, Lent and Fike (2003) reported black rhino intensity of use at 21% in South Africa and Linklater et al. (2000) reported wild horses in New Zealand at 12%. Adult male home ranges were smallest during summer possibly due to the increase in forage availability and cover, especially in agricultural landscapes, at this time of year, which exceeds increases in metabolic demand (Beier and McCullough 1990). Also, juxtaposition and interspersion of feeding (i.e., cropland) and bedding (i.e., woodland and grassland) areas would contribute to smaller home ranges and core areas. In addition, Ozoga et al. (1982) proposed small home ranges during this time of year may result from movement restriction due to females rearing fawns. Adult male home ranges increased sequentially from summer to the breed period with a slight decrease during post-breed and a subsequent increase during winter.

The largest home ranges occurred during pre-breed2 and breed periods. Sequential increases in home range are consistent with the decline in forage quality as well as the onset of rutting behavior (Figure 15; Nelson and Mech 1981, Ivey and Causey 1984, Beier and McCullough 1990). This is evident by the decrease in intensity of use. Although intensity of use will vary depending on type of home range estimator and smoothing approach (Worton 1989, Seaman and Powell 1996), the successional decrease in intensity of use by males throughout the periods indicates a change in behavior, whether a response to environmental or physiological conditions or both. The subsequent decrease in home range and increase in intensity of use during post-breed signals another change in adult male behavior, probably in response to decline of rutting behavior. However, impact of hunting activity during this period was not assessed and should be evaluated to determine if and how human disturbance impacts range use.

Seasonal shifts in home range are evident in northern deer (Heezen and Tester 1967, Rongstad and Tester 1969, Sparrowe and Springer 1970), but not as much in southern deer (Alexander 1968, Marchinton 1968). Adult male white-tailed deer on Chesapeake Farms exhibited individual variation in range shift, but most exhibited a shift from summer to winter (Tierson et al. 1985, Beier and McCullough 1990) probably due to changes in forage availability and cover from crop harvest. I believe range shifts of males 40 orange and 22 blue were related to capture because shifts took place ~1 week post capture and both returned to where they were captured by the beginning of breeding. Male 49 blue's first excursion took place roughly one month post capture and all three excursions were predominantly nocturnal with consistent movements between the two ranges, suggesting prior knowledge of the area and destination. Therefore, I do not believe these excursions were a capture response.

Intensity of use indicated that individual males were capable of obtaining life requisites within confined areas of their range, possibly due to interspersion of habitats within the landscape, allowing for close proximity to food and cover (Kernohan et al. 2002).

Adult male intensity of use was greatest east of highway 20. Similar to Ozoga et al.'s (1982) hypothesis, adult sex ratios were similar between the two landscapes (J. Shaw, North Carolina State University, unpublished data) indicating any impact of fawn rearing on adult male home range should be consistent between the two landscapes. Therefore, discrepancies may be due to habitat composition. Estimates of female home ranges west of highway 20 would facilitate further clarification of the impacts habitat composition, resource partitioning, and sexual segregation may have on range size and use.

The abundance of open habitat east of highway 20 bordered by a thin rim of closed habitat concentrated males and females (Adams 2003), resulting in increased intensity of use. Home ranges and core areas of females on Chesapeake Farms east of highway 20 were previously reported using the adaptive kernel approach (Adams 2003). However, the smoothing parameter Adams used in his estimates is unknown and, if different from the parameter I used, can complicate or invalidate comparisons (Hemson et al. 2005). Summer (i.e., May-September) was the period used for estimation so home range periods are not entirely consistent between males and females, but male home ranges and core areas, during August and September, were approximately 38% larger than females and similar to those reported by Nelson and Mech (1981) and Beier and McCullough (1990).

<u>Movement</u>

Movement step (Favreau 2005) calculations may have resulted in underestimates of adult male movement, because the shortest distance between two points is a straight line, which may not depict actual movement trajectory. Movement of adult males at Chesapeake Farms was exemplified by localized movements (Favreau 2005) from bedding areas to feeding areas during the summer and early fall seasons with a sequential increase in movement due to decline in forage availability, break up of bachelor groups, and escalation of rutting behavior during pre-breed1, pre-breed2, and breed seasons (Hirth 1977, Kammermeyer and Marchinton 1977, Nelson and Mech 1981). Adult male movement peaked during the breed season (Marchinton and Hirth 1984) and subsequently decreased during the post-breed season (Figure 16). Movement during the breed season was characterized by extensive movements in or adjacent to areas used in summer, allowing males to locate more females (Figure 17; Nelson and Mech 1981). On most occasions these extensive movements were characterized by males covering large portions of their home range with continuous movement and returning to the point of origin within 8-30 hours (Figure 18), consistent with Brown's (1974) dominant floater description. However, on a few occasions these extensive movements were accompanied by a period (i.e., 6-24 hours) of relatively little to no movement in an area not previously occupied, suggesting formation of a tending bond (Moore and Marchinton 1974, Hirth 1977). These movements were only evident in a couple males and should not be used as a measure of bonds formed because bonds are undoubtedly formed within a male's normal range. Three males exhibited similar movements during post-breed and winter periods, suggesting courtship behaviors of late or second cycle estrus females.

Excursions of male 49 blue between CFR and HR indicated a selection for familiar terrain (Hölzenbein and Marchinton 1992), possibly 49 blue's natal range. Male 49 blue's excursions raise questions about the effects of social pressure, most likely intra-sexual competition at this time of year (Kammermeyer and Marchinton 1976), on male movement in a population with a balanced sex ratio and mature male age structure. Social pressures are the primary stimulus for dispersal (Hirth 1977, Nixon et al. 1991, Rosenberry et al. 1999, Long et al. 2005, Shaw et al. 2006). Kammermeyer and Marchinton (1976) stated most long range movements during breeding were made by 1.5 and 2.5 year-old males of breeding age but participated little in breeding due their subordinate social status. However, Kammermeyer and Marchinton (1976) do not provide sex and age data except for deer/km^2. Herd parameters at Chesapeake Farms are a result of a QDM program implemented in 1994 (Dr. Conner, Manager, Chesapeake Farms, personal communication). Consequently, male age structure has shifted towards more mature males, resulting in changes in dominance hierarchies and social pressure on subordinate males. Therefore, long range movements of 49 blue, aged at 3.5 (Severinghaus 1949), may be a response to shifts in male age structure and resulting intra-sexual competition.

Regression analyses of the four breeding periods indicated that temperature (Nelson and Mech 1981, Beier and McCullough 1990) and period of day were the most reliable predictors of adult male movement. Similar to previous research on activity in deer (Beier and McCullough 1990), movement of adult males in all seasons shifted to periods when climate conditions were most favorable for thermoregulation. Period of day was a significant predictor in all four seasons and temperature was a significant predictor in all seasons except breed, possibly a result of rutting behavior. Moon phase was a significant predictor during pre-breed2 and post-breed seasons but the movement response was inconsistent between the two seasons (Michael 1970, Carbaugh et al. 1975). Wind speed reduced movement during the breed period, but did not significantly affect activity, supporting Beier and McCullough's (1990) conclusion that deer escape effects of wind speed by shifting habitat without decreasing activity. Also, reducing movement as wind speed increases may reduce vulnerability to predators because deer abilities of sight, sound, and smell are hindered as wind speed increases. The inconsistency of predictors during the breed season may be due to extensive movements during the rut (Beier and McCullough 1990).

Activity

Kammermeyer and Marchinton (1977) demonstrated higher diel activity peaks in fall than in summer, probably because they used distance traveled as a measure of activity (Beier and McCullough 1990). Our results showed that males had higher diel activity peaks during summer and early fall which became less pronounced as breeding season approached. This shift was not due to a decrease in activity but a sequential increase in amount of day active with onset of rutting behavior (Beier and McCullough 1990). Male activity peaked during the breed period (Marchinton and Hirth 1984) and significantly decreased during post-breed (Figure 19). Similar to movement results, increase in fall activity was consistent with decline in forage availability and onset of rutting behavior. Daytime was the period of lowest activity, suggesting this period of day is used for concealment, resting, rumination, and to minimize heat stress (Beier and McCullough 1990).

Regression analyses resulted in a diversity of predictors, especially in relation to analyses of movement data. Period of day was not a consistent predictor with activity and contributed little to model selection during breed and post-breed periods, probably a result of rutting behavior. Responses to changes in temperature were consistent during warmer periods with the exception of winter. This is most likely an artifact of period of day and a thermoregulatory response. When moon phase was a significant predictor, pre-breed2 and breed, activity responses consistently showed higher activity levels during darker moon phases. Newhouse (1973) noted that deer tended to use closed canopy habitats on moonlit nights, which, based on our results, could lead to reduced activity levels. Higher activity in croplands and other open canopy habitats may indicate foraging and/or rutting behavior. However, browsing behavior may not trigger activity sensors due to limited vertical movement (i.e., not breaking the 15° plane), potentially underestimating browsing activity, especially in closed canopy habitats. Activity response to moderate barometric pressures was consistent with Thomas (1966). During pre-breed2, decreased activity when precipitation was present was consistent with Hawkins and Klimstra (1970). Decreased activity during southwest winds is due to warm moist air, resulting in higher temperatures and % relative humidity, and increased potential of precipitation. Higher activity during northwest winds is due to the majority of winds during this time of year being northwest.

Adult male movement, activity, and climatic factors varied by season and period of day, making it difficult to attribute responses solely to climatic factors, especially with only three years of data. Beier and McCullough (1990) stated seasonal changes in activity were not simply responses to climatic conditions, but reflect changes in foraging time necessary to meet seasonally changing metabolic demands in lieu of seasonal changes in forage quality and quantity and stored energy reserves. Beier and McCullough (1990) stated concerns of confounding associating deer activity over a course of a day or season to concomitant changes in climate: diel changes in activity may not be caused by weather, but by changes in light intensity, feeding-rumination cycles, or activity of predator species; seasonal activity are at least partly caused by metabolic rate fluctuations, fat deposition and catabolism, reproduction, and forage quantity and quality. Deer adjust their active periods to avoid dangerous or exasperating circumstances, maintain physical comfort, and optimize energy conservation, and individual movement distances vary according to age, season, habitat, weather, and physical condition (Marchinton and Hirth 1984). Therefore, we may see some tendencies or generalizations with adult male movement and activity responses, but attributing these to specific climatic factors would be misleading.

Habitat Selection

Adult males at and around Chesapeake Farms exhibited scale dependent resource selection, illustrating the importance of using multiple scales in conducting resource selection analyses (Johnson 1980, Apps et al. 2001, D'Eon and Serrouya 2005). At the population level, habitats were used in proportion to their availability during all seasons, except for the summer period (Rouleau et al. 2002), when males selected croplands (Nixon et al. 1991). Adams (2003) noted similar results for adult females on Chesapeake Farms. Selection of croplands during this time is intuitive because cultivated vegetation provides a rich and abundant source of nutrients during summer (Nixon et al. 1991, Lesage et al. 2000*a*). These results support Verme's (1988) hypothesis that adult males inhabit more open habitats during the summer period providing additional protection for antlerogenesis and allowing increased visual interaction with other males prior to breeding season to establish a dominance hierarchy.

At the home range level, adult males exhibited greater selection of croplands during summer with a shift to woodland habitats by the breed period. Early fall analysis showed habitats were used in proportion to their availability, possibly due to maturation of corn and soybean plants (Nixon et al. 1991, Adams 2003). Woodland and cropland habitats were selected for during the pre-breed1 season, but habitats were used in proportion to their availability during the pre-breed2 season. This fluctuation may be an artifact of cash crop harvesting occurring during the pre-breed1 and pre-breed2 seasons and/or because I lumped cash crops and forage crops into one class. Woodland, cropland, and grassland habitats were consistently selected for during breed, post-breed, and winter seasons. Censoring of individuals at different times throughout the study was not thought to impact selection results, because censoring occurred irrespective of habitat type.

Diurnal and nocturnal habitats were used differently by adult males during each season. Adult males used woodlands during the day while grasslands and croplands were used predominantly during the night (Beier and McCullough 1990, Nixon et al. 1991). Deer used closed canopy vegetation during the day for concealment when daylight would otherwise increase visibility and vulnerability to predators (Beier and McCullough 1990). The majority of Chesapeake Farms' cash grain farming operation is East of Maryland State Highway 20. In this landscape adult males did not use diurnal and nocturnal habitats similarly, however tests were unable to detect selection for diurnal habitats during the summer period (Figure 20). Nixon et al. (1991) reported adult males staying in croplands for extended periods of time during summer because periodic trips to other habitats for fawn rearing purposes were not required. Also, phenology of corn at this time provides adequate cover (Nixon et al. 1991) and can ease thermoregulation. Deer may have used cornfields and grasslands to avoid biting insects (i.e., mosquitoes, gnats, and biting flies) on hot, humid days (Beier and McCullough 1990, Nixon et al. 1991).

Intense browsing pressure on forest communities exerted by deer can alter forest communities in rural landscapes (Rouleau et al. 2002) even with cultivated plants in adjacent fields (Augustine and Jordan 1998). Adult male data combined with doe data (Tardiff 1999, Adams 2003) on Chesapeake Farms illustrates the importance of interspersed wooded and early successional habitats in agricultural landscapes. Adult male habitat selection in a rural landscape during the summer period combined with Adams (2003) research on female's warrants further research into spatial segregation of adult sexes of a nonmigratory deer population in an agricultural landscape.

