USING PASSIVE CAMERAS TO MONITOR ACTIVITY PATTERNS OF WHITE-TAILED DEER

by

MICHAEL THURMAN BIGGERSTAFF

(Under the Direction of Karl V. Miller and Richard B. Chandler)

ABSTRACT

Although white-tailed deer (*Odocoileus virginianus*) behavior has been researched extensively, previous studies found conflicting results regarding factors influencing activity patterns. I analyzed trail camera data to assess the impacts of seasonality, diel period, and weather on deer activity patterns in southwestern Georgia. At the annual scale, diel period was the best predictor of adult female activity, with a distinct activity peak during dusk hours. The best predictor of adult male and yearling activity at the annual scale was biological season, with 61.4% of adult male detections occurring during the rut. An extreme drought occurred from October – December 2016, which provided an opportunity to assess the influence of drought on activity. Female activity increased during the drought, but male activity was not influenced, likely because the drought and breeding season occurring concurrently. Differences in nutritional requirements and breeding behaviors likely explain variations between male and female activity patterns.

INDEX WORDS: activity patterns, biological season, diel period, drought, *Odocoileus virginianus*, trail cameras, white-tailed deer

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MICHAEL THURMAN BIGGERSTAFF

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MICHAEL THURMAN BIGGERSTAFF

Major Professor:	Karl V. Miller Richard B. Chandler
Committee:	L. Mike Conner Michael J. Cherry Gino J. D’Angelo

Electronic Version Approved:

Suzanne Barbour
Dean of the Graduate School
The University of Georgia
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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

White-tailed deer (*Odocoileus virginianus*) are the most economically important game species in the United States. Activity rates have been studied extensively, as many management decisions are formed around the knowledge of when deer are active and what influences their activity patterns. However, deer behavior is highly variable, and a wide variety of techniques have been used to measure white-tailed deer activity patterns, resulting in conflicting results.

Factors influencing white-tailed deer activity rates

Activity rates of white-tailed deer vary among demographic groups. Beier and McCullough (1990) found that females tend to be more active than males during gestation and fawning periods, likely due to the increased foraging requirements needed to meet the high metabolic demands of gestation and lactation. Antler growth begins coincident with the gestation period and antlers grow until calcification occurs prior to the breeding season. Males also maximize body growth leading up to the rut because antler and body size are positively correlated with reproductive opportunities (DeYoung et al. 2006). The fawn rearing period is nutritionally demanding for females due to costs of lactation (Moen 1978, Robbins 1983, Oftedal 1985, Pekins et al. 1998, Parker et al. 2009). During the pre-rut, activity rates of males increase as a result of seasonally increasing testosterone levels and associated socio-sexual behaviors (Tomberlin 2007). The rut is the period of highest activity for adult males (Tomberlin 2007), and they can lose a substantial portion of their body mass due to hypophagia during this period

(Warren et al. 1981). Females also tend to be more active during the rut than the pre-rut (Ivey and Causey 1981), although the increase in activity does not seem to be as substantial as with adult males. Female activity often increases just before conception (Ozoga and Verme 1975). For both sexes, the post-rut is a period of recovery from the rut, but coincides with a period of limited resources in northern portions of the white-tailed deer's range (Ozoga and Gysel 1972, Hoskinson and Mech 1976, Beier and McCullough 1990).

White-tailed deer are generally considered crepuscular (Kammermeyer and Marchinton 1977, Ockenfels and Bissonette 1982, Rouleau et al. 2002, Webb et al. 2010), with the highest activity peak occurring at sunset (Hosey 1980, Beier and McCullough 1990). Further research has shown that activity peaks occur just after sunrise and at dusk (Coulombe et al. 2006). Small activity peaks have also been reported at midday and midnight (Michael 1970). Volk et al. (2007) observed higher activity rates during crepuscular periods than during the day, but did not measure night time activity. Further, some research suggests white-tailed deer are least active just before sunrise, in late morning, and during late evening (Kammermeyer and Marchinton 1977, Hosey 1980, Ivey and Causey 1981). Rouleau et al. (2002) monitored two separate deer populations on different landscapes, and both populations were most active during crepuscular hours. Some research suggests that adult males are crepuscular during most of the year, but not during the rut or post-rut (Demarais et al. 1989). Tomberlin (2007) reported that daytime activity of adult males increased during the rut, but daytime was the period of lowest activity for the remainder of the year. Other research has shown that diel activity peaks can vary among years in response to environmental changes, such as floods (Naugle et al. 1997). September and October are reportedly the only months when diel activity patterns differ between demographic groups in Michigan, where adult male activity is higher during the night than the day, and where female activity is higher during the day than the night (Beier and McCullough 1990). Deer have also been reported to have slight shifts in diel activity patterns among seasons. In Pennsylvania, deer were seen entering a field earlier in winter than in spring or summer (Montgomery 1963). Hunting pressure by humans also decreases daytime activity and increases night time activity (Kilgo et al. 1998). Similarly, in response to nocturnal hunting by the Florida panther (*Puma concolor coryi*), deer are primarily diurnal in southern Florida (Crawford et al. 2016).