MANAGEMENT IMPLICATIONS

Movement, activity, and habitat use of adult males revealed by this study combined with previous research on yearling males (Rosenberry et al. 1999, Shaw et al. 2006) and females (Tardiff 1999, Adams 2003) in a mid-Atlantic agricultural landscape suggest effective herd management requires a scale of ≥ 400 ha. Washburn et al. (2006) reported that 90% of nonindustrial private forest (NIPF) landowners hold less than 41 ha and the number of NIPF owners continues to grow. Forty percent of NIPF owner cite recreation and hunting as the primary reason for owning forest land (Washburn et al. 2006). Therefore, in most cases effective herd management would require cooperation between adjacent landowners on goals and objectives of deer management. Cooperation between adjacent landowners would mitigate possible management limitations due to dispersal of yearling male white-tailed deer under a QDM program (Shaw et al. 2006), small property size, and individuals near peripheries of properties.

Escalation of adult male movement from summer to winter with the peak occurring during breed and post-breed periods solicits consideration in how it may impact deer management strategies because these movements will occur during hunting season. Deer hunting seasons (i.e., bow and arrow, blackpowder, and gun) differ by state and within state, and rutting periods will vary by latitude and other factors. Therefore, when different regulated deer hunting seasons occur and how they correspond to the onset of the rut is important in assessing vulnerability of adult males to harvest. Consequently, if management goals differ between adjacent properties then rutting season movements may constitute a limitation to deer management.

Habitat quality and diversity are important components in deer management. The small home ranges of adult males and adult females (Adams 2003) at Chesapeake Farms are indicative of diverse and quality habitat that is interspersed throughout the landscape. Providing adequate forage and cover year round is paramount in management of deer populations, especially in agricultural landscapes. Not just to ensure nutritional quality, provide protection from environmental pressures and predators, and sites for fawn rearing, but due to inflated deer densities maintained by agricultural crops (Kernohan et al. 2002, Rouleau et al. 2002). Resulting pressure on natural forage can reach destructive levels impacting regeneration (Augustine and Jordan 1998, Rouleau et al. 2002) and intermediate canopy nesting birds (deCalesta 1994), and has become a major concern for wildlife managers (Rouleau et al. 2002). Deer in agricultural landscapes are regulated not only by natural forage but by competition for natural and agricultural forage during the dormant season (Rouleau et al. 2002). Therefore, native perennial forages and an aggressive female harvest are important in offsetting pressure on natural forage during periods of dormant growth in fragmented agricultural landscapes.

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Table 1. Age, capture date, and data collection period of 15 adult male white-tailed deer fitted with GPS radio telemetry collars at Chesapeake Farms, Kent County, Maryland, 2003 – 2005.

Deer ID[a]	Age[b]	Capture date	Data collection period
30 Orange	4.5	23 Jul 2003	23 Jul 2003 – 13 Dec 2003
32 Orange	5.5	01 Aug 2003	01 Aug 2003 – 19 Jan 2004
33 Orange	4.5	22 Aug 2003	22 Aug 2003 – 30 Jan 2004
40 White	4.5	24 Jul 2004	24 Jul 2004 – 05 Mar 2005
46 Blue	unknown	26 Jul 2004	26 Jul 2004 – 23 Oct 2005
35 Orange	3.5	08 Aug 2004	8 Aug 04 – 30 Sep 04, 8 Oct 04 – 23 Nov 04
46 White	unknown	30 Jun 2005	30 Jun 2005 – 04 Jan 2006
39 Orange	4.5	05 Jul 2005	05 Jul 2005 – 12 Jun 2006
36 Orange	5.5	07 Jul 2005	07 Jul 2005 – 7 Dec 2005
50 Blue	5.5	08 Jul 2005	08 Jul 2005 – 13 Nov 2005
40 Orange	4.5	13 Jul 2005	13 Jul 2005 – 10 Nov 2005
22 Blue	unknown	18 Jul 2005	18 Jul 2005 – 07 Dec 2005
40 Blue	5.5	01 Aug 2005	01 Aug 2005 – 13 Nov 2005
42 Orange	unknown	02 Aug 2005	02 Aug 2005 – 05 Dec 2005
49 Bue	3.5	09 Aug 2005	09 Aug 2005 – 04 Jan 2006

[a] Deer ID denoted by ear tag number and color

[b] Age when wearing GPS collar was determined from harvested or deceased individuals. All unknown ages were ≥ 2.5 years old.

Table 2. Adaptive kernel home range (95%) and core area (50%) of 15 adult male white-tailed deer fitted with GPS radio telemetry collars at Chesapeake Farms, Kent County, Maryland, 2003-2005.

Year	Volume	N	Mean (ha)	SE (ha)	Minimum (ha)	Maximum (ha)
All	Home Range	15	299.4	31.3	140	586
	Core Area	15	40.7	5.1	8	77
2003	Home Range	3	254.0	73.0	140	390
	Core Area	3	47.7	16.2	21	77
2004	Home Range	3	365.3	68.0	290	501
	Core Area	3	37.0	6.8	27	50
2005	Home Range	9	292.6	41.9	153	586
	Core Area	9	39.6	6.8	8	63

Table 3. Regression analysis of adult male movement step during four breeding seasons (*n*) predetermined by fawning data at Chesapeake Farms, Kent County, Maryland, 2003-2005. Type 3 tests of fixed effects (PROC MIXED, SAS, 2001) reported below.

Effect	Pre-breed1 (14)	Pre-breed2 (13)	Breed (11)	Post-breed (10)
Period of Day[a]	**	**	***	***
Temperature	*	*		*
Moon Phase[b]		*		**
Wind Speed			*	

[a] Period of Day = dawn, day, dusk, and night
[b] Moon Phase = new, first quarter, full, last quarter
* $P < 0.05$
** $P < 0.001$
*** $P < 0.0001$

Table 4. Regression analysis of adult male activity during four breeding seasons (*n*) predetermined by fawning data at Chesapeake Farms, Kent County, Maryland, 2003-2005. Type 3 tests of fixed effects (PROC MIXED, SAS, 2001) reported below.

Effect	Pre-breed1 (13)	Pre-breed2 (12)	Breed (10)	Post-breed (9)
Habitat Type[a]		**	***	***
Difference in Temperature[b]	**	***		*
Period of Day[c]	***	**		
Moon Phase[d]		***	***	
Barometric Pressure	*			
Precipitation[e]		*		
Wind Direction		*		
Temperature x Period of Day[f]	*			

[a] Habitat types = cropland, grassland, marsh, woodland, other
[b] Difference in temperature between the n^{th} observation and n-1
[c] Period of Day = dawn, day, dusk, and night
[d] Moon Phase = new, first quarter, full, last quarter
[e] Presence or absence of precipitation
[f] Interaction between temperature and period of day
* $P < 0.05$
** $P < 0.001$
*** $P < 0.0001$

Table 5. Comparison of significant predictors from regression analyses (PROC MIXED, SAS 2001) of adult male movement and activity by season at Chesapeake Farms, Kent County, Maryland, 2003-2005. Significance was considered at $P < 0.05$.

Season[a]	Movement	Activity
Pre-breed1	Temperature Period of Day[c]	Difference in Temperature[b] Period of Day
Pre-breed2	Temperature Period of Day Moon Phase[d]	Difference in Temperature Period of Day Moon Phase
Breed	----	----
Post-breed	Temperature	Difference in Temperature

[a] Seasons determined by fawn capture and parturition data gathered from Chesapeake Farms (J. L. Bowman, University of Delaware, unpublished data, M.C. Conner, Chesapeake Farms, unpublished data)
[b] Difference in temperature between the n^{th} observation and n-1
[c] Period of Day = dawn, day, dusk, and night
[d] Moon Phase = new, first quarter, full, last quarter

Table 6. Ranking results from Compositional Analysis of adult male habitat selection by season (*n*) at Chesapeake Farms, Kent County, Maryland, 2003-2005. Higher rank indicates greater selection and within season ranks with the same letter are not significantly different at *P*<0.05.

	Season[a]				
Habitat Type	Summer (14)	Pre-breed1 (15)	Breed (12)	Post-breed (10)	Winter (6)
Woodland	2 - a	2 - a	3 - a	3 - a	3 - a
Cropland	3 - a	3 - a	1 - b	2 - a	1 - a
Grassland	1 - ab	1 - ab	2 - ab	1 - a	2 - a
Other[b]	0 - b	0 - b	0 - c	0 - b	0 - b

[a] Seasons were delineated by fawn capture and parturition data from Chesapeake Farms
[b] Other = buildings and grounds, marsh, pond, roadway, and tidal water

Table 7. Summer season diurnal and nocturnal habitat use (%) by adult male white-tailed deer inhabiting landscapes west (*n*) and east (*n*) of Maryland state highway 20 at Chesapeake Farms, Kent County, Maryland, from 2003-2005. MANOVA tested the hypothesis of similar diurnal and nocturnal use of habitats at the home range level, which was completed by paired t-tests to detect significant diurnal (+) or nocturnal (-) selection.

	West of 20 (9)				East of 20 (5)		
Habitat Type	Diurnal	Nocturnal	*t*		Diurnal	Nocturnal	*t*
Cropland	29.6	83.9	-4.54	**	45.4	62.9	-1.76
Grassland	2.6	9.2	-2.00		19.7	14.2	+1.03
Woodland	66.3	5.4	+6.07		24.6	14.6	+2.04
Other[a]	1.5	1.4	+0.11	**	10.2	8.3	+0.19

[a] Other = buildings and grounds, marsh, pond, roadway, and tidal water
** $P < 0.001$

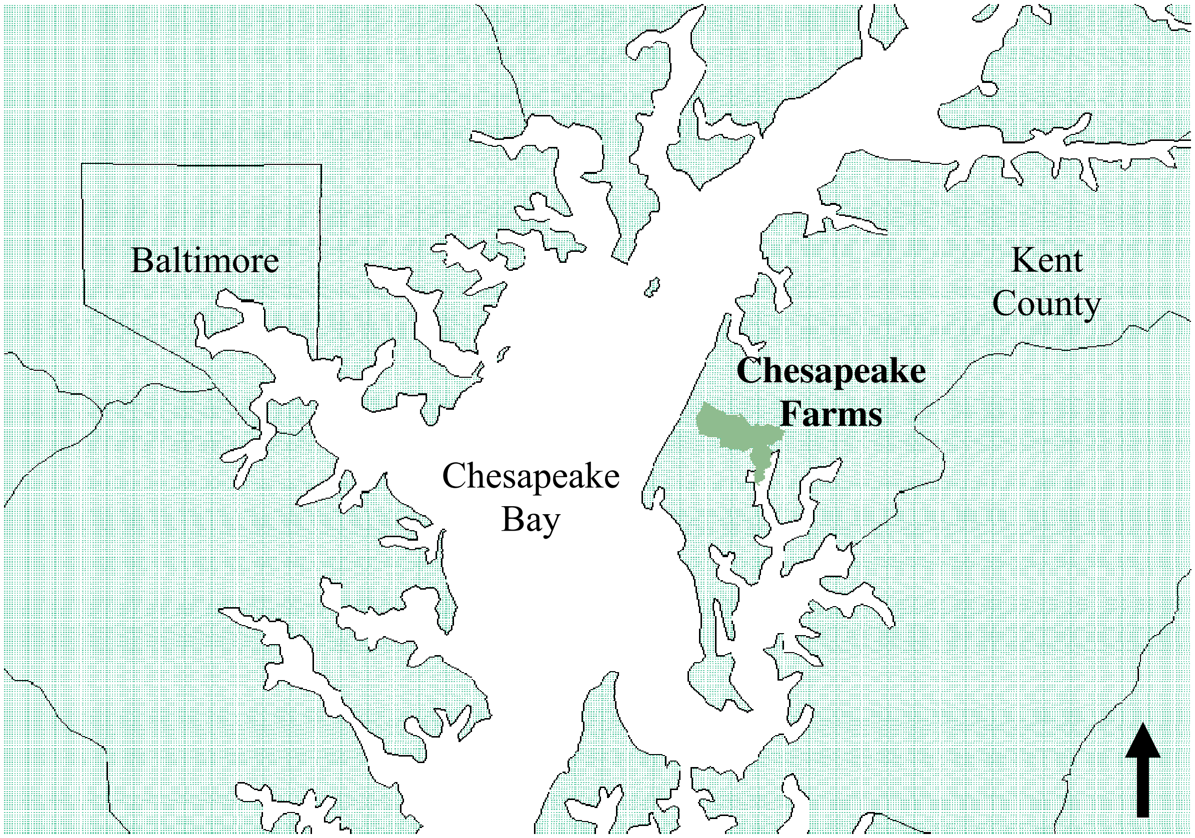

Figure 1. Location of Chesapeake Farms, Kent County, Maryland.