The influence of weather variables such as temperature, wind speed, and precipitation on white-tailed deer activity rates has been investigated, although results among studies often conflict. In Oklahoma, daily and hourly variation in weather events had minimal impact on white-tailed deer activity (Webb et al. 2010). Temperature has been reported as an influence on white-tailed deer activity rates, but the influence varies among study sites. In Michigan, Beier and McCullough (1990) reported that deer move most when the temperature is between 6°C and 16°C. Similarly, black-tailed deer (*O. hemionus columbianus*) have been shown to become less active when temperatures were above 15.6°C or below 0°C (Miller 1970). In South Dakota, Progulske and Duerre (1964) found a direct, negative effect of temperature on observability of deer during spotlight surveys at night. In contrast, a Texas study (Michael 1968) reported that there was no negative effect of temperatures over 37.8°C on activity, but there was an increase in activity when temperatures went below 0°C. Other studies have shown a negative correlation between activity patterns and temperature across all seasons (Cartwright 1975). A Maryland study found a negative correlation between temperature and male deer activity during the pre-rut and a positive correlation with male activity during the post-rut (Tomberlin 2007), which may be related to the difference in ambient temperature between those periods. Interactions between temperature and diel period may also influence activity. For example, in Maryland, adult male activity decreased with higher temperatures at sunrise (Tomberlin 2007). In instances like this, the combination of temperature with other environmental characteristics associated with a certain time of day drives activity more than either temperature or diel period alone. Some of these conflicting results may be due to differential responses to temperature resulting from adaptations to local climatic patterns.

Wind speed seems to have less of an impact on deer activity than other weather variables (Newhouse 1973), but it does have a negative effect on activity during winter in northern parts of the range (Ozoga and Gysel 1972, Beier and McCullough 1990). Deer also tend to seek refugia on windy days (Zagata and Haugen 1974). During extreme precipitation events with high winds, deer are inactive (Severinghaus and Cheatum 1956, Michael 1970).

Reported effects of precipitation on deer activity patterns are typically the result of floods and droughts. In Mexico, activity rates increased in years with above average amounts of rainfall (Bello et al. 2004). Drought has been shown to affect use of cover types (Grovenburg et al. 2011) and alter nutritional value and selection of plants by deer (Lashley and Harper 2012). However, research investigating the effects of droughts on activity rates is limited.

Methodologies to investigate deer activity patterns

The advancement of technology has increased understanding of deer behavior. Early research on deer activity patterns relied on visual observations (Progulske and Duerre 1964, Sparrowe and Springer 1970, Brown 1971, Pledger 1975). However, inherent biases associated with visual observations exist, including the assumption that a random sample is observed. The main limitation of using visual observations to understand activity patterns is that researchers are counting how many deer they see in the most open areas, and do not gain a full understanding of what the deer are doing when they cannot be seen. Other potential biases include differences in skill between observers and the lack of visibility due to environmental factors, such as weather and vegetation. In addition, visual observations only provide information at certain spatial points rather than monitoring the entire landscape, when deer resource selection can change daily or seasonally (Massé and Côté 2013).