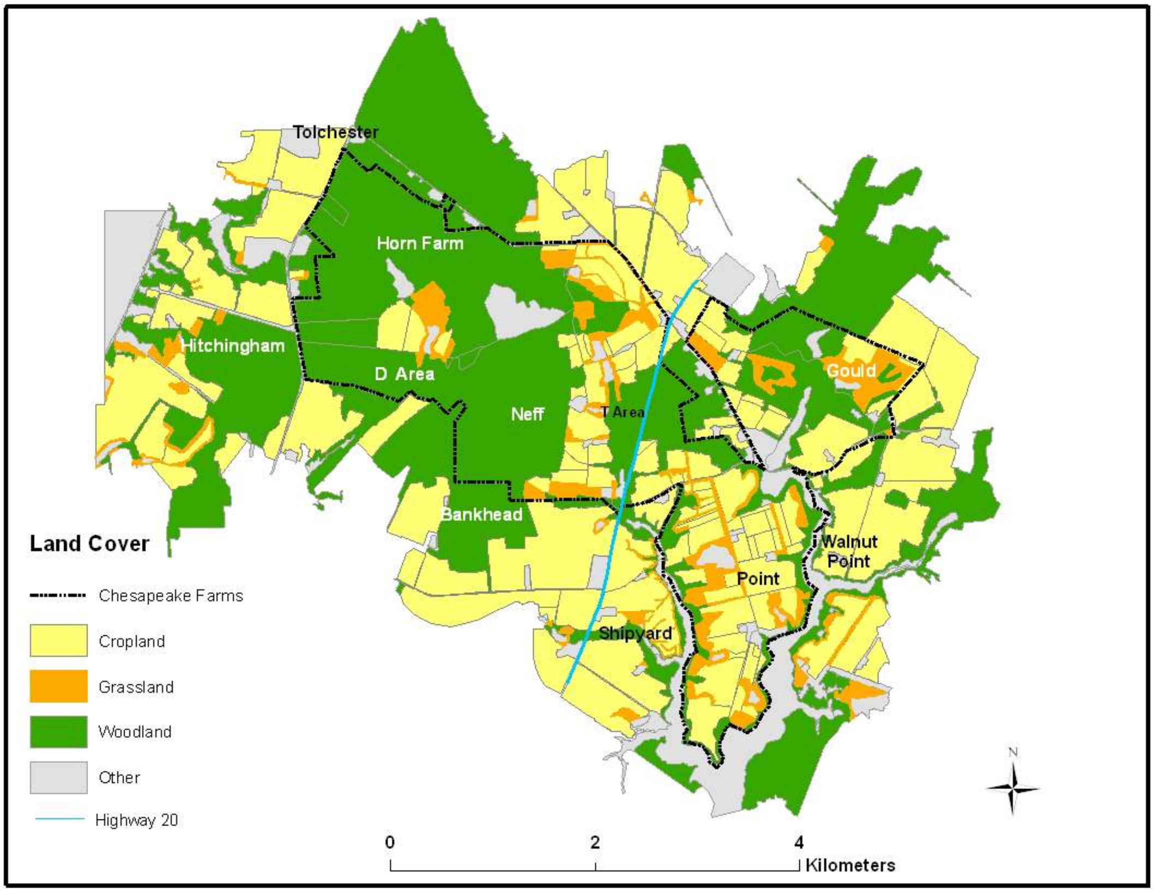

Figure 2. Land cover of Chesapeake Farms and adjacent lands. Croplands included both cash and forage crops. Grasslands included warm and cold season grasses and early successional areas. Woodlands were mainly mesic deciduous stands with a few mixed deciduous/evergreen stands. Other represented ponds, tidal waters, marsh, roadways, and buildings and grounds

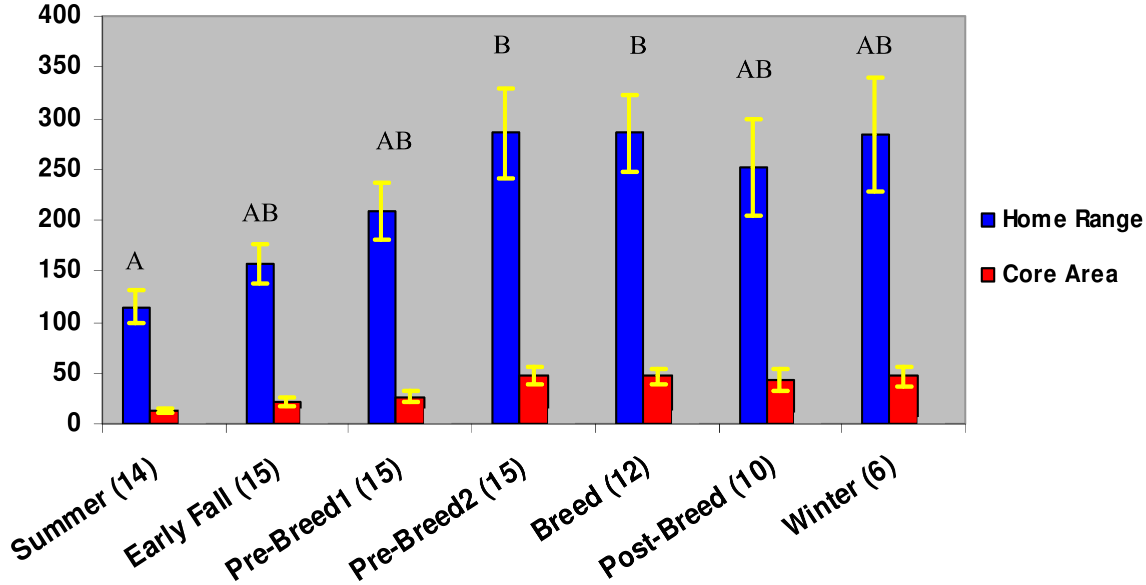

Figure 3. Adaptive kernel home ranges (95%) and core areas (50%) of adult male white-tailed deer by season (*n*) fitted with GPS radio telemetry collars at Chesapeake Farms, Kent County, Maryland, 2003-2005. Seasons with the same letter were not statistically different and apply to both home range and core area. Error bars represent ± SE.

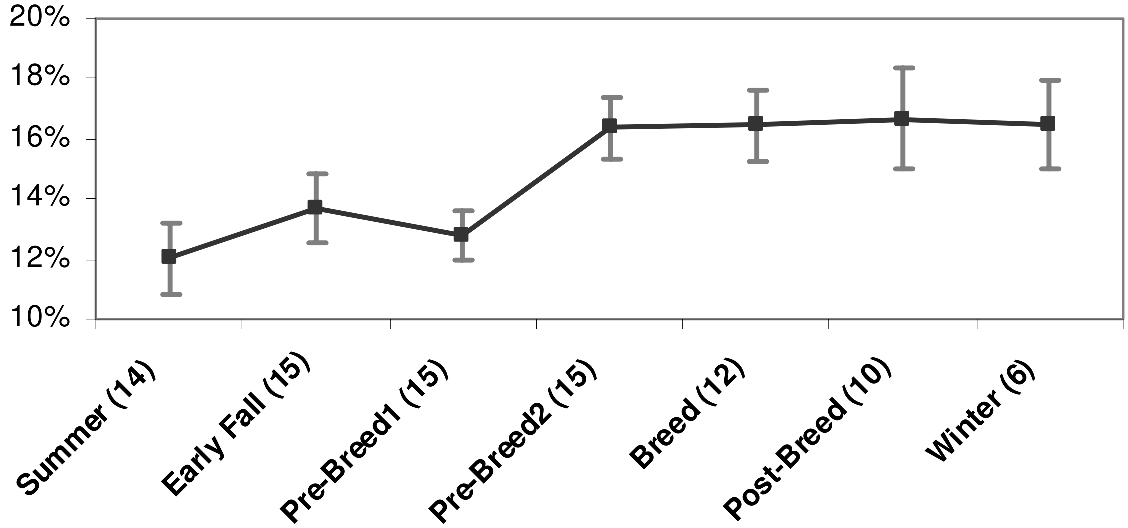

Figure 4. Intensity of use as percent core area (50%) of home range (95%) by season (*n*) for adult male white-tailed deer fitted with GPS radio telemetry collars at Chesapeake Farms, Kent County, Maryland, 2003-2005.

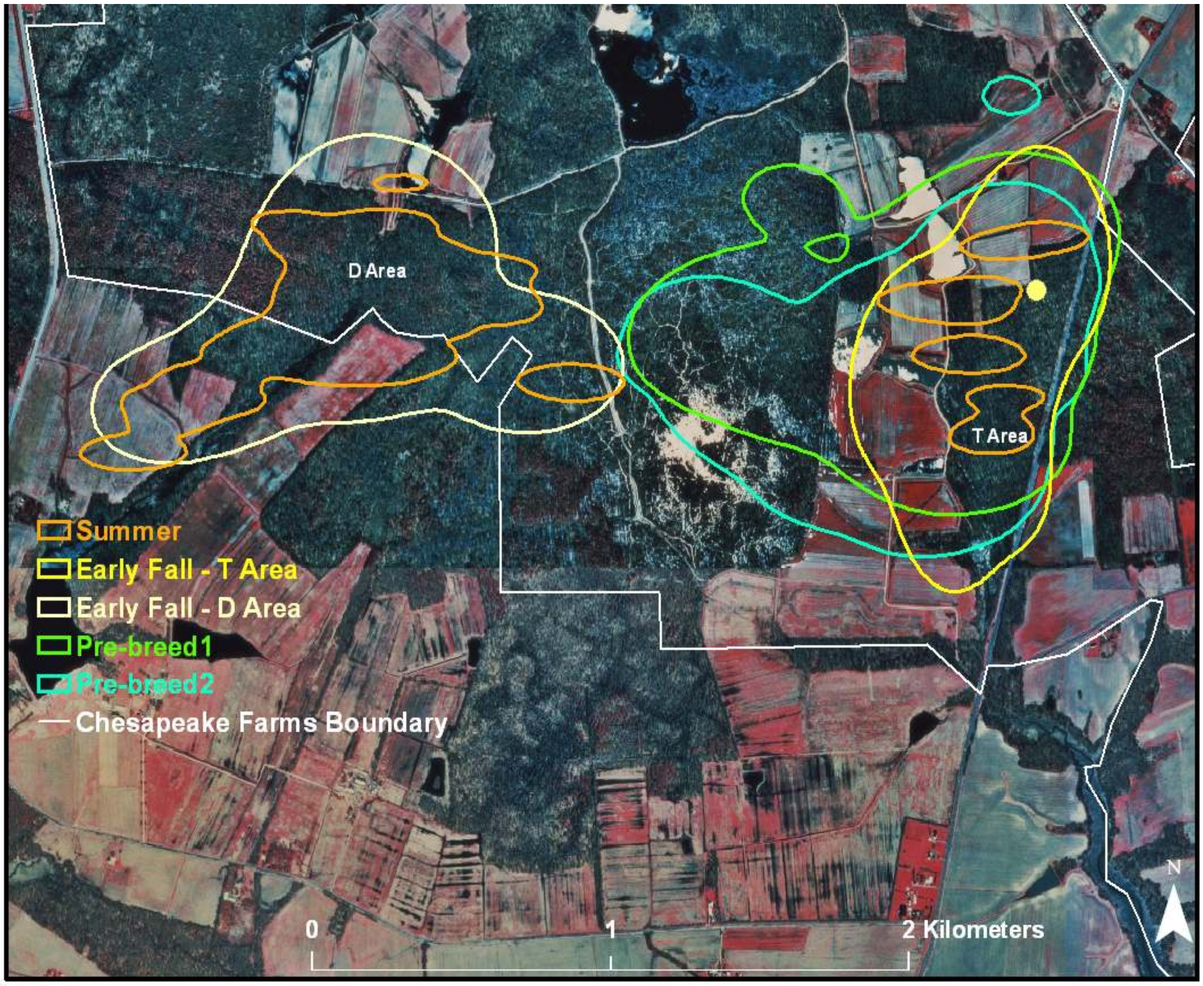

Figure 5. Range shift of male 40 orange from T area to D area during summer and early fall and then back to T area by pre-breed1 on Chesapeake Farms, Kent County, Maryland, 2005. The yellow dot marks where 40 orange was captured.