The development of Very High Frequency (VHF) technology allowed for more accurate and intense sampling of deer behavior (Coulombe et al. 2006). VHF telemetry has been used to monitor white-tailed deer activity patterns in multiple studies (Montgomery 1963, Marchinton 1968, Pledger 1975, Kammermeyer and Marchinton 1977, Hosey 1980, Ivey and Causey 1981, Gillingham and Bunnell 1985, Beier and McCullough 1988, Beier and McCullough 1990, Evans 1992, Naugle et al. 1997, Kilpatrick and Lima 1999, Hellickson 2002, Coulombe et al. 2006). One method to measure activity with VHF collars is through the calculation of distance traveled between locations (Marchinton 1968, Sparrowe and Springer 1970, Pledger 1975, Kammermeyer and Marchinton 1977, Evans 1992). However, this method does not truly measure the proportion of time that an individual is active and assumes that stationary animals are inactive (Garshelis et al. 1982). Many VHF collars use activity sensors, such as tip switches, to determine the head position, which is then used to determine activity rates. However, with the exception of running, it is difficult to accurately determine if a deer is active or simply moving its head while lying down (Hellickson 2002, Gillingham and Bunnell 1985, Beier and McCullough 1988). Researchers often collected infrequent observations and triangulations were typically not precise due to the lengthy time required to triangulate individuals using VHF telemetry.

Use of Global Positioning Systems (GPS) technology has increased recently (Cagnacci et al. 2010) and has been used to accurately locate deer as often as every minute (Ryan et al. 2004).

GPS technology has provided improved insights into white-tailed deer behavior due to highly accurate fixes and short fix intervals. GPS technology also reduces the amount of time spent in the field since researchers do not have to triangulate the animals. Depending on the fix schedule and battery life, GPS collars can be active on a deer for several years. Webb et al. (2010) reported having operational collars on deer for seven years. However, due to the high costs of GPS technology and the capture process, researchers typically deploy collars on a small sample of the population of interest. Activity patterns of those individuals are then extrapolated across the population, assuming that all individuals in a population move similarly to the study animals. This assumption may be violated if deer are not randomly sampled. For example, collars could be deployed selectively on deer that utilize open areas where they are easier to catch. While GPS collars have the capability to tell whether or not a deer is moving, it may not be possible to determine whether and individual is bedded or feeding, which reduces accuracy of activity rate measurements.

Motion-triggered trail cameras have been utilized in many research and management situations because they provide a noninvasive method to monitor animal activity (Rowcliffe et al. 2014). Passive trail camera grids have been used to monitor activity patterns of a variety of taxa (eg., Leuchtenberger et al. 2014, Palomo-Munoz et al. 2014, Edwards et al. 2017), including the effects of weather patterns and diel period on sika deer (*Cervus nippon*) activity (Ikeda et al. 2015). Baited trail camera surveys allow managers to estimate white-tailed deer density (Jacobson et al. 1997) and monitor behaviors like vigilance (Lashley et al. 2014, Cherry et al. 2015, Biggerstaff et al. 2017). However, estimating activity rates at baited sites may be biased due to variation in activity among individual white-tailed deer (Hosey 1980, Hellickson 2002) as well as by dominance of certain age or sex classes at bait sites. Passive cameras minimize such biases. Passive trail cameras might also provide a better opportunity to monitor population-level activity patterns than GPS collars because they can be used to monitor more individuals in the population rather than a small, potentially non-random, sample of individuals (Lashley et al. 2018).

Field site description

I conducted this study on the Joseph W. Jones Ecological Research Center at Ichauway, a privately owned property in Baker County, Georgia. Ichauway is comprised of 12,000 ha dominated by longleaf pine (*Pinus palustris*) savanna. Private land surrounds the property and is primarily comprised of center-pivot agriculture. Primary water sources include the Ichawaynotchaway Creek and the Flint River. Ichauway is located in the Upper Coastal Plain physiographic region, which is in the southern temperate forest. This area is characterized by mild winters and hot summers. During winter, the area has a mean temperature of 11.0° C and a mean wind speed of 4.1 kph. During spring, the mean temperature is 21.3° C and the mean wind speed is 4.1 kph. Mean summer temperature is 26.0° C and the mean wind speed is 3.7 kph. During fall, the mean temperature is 15.8° C and the mean wind speed is 3.7 kph. The yearly mean precipitation is 132.4 cm. The longleaf pine forest at Ichauway is fire-maintained with a 1-3 year fire return interval. I utilized a 1,000 ha block on the site, which was considered a Multiple Use Zone. Multiple Use Zones are managed for hunting as well as for conservation purposes, whereas other zones are managed primarily for biodiversity. Common cover types on Ichauway include longleaf pine forest, pine restoration areas with young planted pines, mixed pine/hardwood forest, bottomland hardwood forest, and food plots/agricultural fields. Food plots and agricultural fields are planted throughout the property, but the density of openings varies among management zones. The majority of my block was forested, but also had 146 openings with an average of 0.93 ha per opening. Wildlife openings are planted in agricultural crops such as corn and grain sorghum and various combinations of food plot species, including oats, wheat, and white clover. White-tailed deer density in this area is approximately 30 deer/km^2 (J.T. Johnson, Unpublished Data).

White-tailed deer are hunted on Ichauway in accordance with Ichauway property regulations. Foot-hold and cage trapping of predators are performed throughout the year. Targeted species include northern raccoon (*Procyon lotor*), Virginia opossum (*Didelphis virginiana*), striped skunk (*Mephitis mephitis*), gray fox (*Urocyon cinereoargenteus*), bobcat (*Lynx rufus*), and coyote (*Canis latrans*). Of these, coyotes are the primary predator of deer, and especially fawns, in this area (Nelson et al. 2015).

OBJECTIVES

Using passive cameras in southwestern Georgia, I investigated white-tailed deer activity patterns to achieve the following objectives:

1. Determine how extreme drought influences white-tailed deer activity patterns.
2. Quantify the effects of season and diel period on white-tailed deer at an annual scale.
3. Examine relationships between weather variables (temperature, wind speed, and precipitation) and deer activity rates within all biological seasons.

THESIS FORMAT

This thesis is presented in manuscript format. Chapter 1 presents an introduction and literature review of previous work pertinent to my study. Chapter 2 presents an investigation into how a seasonal drought in 2016 influenced white-tailed deer activity rates. Chapter 3 presents a study of the differences in activity among biological seasons and diel periods for adult female, adult male, and yearling male white-tailed deer. Further, Chapter 3 presents the effects of temperature, wind speed, and precipitation on the activity rate of adult females, yearling males, and adult males within each biological season. Chapter 4 presents conclusions and management implications of the research described in this thesis.

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CHAPTER 2

THE INFLUENCE OF A SEASONAL DROUGHT ON WHITE-TAILED DEER ACTIVITY PATTERNS

Biggerstaff, M. T., M. J. Cherry, L. M. Conner, C. H. Killmaster, J. T. Johnson, R. B. Chandler, and K. V. Miller. To be submitted to the *Southeastern Naturalist*

Abstract. We report the influence of a seasonal drought on *Odocoileus virginianus* Zimmerman (white-tailed deer) activity rates. Using an array of passive infrared cameras, we monitored deer activity on a study site in southwestern Georgia, USA. We compared activity data recorded from September 2015 – January 2016 with a similar period during 2016 – 2017. During 2015, the study site received a normal amount of rainfall. However, between October 18 and December 4, 2016, the study site only received 19.4% of the long term average rainfall amount. Adult female activity was 2.2 times greater during the drought of 2016 than during the same time frame in 2015. Male activity was not different in the drought period of 2016 than during the same time frame in 2015. The drought period overlapped with the breeding season, and the expected increase in male activity during the rut may explain the lack of an effect of the drought on male activity.

The effects of weather on *Odocoileus virginianus* Zimmerman (white-tailed deer) behavior have been studied extensively, but relatively little information is available about the influences of drought on activity patterns due to the infrequency at which extreme drought events occur. Existing data suggest drought affects resource selection (Gould and Jenkins 1993, Grovenburg et al. 2011) and alters nutritional value and selection of plants by white-tailed deer (Lashley and Harper 2012). Decreased nutritional quality and quantity due to drought can lead to increased overwinter mortality of fawns (Tosa et al. 2018). Similarly, habitat use and distribution of *Cervus elaphus* Linnaeus (elk) are influenced by precipitation levels (Marcum and Scott 1985). *Odocoileus hemionus* Rafinesque (mule deer) body condition and survival have also been linked to precipitation levels (Bender et al. 2007). Precipitation patterns can even drive mule deer population declines (Bender et al. 2007, Lawrence et al. 2004, McKinney et al. 2003).

While conducting a study of white-tailed deer activity patterns in southwestern Georgia, we were provided a unique opportunity to evaluate deer activity responses to a severe seasonal drought. During fall 2016, an extreme drought took place across much of the southeastern United States, including southwestern Georgia (Fig. 2.1). The National Drought Mitigation Center (University of Nebraska – Lincoln, Lincoln, NE, USA) determined that conditions were considered abnormally dry beginning on October 18, and these conditions continued until November 7. From November 8 until November 14, the area was classified as a moderate drought, and was subsequently upgraded to extreme drought conditions from November 15 through December 5. Conditions were downgraded to moderate drought from December 6 through December 12, and abnormally dry from December 13 until December 27 (United States Drought Monitor, University of Nebraska-Lincoln, Lincoln, NE, USA). Total precipitation in October 2016 was 0.61 cm, which is only 10.9% of the mean historical rainfall of 5.61 cm. In

November 2016, the total precipitation was 1.93 cm, which is only 25.9% of the mean historical amount of 7.44 cm. From December 4 through December 6, 2016, a single storm front brought 18.85 cm of rainfall, which initiated a progression out of the drought (Fig. 2.1). Due to this variation from typical precipitation amounts, we were able to compare activity from October 18 – December 27, 2015, a year with normal rainfall patterns, to a similar time period in 2016, a year with a seasonal drought period.