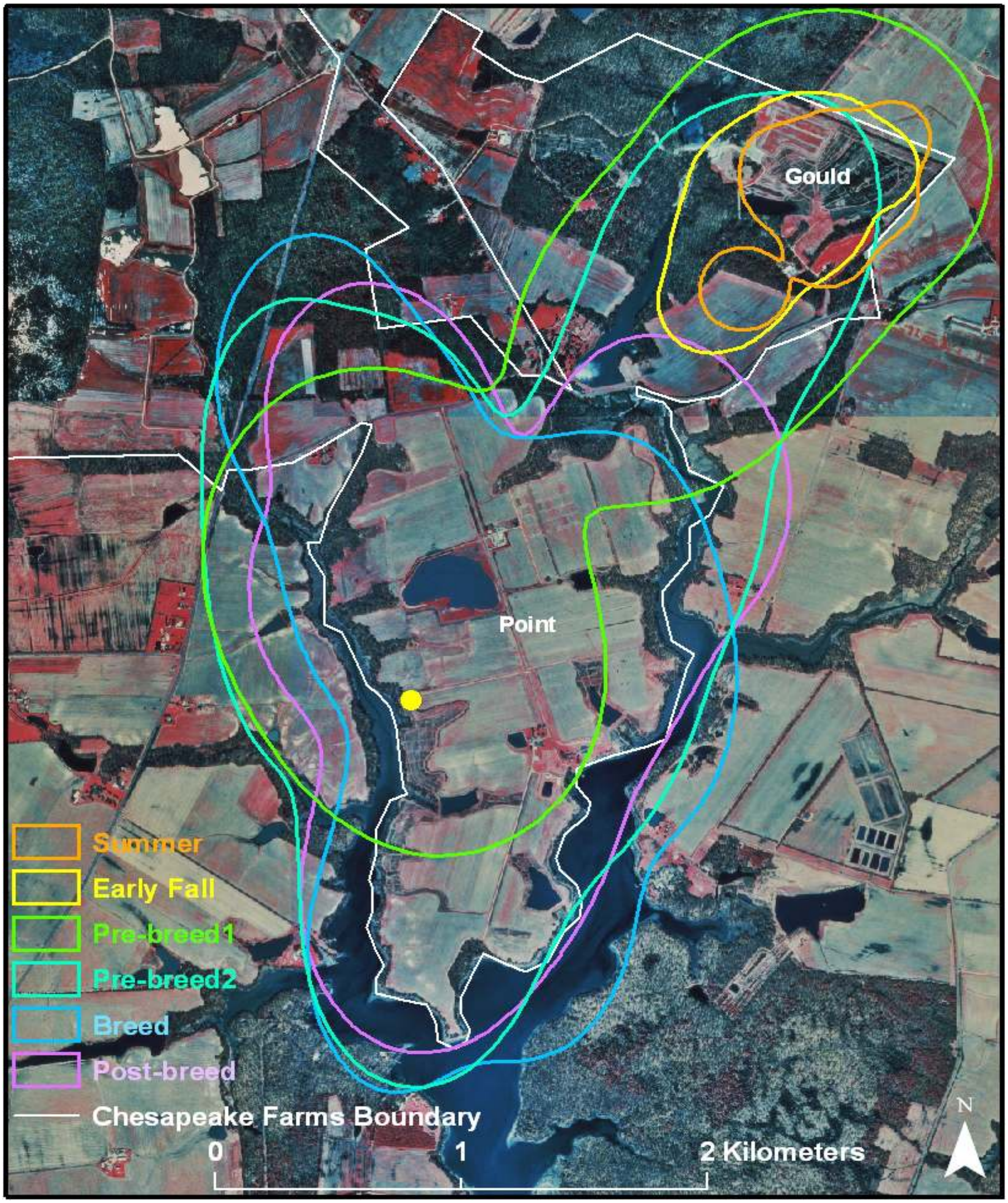

Figure 6. Range shift of male 46 blue from the Gould Area to the Point during pre-breed1 on Chesapeake Farms, Kent County, Maryland, 2005. The yellow dot marks where 46 blue was captured.

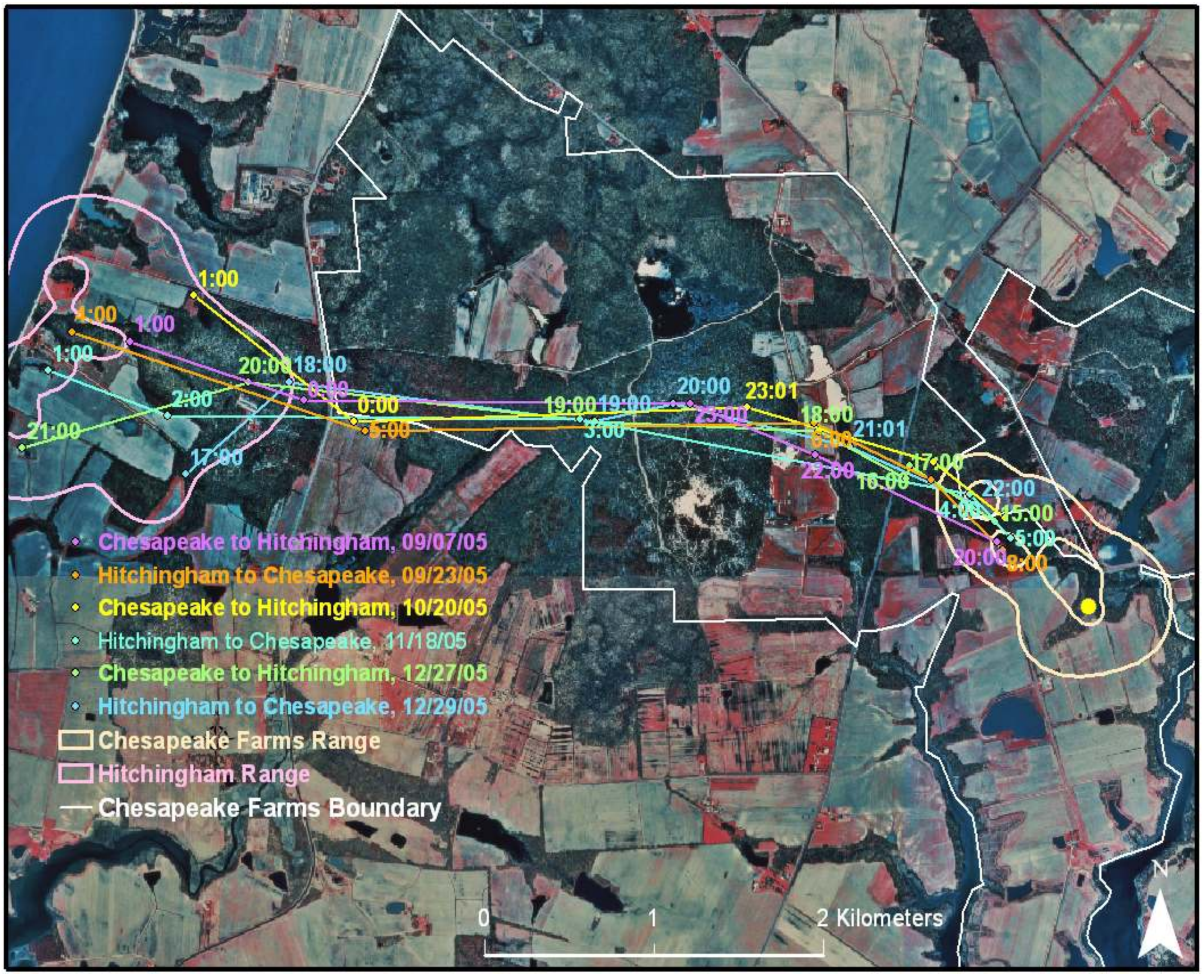

Figure 7. Excursions by male 49 blue, aged at 3.5, from his Chesapeake Farms range to his Hitchingham range between early fall and winter. All 3 excursions were predominantly nocturnal and show consistency of movement path between the two ranges, demonstrating prior knowledge of the area and destination. The yellow dot marks where 49 blue was captured.

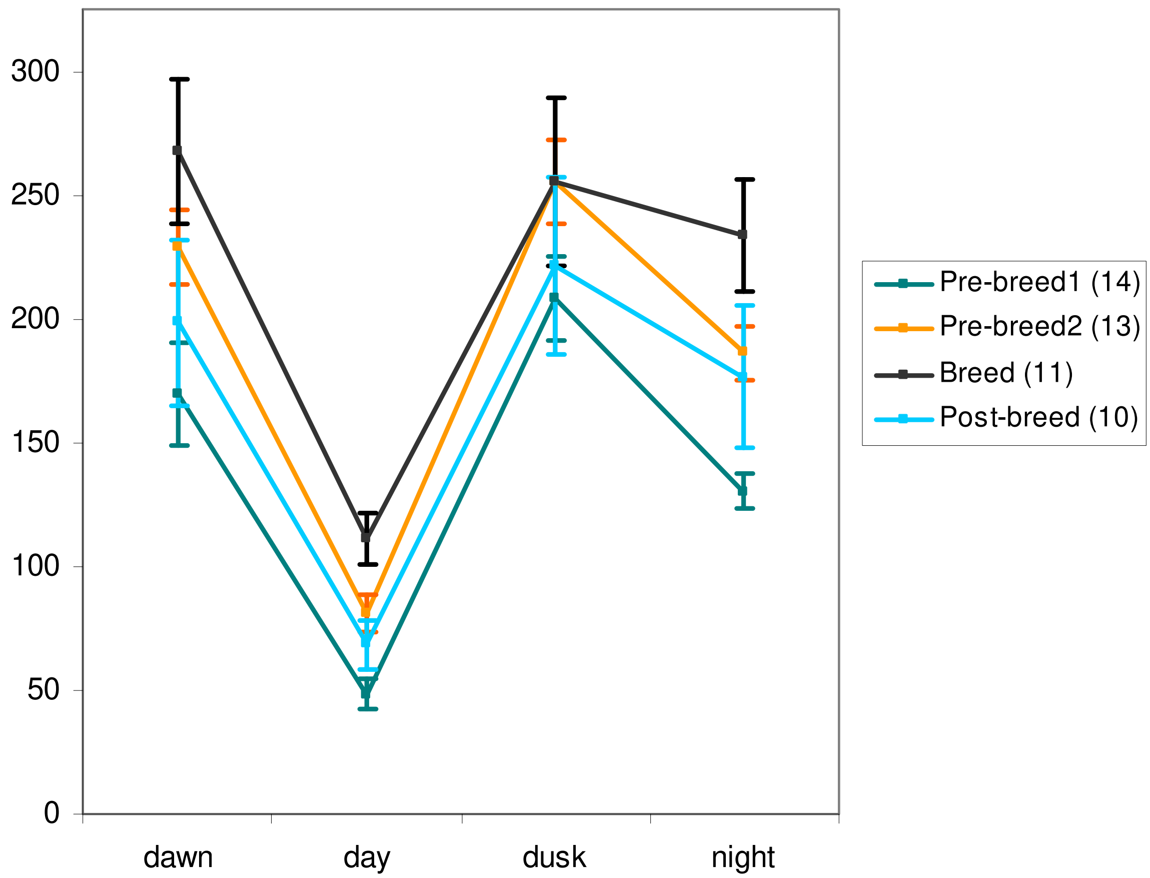

Figure 8. Average movement step (m), straight line distance between successive GPS locations, of adult males during period of the day by season (*n*) at Chesapeake Farms, Kent County, Maryland, 2003-2005. Seasons were delineated by fawn capture and parturition data from Chesapeake Farms. Error bars represent ± SE.

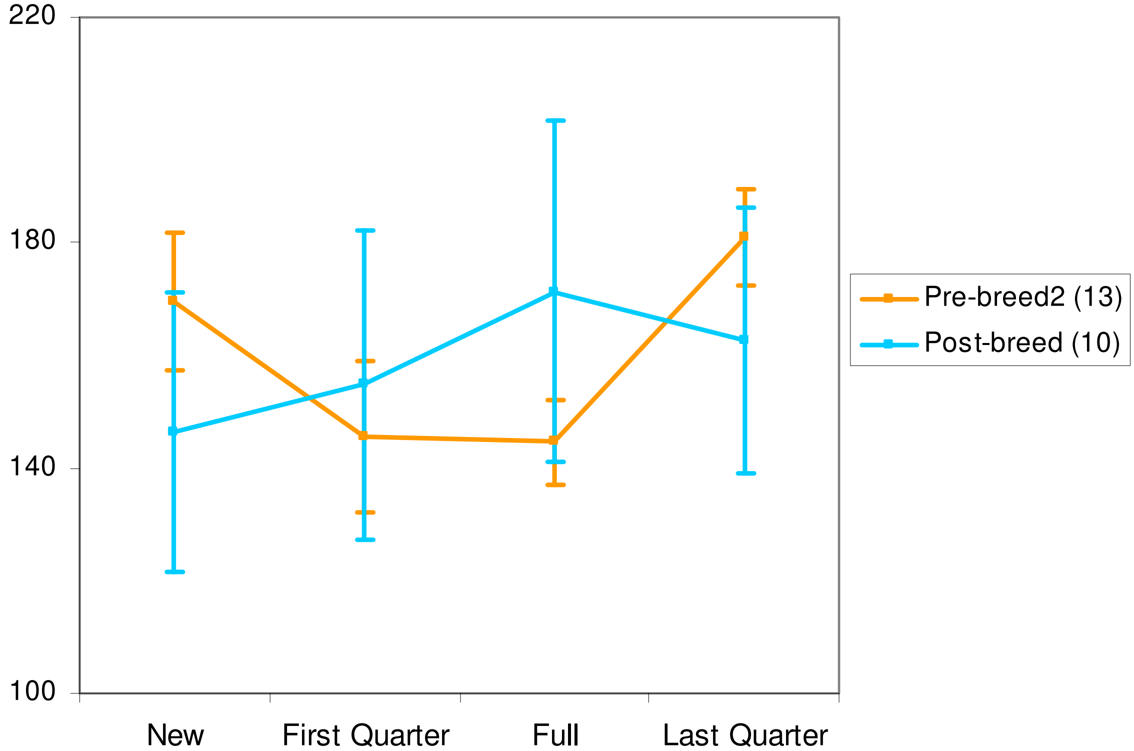

Figure 9. Average movement step (m), straight line distance between successive GPS locations, of adult males during phases of the moon by season (*n*) at Chesapeake Farms, Kent County, Maryland, 2003-2005. Seasons were delineated by fawn capture and parturition data from Chesapeake Farms. Error bars represent ± SE.

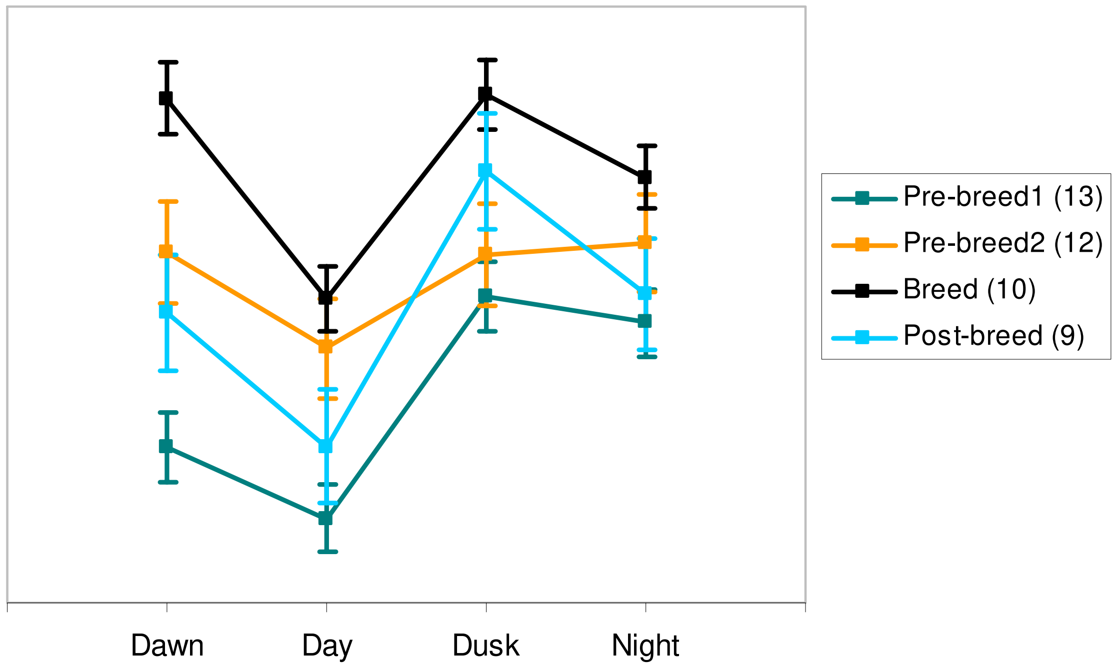

Figure 10. Relative activity, calculated by tip-switch vertical activity sensor located inside the GPS collar, of adult males during period of the day by season (*n*) at Chesapeake Farms, Kent County, Maryland, 2003-2005. Seasons were delineated by fawn capture and parturition data from Chesapeake Farms. Error bars represent ± SE.

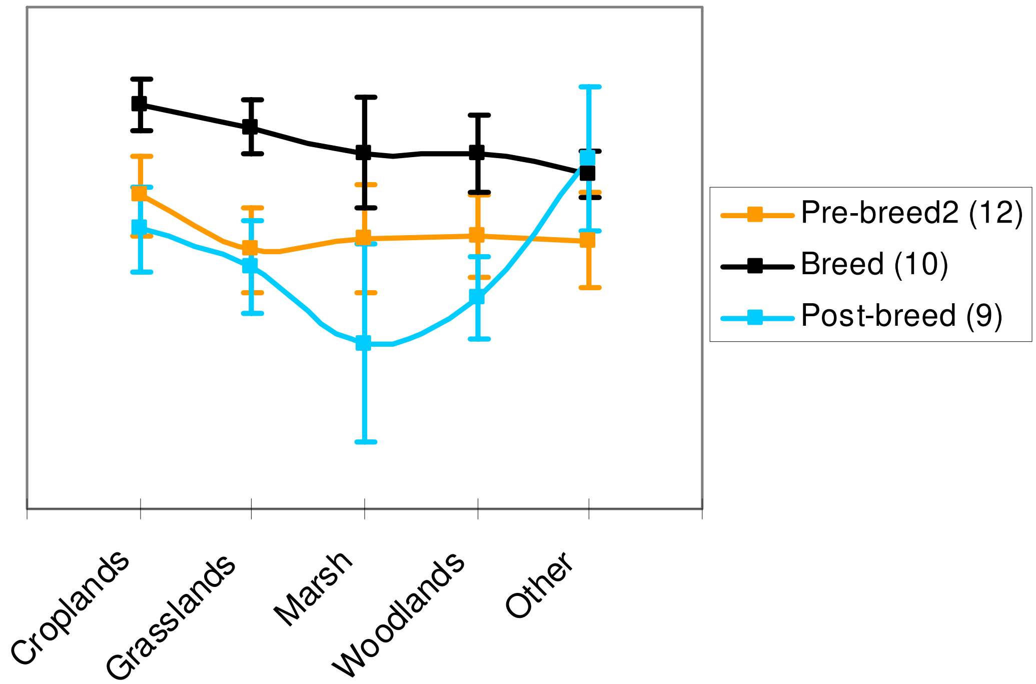

Figure 11. Relative activity, calculated by tip-switch vertical activity sensor located inside the GPS collar, of adult males within habitat types by season (*n*) at Chesapeake Farms, Kent County, Maryland, 2003-2005. Seasons were delineated by fawn capture and parturition data from Chesapeake Farms. Error bars represent ± SE.

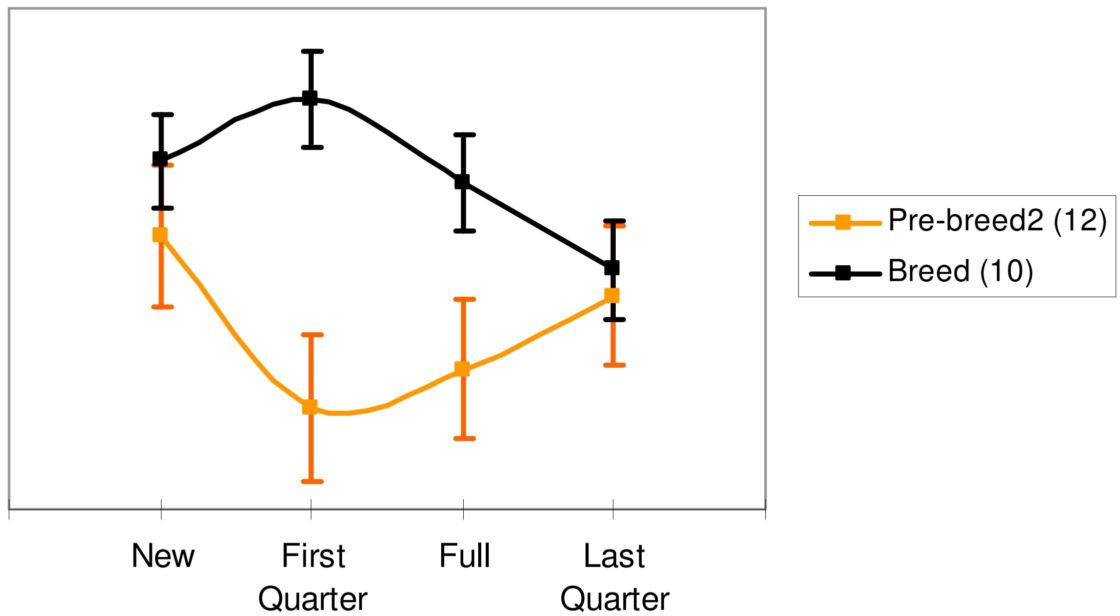

Figure 12. Relative activity, calculated by tip-switch vertical activity sensor located inside the GPS collar, of adult males during phases of the moon by season (*n*) at Chesapeake Farms, Kent County, Maryland, 2003-2005. Seasons were delineated by fawn capture and parturition data from Chesapeake Farms. Error bars represent ± SE.

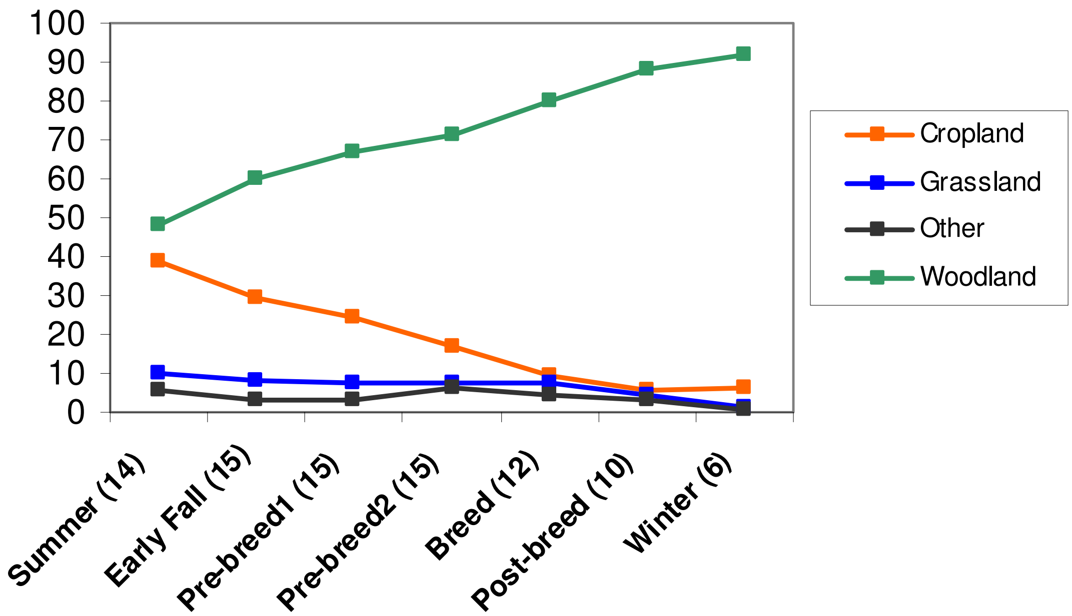

Figure 13. Percent of diurnal locations by habitat of adult male white-tailed deer during each season (*n*) at Chesapeake Farms, Kent County, Maryland, 2003-2005.

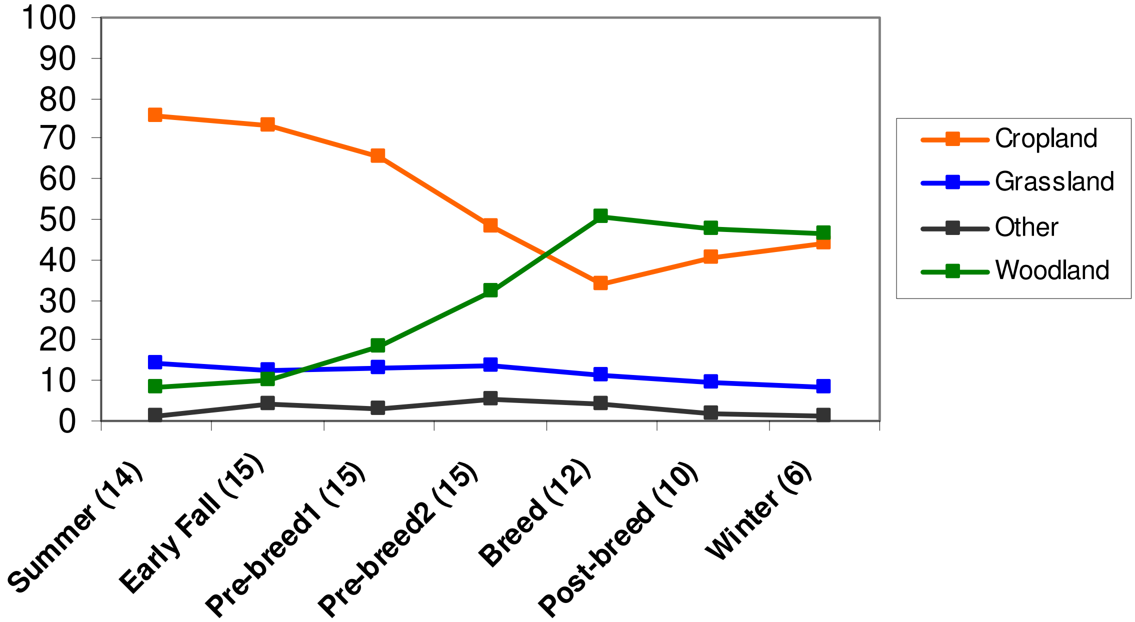

Figure 14. Percent of nocturnal locations by habitat of adult male white-tailed deer during each season (*n*) at Chesapeake Farms, Kent County, Maryland, 2003-2005.

Figure 15. Seasonal home ranges of male 36 orange at Chesapeake Farms, Kent County, Maryland, 2005. Increase in home range size peaks during breeding season with a subsequent decrease during post-breed.