Methods. We conducted this study on the Joseph W. Jones Ecological Research Center at Ichauway in Baker County, Georgia. Ichauway is comprised of 12,000 ha dominated by *Pinus palustris* Miller (longleaf pine) forest. Ichauway is located in the Upper Coastal Plain physiographic region, which is in the southern temperate forest region. The longleaf pine forest is fire-maintained with a 1-3 year fire return interval to maintain an open, low-density forest structure.

We placed one Uway VH400HD infrared trail camera (HCO Outdoors, Norcross, Georgia, USA) on the nearest game trail to the center of 49 equally sized areas in a 1,000 ha study area (~20 ha/camera). The cameras were placed in a 7 x 7 grid in the center of the property (Fig. 2.2) and were operational from September 2015 – January 2017. We monitored cameras monthly to ensure proper function and to download photos. We removed photographs considered to be non-independent detections of deer by delineating a minimum 3-minute interval between photographs. This procedure reduced the inclusion of consecutive photographs of the same individual at each camera. We recorded the number of adult females, fawns, yearling males and adult males in each photo.

We obtained weather data from a datalogger located in Camilla, GA, which was operated by the University of Georgia Weather Network (University of Georgia, Athens, GA, USA). The station collected hourly measurements of precipitation, wind speed, and temperature throughout the study period.

We analyzed the activity patterns of adult females (≥1.5 years-of-age), adult males (≥2.5 years-of-age), and yearling males (1.5 years-of-age). We divided the number of deer photos per day by the number of operational cameras per day to analyze the effects of the drought period on activity rate. For our analysis, we defined the study period to encompass one month prior to the drought through 23 days following the drought, due to our cameras being removed 23 days after the drought period ended. Therefore, our study periods were September 18, 2015 – January 19, 2016 and September 18, 2016 – January 19, 2017. We considered September 18 – October 17 the pre-drought period, October 18 – December 27 the drought period, and December 28 – January 19 the post-drought period. We used paired *t*-tests in Program R version 3.2.1 (R Development Core Team, 2015) to identify differences in activity patterns between 2015, a year with normal rainfall, and 2016, the drought year. We also compared activity among drought categories during 2016, (abnormally dry, moderate drought, severe drought, and extreme drought) using an analysis of variance (ANOVA) and Tukey multiple comparisons of means.

Results. We recorded 3,323 observations of adult females during the study period; 36.1% (n=1,200) of adult female detections occurred during 2015 – 2016, and 63.9% (n=2,123) during 2016 – 2017. We recorded 1,291 observations of adult males, of which 40.0% (n=490) occurred during 2015 – 2016, and 60.0% (n=801) during 2016 – 2017. We also recorded 699 observations of yearling males, of which 42.8% (n=299) occurred during 2015 – 2016, and 57.2% (n=400) during 2016 – 2017.

The mean activity rate of adult females was greater during the pre-drought ($t_{28} = -2.261$, $p = 0.03$) and drought ($t_{70} = -8.715$, $p < 0.01$) periods of 2016 than during the same periods in 2015

(Table 2.1) (Fig. 2.3). During the drought period of 2016, we observed no differences in adult female activity among drought categories ($F_{3,67} = 2.084$, $P = 0.11$). The mean activity rate of adult females during the post-drought period in 2016 was not different ($t_{21} = 0.816$, $p = 0.42$) than during the same period in 2015.

The mean activity rate of adult males was greater during the pre-drought ($t_{29} = -5.900$, $p < 0.01$) and drought ($t_{70} = -6.234$, $p < 0.01$) periods of 2016 than during the same periods in 2015 (Table 2.1) (Fig. 2.3). During the drought period of 2016, we observed no differences in activity of adult bucks among drought categories ($F_{3,67} = 1.75$, $P = 0.17$). The mean activity rate of adult males during the post-drought period of 2016 was not different ($t_{22} = 1.939$, $p = 0.07$) than during the same period in 2015.