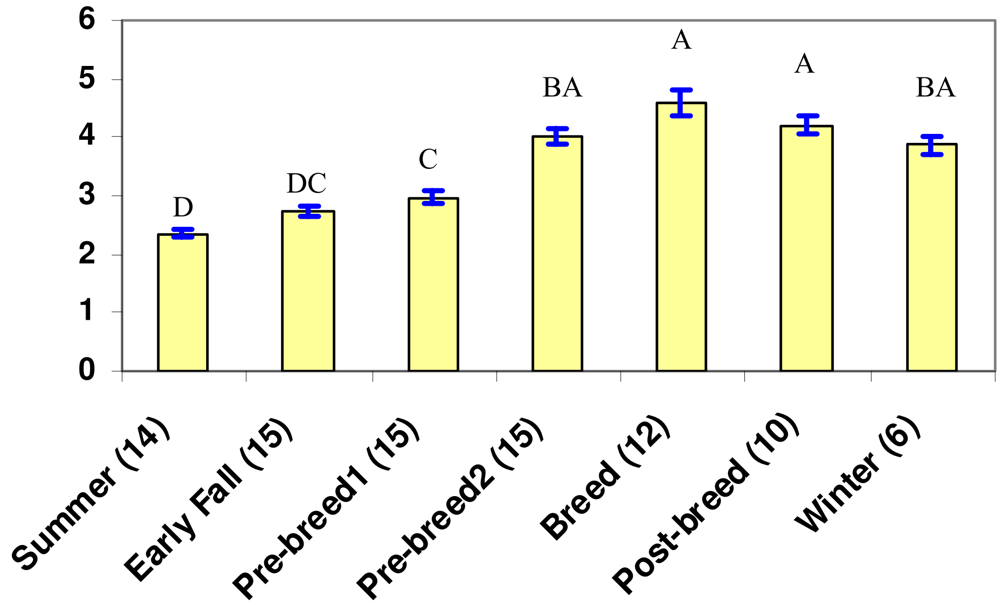

Figure 16. Average diel movement step (km), straight line distance between successive GPS locations, of adult males by season (*n*) at Chesapeake Farms, Kent County, Maryland, 2003-2005. Seasons with the same letter were not statistically different at $P < 0.05$. Error bars represent ± SE.

Figure 17. Breed and post-breed movements of male 40 white at Chesapeake Farms, Kent County, Maryland, 2004. These movements were characterized by extensive movements in or adjacent to the home range, accompanied by a period of relatively little movement in an area not previously occupied, suggesting formation of a tending bond. Yellow dots mark the beginning of each movement path.

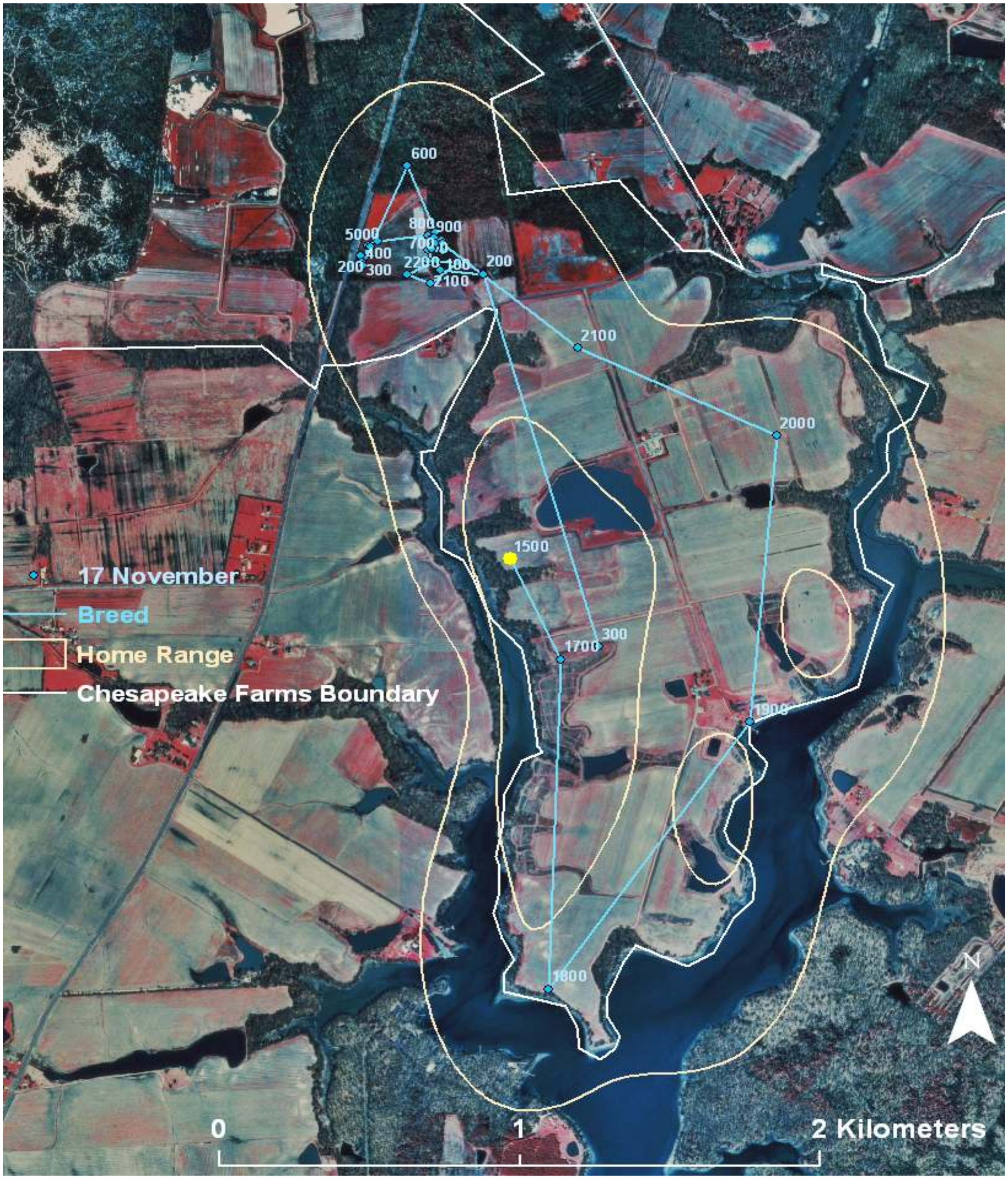

Figure 18. Breed movement of male 22 blue at Chesapeake Farms, Kent County, Maryland, 2005. This characterizes the extensive movement covering large portions of the home range and returning to the point of origin within 8 – 36 hours. Yellow dots mark the beginning of each movement path.

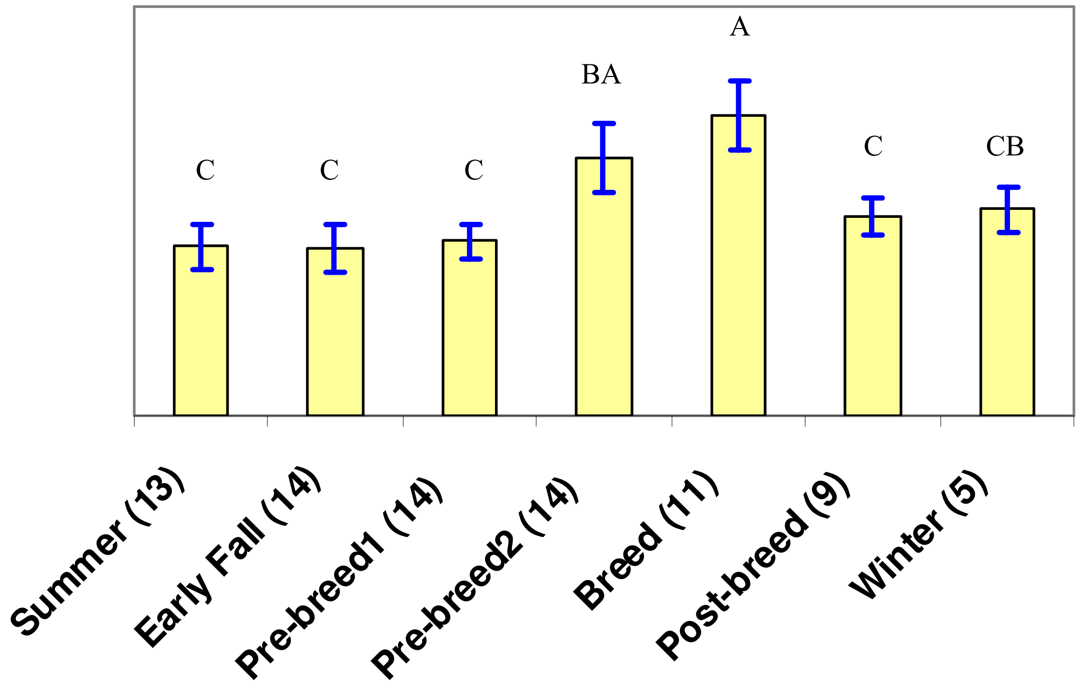

Figure 19. Average diel relative activity, calculated by tip-switch vertical activity sensor located inside the GPS collar, of adult male white-tailed deer by season (*n*) at Chesapeake Farms, Kent County, Maryland, 2003-2005. Seasons with the same letter were not statistically different at $P < 0.05$. Error bars represent ± SE.

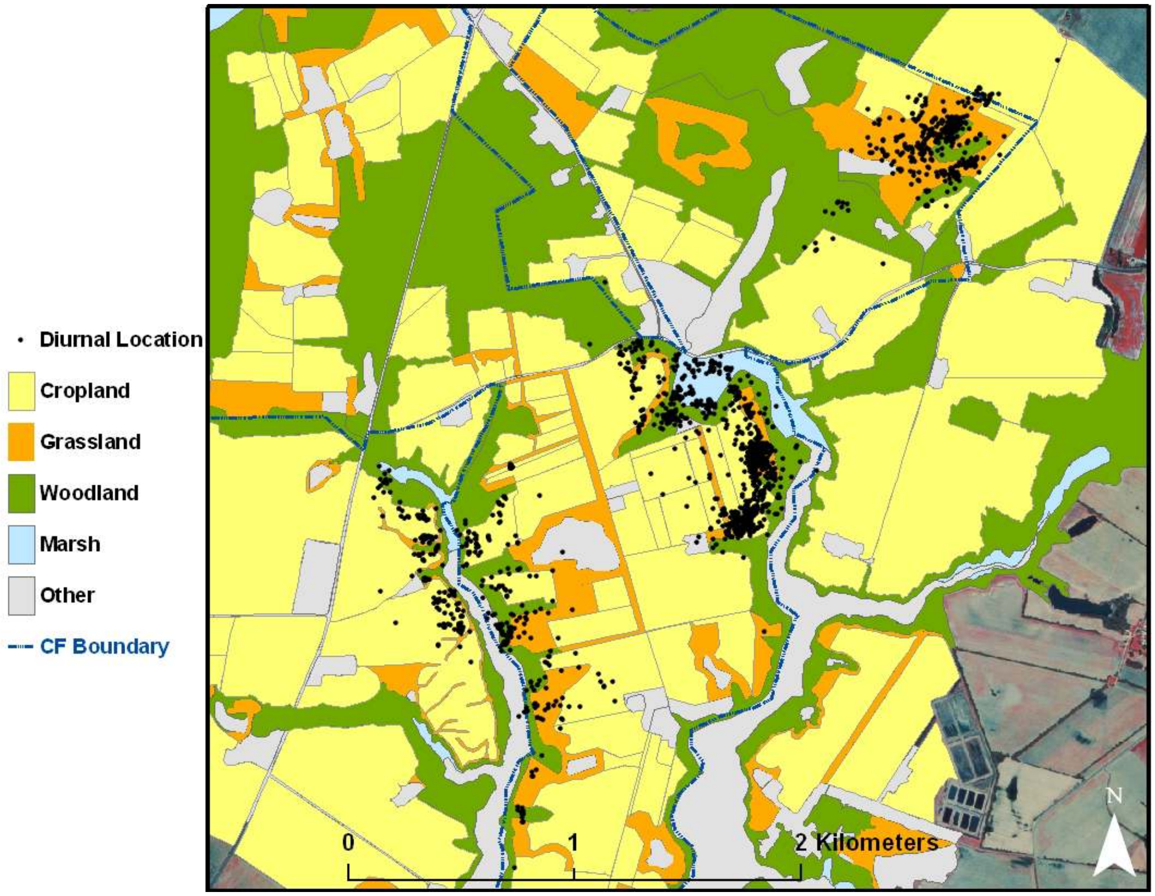

Figure 20. Summer season diurnal locations of adult males east of Maryland state highway 20. In this predominantly agricultural landscape males did not use diurnal and nocturnal habitats similarly, however males showed no selection for diurnal habitats during this period and utilized cropland (i.e., corn) and grassland areas consistently during the day.

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Appendix 1. Data screening of GPS location error test data at Chesapeake Farms, Kent County, Maryland 2005. Table is divided by land cover type on the left and by fix status on the right. Fix status data is pooled across land covers. Percent data loss represents the percentage of GPS locations screened using each screening criteria.

	Raw Data			
Land Cover	n	3D	2D	Error (SE)
Field	85	85	0	4.3 (0.5)
Wood-Leaf Off	121	114	7	36.7 (7.4)
Wood-Leaf On	91	81	10	61.8 (20.6)
Total	297	280	17	

	Raw Data			
Fix Type	n	mean (SE)	median	max
3D	280	24.6 (20)	12.4	190.8
2D	17	208.7 (114.6)	31	1890.7
All	297	35.1 (6)	13.8	1890.7

	PDOP[a] Screened			
Land Cover	n	3D	2D	Error (SE)
Field	85	85	0	4.3 (0.5)
Wood-Leaf Off	113	107	6	29.5 (5.4)
Wood-Leaf On	85	76	9	60.8 (22)
Total	283	268	15	

	PDOP Screened			
Fix Type	n	mean (SE)	median	max
3D	268	22.6 (1.7)	14.5	181.0
2D	15	188.6 (126.5)	30.4	1890.7
All	283	31.4 (7)	15.3	1890.7

	Altitude[b] Screened			
Land Cover	n	3D	2D	Error (SE)
Field	85	85	0	4.3 (0.5)
Wood-Leaf Off	103	98	5	19.4 (1.9)
Wood-Leaf On	81	73	8	37.7 (2.9)
Total	269	256	13	

	Altitude Screened			
Fix Type	n	mean (SE)	median	max
3D	256	19.5(1.4)	13.4	152
2D	13	29.7 (4.1)	29.3	56
All	269	20 (1.4)	14.5	152

	Percent Data Loss
Field	0.0%
Wood-Leaf Off	14.9%
Wood-Leaf On	11.0%
Total	9.4%

	Percent Data Loss
3D	8.6%
2D	23.5%
All	9.4%

[a] PDOP = position dilution of precision value. 3-dimensional (3D) GPS location with PDOP > 10 and 2-dimensional (2D) GPS location with PDOP > 5.
[b] GPS locations with altitude values < -100m or > 100m were screened

Appendix 2. Breakdown of seasons for adult male movement and activity analyses, number of adult males collared during each season, and date range of each season derived from parturition and fawn capture data at Chesapeake Farms, Kent County, Maryland.

Season	*n*	Dates
Summer	14	1 Aug. - 2 Sept.
Early Fall	15	3 Sept. - 23 Sept.
Pre-breed1	15	24 Sept. - 14 Oct.
Pre-breed2	15	15 Oct. - 4 Nov.
Breed	12	5 Nov. - 25 Nov.
Post-breed	10	26 Nov. - 16 Dec.
Winter	6	17 Dec. - 3 March

Appendix 3. Categorical variables included in multiple regression analyses (PROC MIXED, SAS 2001) and level chosen as the basis for comparison.

Effect	Level
Period of Day	Dusk
Moon Phase	New
Habitat Type	Woodland
Wind Direction	Northwest

Appendix 4. Fix rate, percent 3D and 2D fixes, and number of locations by GPS collar model and individual animal for 15 adult male white-tailed deer at Chesapeake Farm Kent County, Maryland, 2003-2005.

Collar Model	Deer_ID[a]	Fix Rate	3D	2D	locations
2200L	30 Orange	90	39.8	60.2	2142
	32 Orange	89.4	36.1	63.9	4493
	33 Orange	U[b]	40.7	59.3	4404
	Mean	89.7	41.7	58.3	3680
	SE	0.3	3.9	3.9	769.3
3300L	40 White	95.4	64.5	35.6	5406
	46 Blue	99.2	82.8	16.7	1921
	35 Orange	97	75.4	24.6	1448
	46 White	98.2	77.8	22.2	5254
	39 Orange	99.4	82.7	17.3	9109
	36 Orange	99.6	86.1	13.9	4570
	50 Blue	99.9	89.3	10.7	2556
	40 Orange	99	71.4	28.6	2685
	22 Blue	99.7	90.2	9.8	4553
	40 Blue	99.6	88.2	11.8	2920
	42 Orange	99.3	82.3	17.7	4311
	49 Blue	99.6	84.3	15.7	4973
	Mean	98.8	81.3	18.7	4142
	SE	0.4	2.2	2.2	596.1

[a] Deer ID denoted by ear tag number and color
[b] U represents cases when raw data was unavailable

Appendix 5. Number of observations screened across years and individuals, and percent data loss post-screening of 15 GPS collars deployed on adult male white-tailed deer at Chesapeake Farms, Kent County, Maryland, 2003-2005.

Data Status	n	Percent Data Loss
Raw Data	60,008	
PDOP Screen	4,946	8.2%
Altitude Screen	1,215	2.0%
Post Screen	53,847	10.2%

Appendix 6. Results of movement data model selection (StepAIC, R 2006) by season (*n*) for adult male white-tailed deer fitted with GPS collars at Chesapeake Farms, Kent County, Maryland, 2003-2005.

Season[a]	Dependent	Independent Variables		
Pre-breed (14)				
	log of Movement[b] =	Barometric Pressure	Diff. in Temp[c]	POD[d]
		Precipitation	Temperature	Temperature*POD
		Wind Direction		
Pre-breed2 (13)				
	log of Movement =	Diff. in Precipitation[e]	Moon Phase[f]	POD
		Temperature	Temperature*POD	Wind Direction
Breed (11)				
	log of Movement =	Diff. in BP[g]	Moon Phase	POD
		Temperature	Wind Direction	Wind Speed
Post-breed (10)				
	log of Movement =	Moon Phase	POD	Precipitation
		Temperature		

[a] Seasons were delineated by fawn capture and parturition data from Chesapeake Farms
[b] Movement step (i.e., straight line distance between successive locations) data with log+1 transformation
[c] Hourly difference in temperature
[d] Dawn, daytime, dusk, and nighttime
[e] Hourly difference in precipitation
[f] New, first quarter, full, and last quarter
[g] Hourly difference in barometric pressure

Appendix 7. Results of activity data model selection (StepAIC, R 2006) by season (*n*) for adult male white-tailed deer fitted with GPS collars at Chesapeake Farms, Kent County, Maryland, 2003-2005.

Season[a]	Dependent	Independent Variables		
Pre-breed1 (13)				
	log of activity[b] =	Barometric Pressure	Diff. in Temp[c]	Habitat Type[d]
		Moon Phase[e]	POD[f]	Temperature
		Temperature*POD	Wind Direction	
Pre-breed2 (12)				
	log of activity =	Diff. in Precipitation[g]	Diff. in Temp	Habitat Type
		Moon Phase	POD	Precipitation
		Rainclass[h]	Temperature*POD	Wind Direction
		Wind Speed		
Breed (10)				
	log of activity =	Diff. in Precipitation	Habitat Type	Moon Phase
		POD	Temperature*POD	Wind Direction
		Wind Speed		
Post-breed (9)				
	log of activity =	Diff. in Temp	Habitat Type	POD
		Rainclass	Temperature	Temperature*POD
		Wind Direction	Wind Speed	

[a] Seasons were delineated by fawn capture and parturition data from Chesapeake Farms
[b] Y-activity sensor data with log+1 transformation
[c] Hourly difference in temperature
[d] Cropland, grassland, marsh, woodland, other
[e] New, first quarter, full, and last quarter
[f] Dawn, daytime, dusk, and nighttime
[g] Hourly difference in precipitation
[h] Presence or absence of precipitation

Appendix 8. Multiple regression analysis of adult male movement step during four breeding seasons (*n*) predetermined by fawning data at Chesapeake Farms, Kent County, Maryland, 2003-2005. Type 3 tests of fixed effects (PROC MIXED, SAS, 2001) reported below with significance at $P < 0.05$.

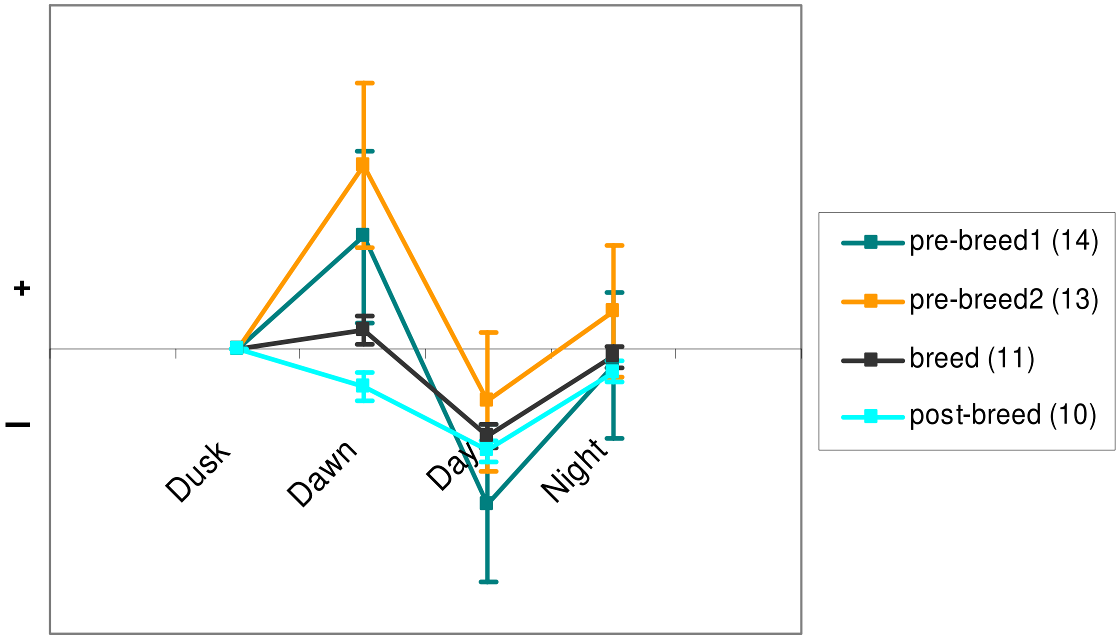
	Pre-breed1 (14)			
Effect	DF	Den DF	F-value	P-value
Temperature	1	1934	4.92	0.0267
Period of Day[a]	3	3354	4.78	0.0025
	Pre-breed2 (13)			
Effect	DF	Den DF	F-value	P-value
Temperature	1	1829	9.76	0.0018
Period of Day[a]	3	2851	4.01	0.0073
Moon Phase[b]	3	1282	3.28	0.0204
	Breed (11)			
Effect	DF	Den DF	F-value	P-value
Period of Day[a]	3	2525	39.76	<.0001
Wind Speed	1	1620	6.62	0.0102
	Post-breed (10)			
Effect	DF	Den DF	F-value	P-value
Temperature	1	939	4.5	0.0342
Period of Day[a]	3	1840	38.27	<.0001
Moon Phase[b]	3	836	6.12	0.0004

[a] Period of Day = dawn, day, dusk, and night
[b] Moon Phase = new, first quarter, full, last quarter

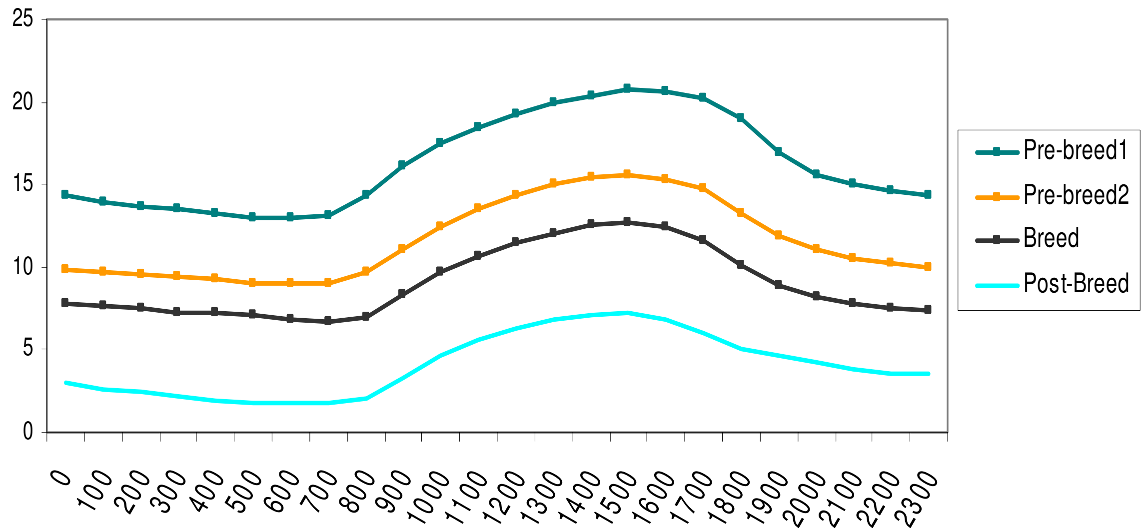
Appendix 9. Multiple regression results of adult male activity, 2003-2005, during four breeding seasons predetermined by fawning data at Chesapeake Farms, Kent County, Maryland. Type 3 tests of fixed effects (PROC MIXED, SAS, 2001) reported below and significant at $P < 0.05$.