The mean activity rate of yearling males was greater during the pre-drought ($t_{29} = -3.337$, $p < 0.01$) and drought periods ($t_{70} = -2.788$, $p = 0.01$) of 2016 than during the same periods in 2015 (Table 2.1) (Fig. 2.3). During the drought period of 2016, we observed no differences in activity of yearling males among drought categories ($F_{3,67} = 1.262$, $P = 0.30$). The mean activity rate of yearling males during the post-drought period of 2016 was not different ($t_{22} = 1.329$, $p = 0.20$) than during the same period in 2015.

Discussion. The extreme seasonal drought that occurred during our study period provided a unique opportunity to assess deer behavioral responses. The increase in adult female activity was greater from the pre-drought period of 2016 to the drought period of 2016 (38%) than from the pre-drought period of 2015 to the drought period of 2015 (-3.9%), suggesting that female activity increased due to the drought.

Peak conception on our study site was estimated at December 15 based on fawn capture data (Nelson et al. 2015) and fetal measurement data (B.T. Rutledge, Joseph W. Jones Ecological

Research Center at Ichauway, Unpublished Data). Thus, the 2016 drought occurred during a time when does were lactating and fawns were being weaned. Lactation is nutritionally demanding for white-tailed deer females (Moen 1978, Robbins 1983, Oftedal 1985, Parker et al. 2009, Pekins et al. 1998). In addition, fawns at weaning require a high energy and high protein diet (National Research Council 2007). Body mass of fawns and older adult females decrease during drought years (Gulsby et al. 2018) and winter fawn mortality may increase following a drought year (Tosa et al. 2018). Drought has been shown to impact plant selection and nutritional value for white-tailed deer (Lashley and Harper 2012), so females and fawns may have to increase activity to acquire necessary nutrition.

In contrast, yearling and adult male activity did not increase in response to the drought in 2016. Rather, male activity was likely driven by seasonal changes in socio-sexual activity as has been reported for male white-tailed deer throughout the species' range (Beier and McCullough 1990, Nelson and Mech 1981, Tomberlin 2007). Male white-tailed deer undergo a period of hypophagia during the pre-rut and rut periods (Warren et al. 1981) due to their drive to breed. During the non-breeding season, male deer typically form bachelor groups (Brown 1971) and movements of males during late summer/early fall are highly localized (Tomberlin 2007). Prior to the rut, bachelor groups dissolve and male activity increases dramatically both in mean distance moved, and area of use (Beier and McCullough 1990, Tomberlin 2007). While males forage heavily during the summer and early fall to increase body mass, these seasons are not as nutritionally demanding for males as for females. Therefore, changing nutritional needs associated with the drought may be less likely to affect male activity patterns since seasonal reproductive drive has such a great influence on male activity.

Future research should assess effects of drought on white-tailed deer activity at a different time of the year, when nutritional demands are not as inflated for does and male activity is not already elevated due to breeding behavior.

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Tables

Table 2.1. Female, adult male, and yearling male activity rates during the pre-drought (September 18 – October 17), drought (October 18 – December 27), and post-drought (December 28 – January 19) periods of 2015 (non-drought) and 2016 (drought).

	Pre-Drought		Drought		Post-Drought	
	Mean	S.E.	Mean	S.E.	Mean	S.E.
Females						
2015	0.358	0.042	0.344	0.021	0.387	0.036
2016	0.529	0.046	0.730	0.035	0.302	0.063
Adult males						
2015	0.011	0.003	0.173	0.021	0.168	0.024
2016	0.075	0.010	0.301	0.019	0.117	0.025
Yearling males						
2015	0.036	0.007	0.100	0.011	0.091	0.012
2016	0.078	0.009	0.136	0.009	0.065	0.016