Effect	DF	Den DF	F-value	P-value
		Pre-breed1 (13)		
Period of Day[a]	3	3304	7.8	<.0001
Barometric Pressure	1	1837	7.99	0.0048
Difference in Temperature[b]	1	4431	6.73	0.0095
Temperature*Period of Day[a]	3	3279	4.39	0.0043
		Pre-breed2 (12)		
Effect	DF	Den DF	F-value	P-value
Period of Day[a]	3	2956	4.39	0.0043
Wind Direction	7	2998	2.66	0.0097
Moon Phase	3	1458	14.95	<.0001
Habitat Type[c]	4	4498	5.81	0.0001
Difference in Temperature[b]	1	3814	43.3	<.0001
Precipitation[d]	1	3805	5.41	0.0201
		Breed (10)		
Effect	DF	Den DF	F-value	P-value
Moon Phase	3	1237	10.11	<.0001
Habitat Type[c]	4	3737	8.42	<.0001
		Post-breed (9)		
Effect	DF	Den DF	F-value	P-value
Habitat Type	4	3072	6.16	<.0001
Difference in Temperature[b]	1	2713	5.53	0.0187

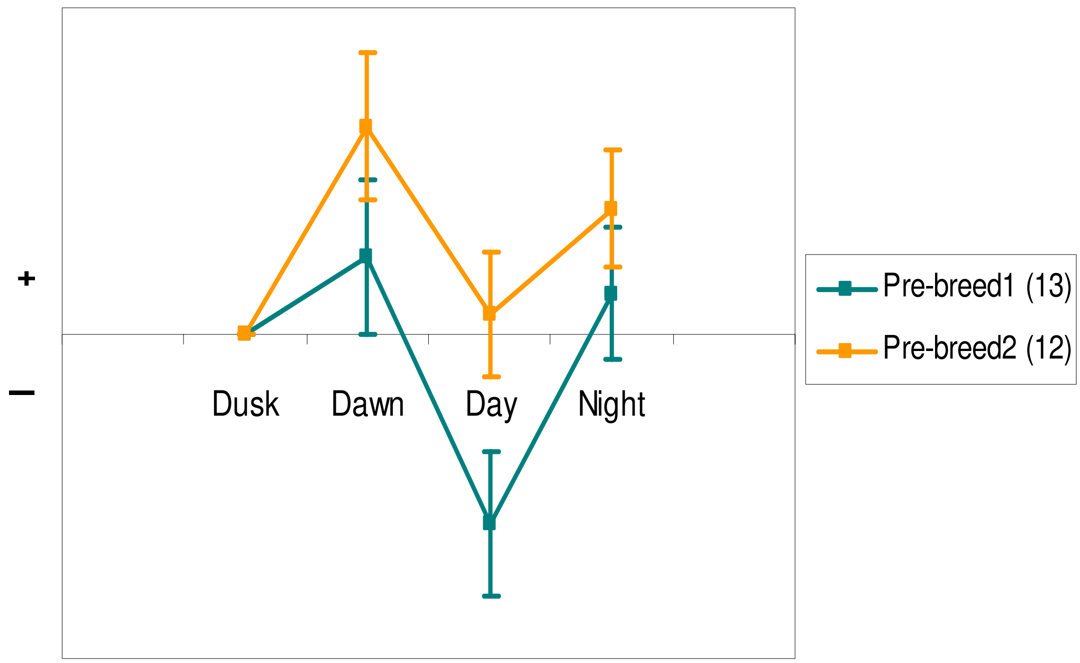
[a] Period of Day = dawn, day, dusk, and night
[b] Difference in temperature between the n^{th} observation and n-1
[c] Habitat types = cropland, grassland, marsh, woodland, other
[d] Presence or absence of precipitation



Appendix 10. Movement of adult males during period of the day by season (*n*) at Chesapeake Farms, Kent County, Maryland, 2003-2005. The dusk period was the basis for comparison in regression analysis (PROC MIXED, SAS 2001) because period of day is a categorical variable. Error bars (i.e., ± SE) not crossing the x-axis are significantly different from dusk period activity.



Appendix 11. Average temperature (C˚) by hour of the day for each of four breeding seasons showing dawn as the coldest and daytime as the warmest parts of the day. Temperature data recorded at Chesapeake Farms weather station, Kent County, Maryland, 2003-2005.



Appendix 12. Activity of adult males by period of day during breeding seasons (*n)* at Chesapeake Farms, Kent County, Maryland, 2003-2005. The dusk period was the basis for comparison in regression analysis (PROC MIXED, SAS 2001) because period of day is a categorical variable. Error bars (i.e., ± SE) not crossing the x-axis are significantly different from dusk period activity.

Appendix 13. Summer season habitat selection ranking of 14 adult male white-tailed deer at the population level, comparing proportional habitat use within kernel home ranges with proportions of total available habitats, and home range level, comparing proportions of GPS positions of each individual within each habitat with proportions of each habitat within the animal's kernel home range. A triple sign indicates significant deviation from random at $P < 0.05$.

Habitat Type	Population Level				
	Woodland	Cropland	Grassland	Other	Rank[a]
Woodland		-	+	+	2
Cropland	+		+	+++	3
Grassland	-	-		+	1
Other[b]	-	- - -	-		0

Habitat Type	Home Range Level				
	Woodland	Cropland	Grassland	Other	Rank[a]
Woodland		-	+	+++	2
Cropland	+		+	+++	3
Grassland	-	-		+	1
Other[b]	- - -	- - -	-		0

[a] Higher rank indicates greater selection
[b] Other = buildings and grounds, marsh, pond, roadway, and tidal water

Appendix 14. Pre-breed1 season habitat selection ranking of 15 adult male white-tailed deer at the population level, comparing proportional habitat use within kernel home ranges with proportions of total available habitats, and home range level, comparing proportions of GPS positions of each individual within each habitat with proportions of each habitat within the animal's kernel home range. A triple sign indicates significant deviation from random at *P* < 0.05.

Habitat	Home Range Level				
Type	Woodland	Cropland	Grassland	Other	Rank[a]
Woodland		-	+	+++	2
Cropland	+		+	+++	3
Grassland	-	-		+	1
Other[b]	- - -	- - -	-		0

[a] Higher rank indicates greater selection
[b] Other = buildings and grounds, marsh, pond, roadway, and tidal water

Appendix 15. Breed season habitat selection ranking of 12 adult male white-tailed deer at the population level, comparing proportional habitat use within kernel home ranges with proportions of total available habitats, and home range level, comparing proportions of GPS positions of each individual within each habitat with proportions of each habitat within the animal's kernel home range. A triple sign indicates significant deviation from random at $P < 0.05$.

Habitat Type	Home Range Level				
	Woodland	Cropland	Grassland	Other	Rank[a]
Woodland		+++	+	+++	3
Cropland	---		-	+++	1
Grassland	-	+		+++	2
Other[b]	- - -	- - -	- - -		0

[a] Higher rank indicates greater selection
[b] Other = buildings and grounds, marsh, pond, roadway, and tidal water

Appendix 16. Post-breed season habitat selection ranking of 10 adult male white-tailed deer at the population level, comparing proportional habitat use within kernel home ranges with proportions of total available habitats, and home range level, comparing proportions of GPS positions of each individual within each habitat with proportions of each habitat within the animal's kernel home range. A triple sign indicates significant deviation from random at $P < 0.05$.

Habitat Type	Home Range Level: Woodland	Cropland	Grassland	Other	Rank[a]
Woodland		+	+	+++	3
Cropland	-		+	+++	2
Grassland	-	-		+++	1
Other[b]	- - -	- - -	- - -		0

[a] Higher rank indicates greater selection
[b] Other = buildings and grounds, marsh, pond, roadway, and tidal water

Appendix 17. Winter season habitat selection ranking of 6 adult male white-tailed deer at the population level, comparing proportional habitat use within kernel home ranges with proportions of total available habitats, and home range level, comparing proportions of GPS positions of each individual within each habitat with proportions of each habitat within the animal's kernel home range. A triple sign indicates significant deviation from random at $P < 0.05$.

Habitat Type	Population Level: Woodland	Cropland	Grassland	Other	Rank[a]
Woodland		+	+	+	3
Cropland	-		+	+	2
Grassland	-	-		-	0
Other[b]	-	-	+		1

Habitat Type	Home Range Level: Woodland	Cropland	Grassland	Other	Rank[a]
Woodland		+	+	+++	3
Cropland	-		-	+++	1
Grassland	-	+		+++	2
Other[b]	- - -	- - -	- - -		0

[a] Higher rank indicates greater selection
[b] Other = buildings and grounds, marsh, pond, roadway, and tidal water

Appendix 18. Seasonal diurnal and nocturnal location percentage of adult male white-tailed deer (*n*) at Chesapeake Farms, Kent County, Maryland, from 2003-2005. MANOVA tested the hypothesis of similar diurnal and nocturnal use of habitats at the home range level, which was completed by paired t-tests to detect significant diurnal (+) or nocturnal (-) selection.

	Summer (14)			
Habitat	Diurnal	Nocturnal	*t*	
Cropland	35.3	76.4	-4.3	**
Grassland	8.7	11	-0.73	
Woodland	51.4	8.7	+4.55	**
Other[a]	4.6	3.9	+0.22	

	Early Fall (15)			
Habitat	Diurnal	Nocturnal	*t*	
Cropland	28.5	72.8	-5.58	***
Grassland	7.7	12.2	-2.12	
Woodland	61.3	10.7	+6.01	***
Other[a]	2.5	4.3	-1.22	

	Pre-Breed1 (15)			
Habitat	Diurnal	Nocturnal	*t*	
Cropland	23.2	65.2	-6.87	***
Grassland	7.2	12.9	-2.31	*
Woodland	68	18.7	+8.5	***
Other[a]	1.6	3.2	-1.34	

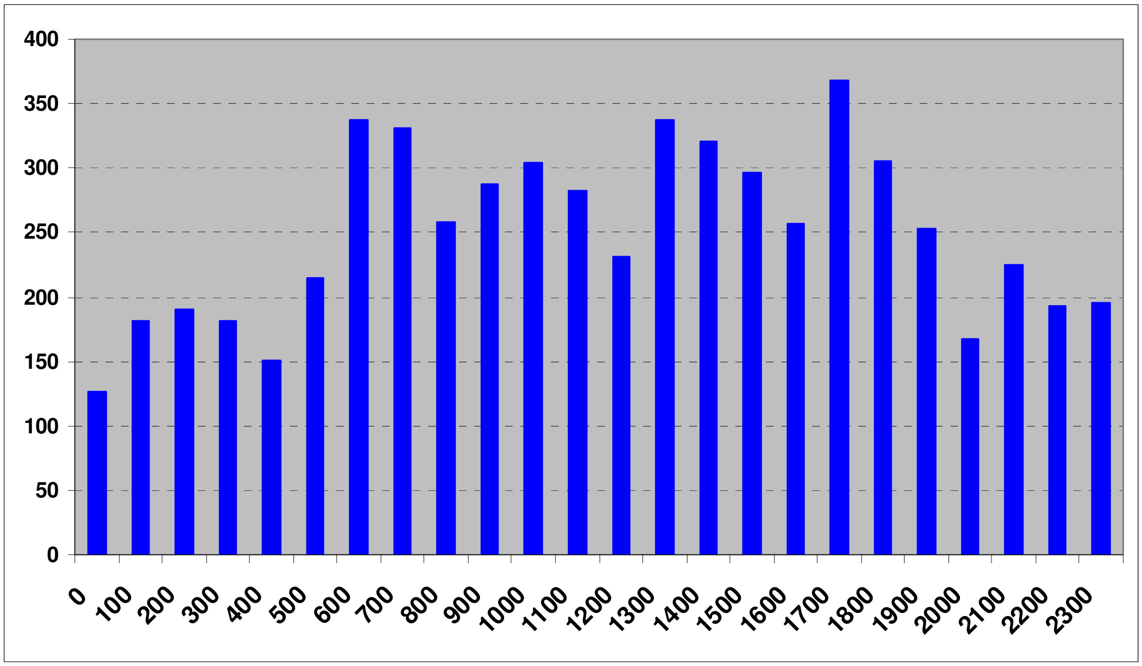
	Pre-Breed2 (15)			
Habitat	Diurnal	Nocturnal	*t*	
Cropland	16.8	48.9	-6.59	***
Grassland	7	13.3	-5.22	**
Woodland	72.6	32.2	+7.97	***
Other[a]	3.6	5.6	-1.1	

	Breed (12)			
Habitat	Diurnal	Nocturnal	*t*	
Cropland	9	37.1	-6.47	***
Grassland	7.1	11.1	-1.94	
Woodland	79.9	48	+7.93	***
Other[a]	4	3.8	+0.13	

	Post-Breed (9)			
Habitat	Diurnal	Nocturnal	*t*	
Cropland	5.5	41.1	-4.55	*
Grassland	6.8	10.6	-0.91	
Woodland	85.5	46.4	+4.62	*
Other[a]	2.2	1.9	+0.2	

	Winter (6)			
Habitat	Diurnal	Nocturnal	*t*	
Cropland	5.5	42	-4.56	*
Grassland	1.8	11.9	-1.82	
Woodland	92.2	44.7	+5.75	*
Other[a]	0.5	1.4	-1.32	

[a] Other = buildings and grounds, marsh, pond, roadway, and tidal water
* $P < 0.05$
** $P < 0.001$
*** $P < 0.0001$



Appendix 19. Missing data (i.e., number of unsuccessful attempts and screened data) of 15 GPS radio collared adult male white-tailed deer at Chesapeake Farms, Kent County, Maryland, 2003-2005. Data are separated by time of day to determine whether missing data occurred at random or if their distribution was skewed towards certain times.