Figures

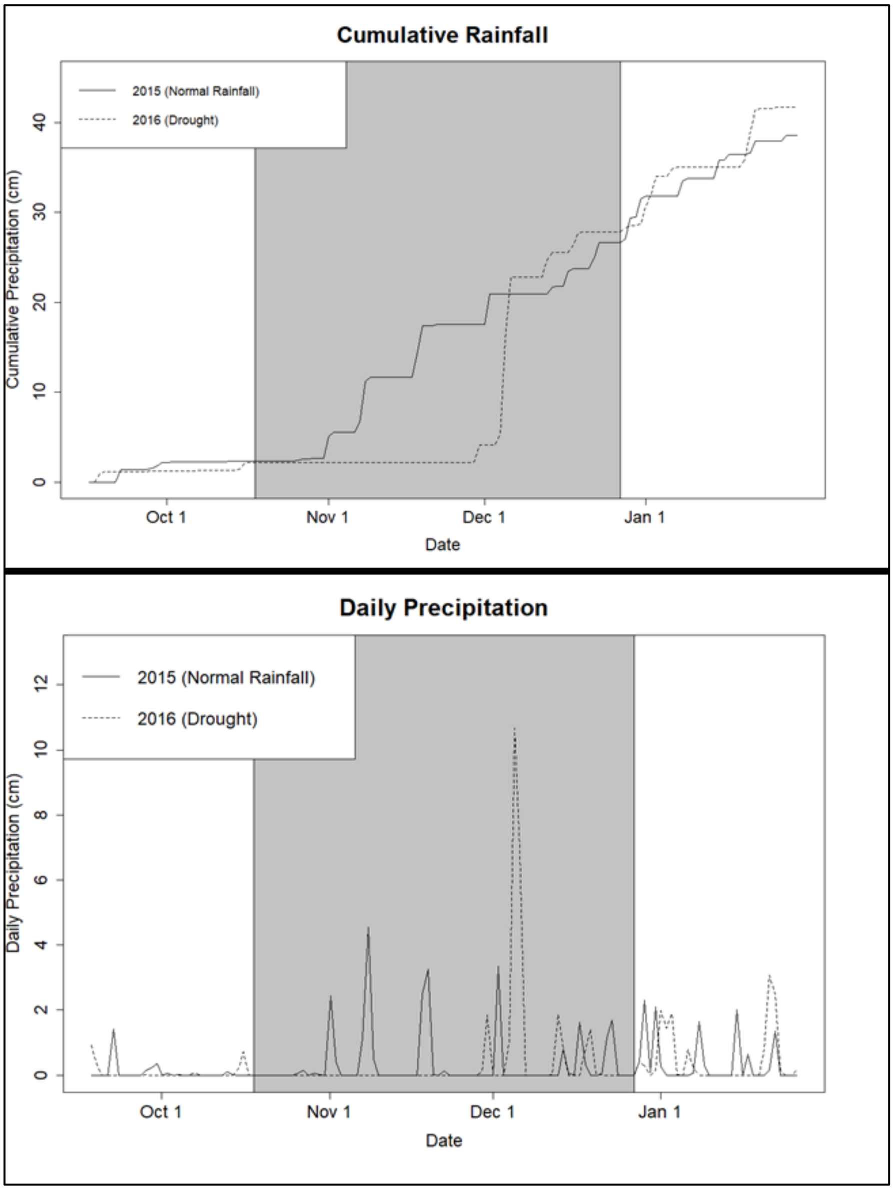
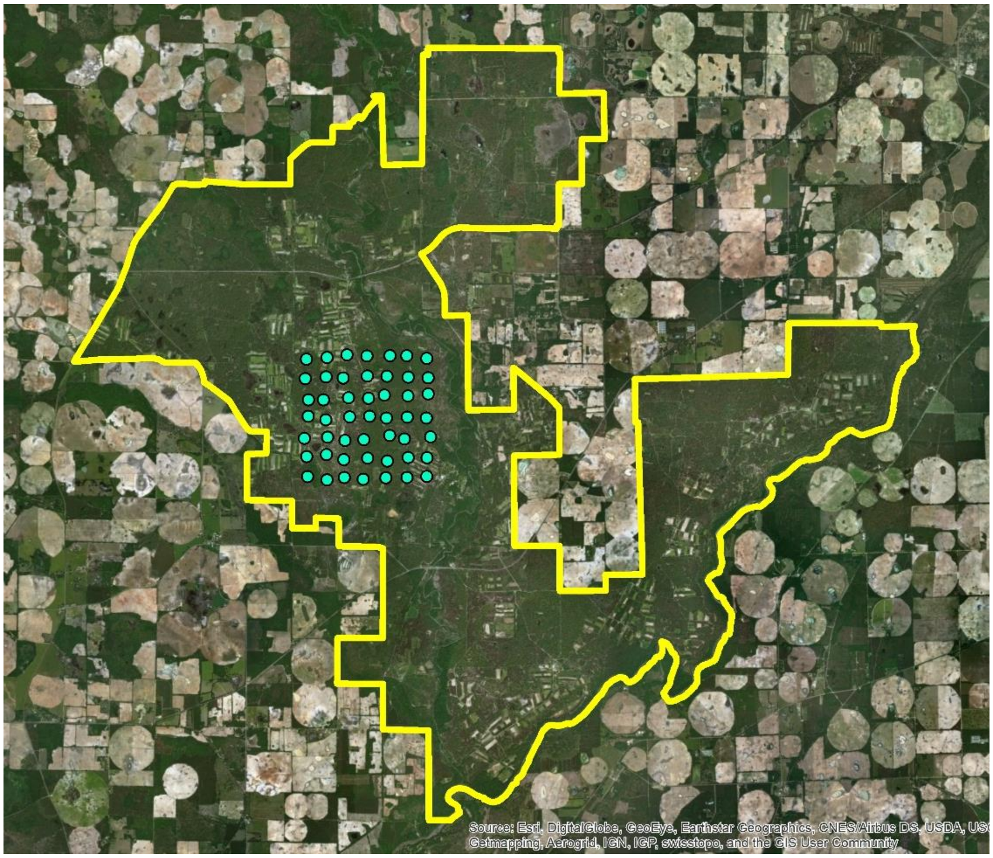


Figure 2.1. Cumulative and daily precipitation beginning September 18 for 2015, a year with normal rainfall, and the drought year of 2016, recorded at Camilla Weather Station, Georgia. The time period when the study area was classified as abnormally dry to extreme drought according to the National Drought Mitigation Center, Lincoln, NE is shown in gray.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, US
Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 2.2. Location of passive infrared cameras (blue circles) within a 1,000 ha survey grid at the Joseph W. Jones Ecological Research Center at Ichauway (yellow property boundary), Baker County, Georgia, 2015-2016.

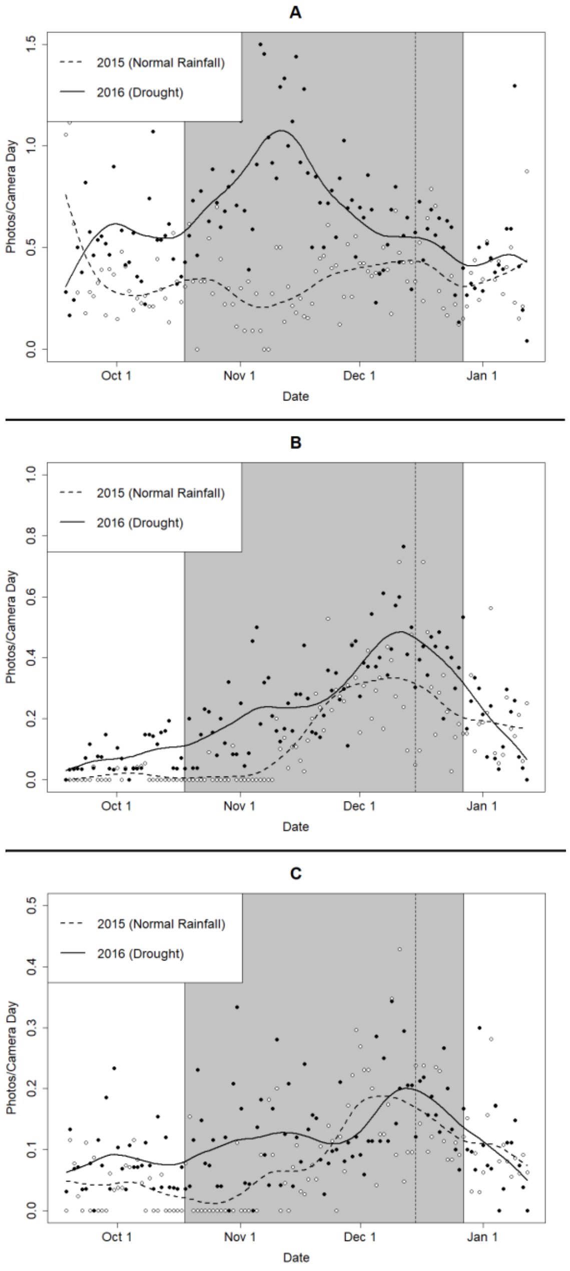


Figure 2.3. Activity rates (# photos/camera-day) of female (A), adult male (B), and yearling male (C) white-tailed deer during 2015 (normal rainfall) and 2016 (drought) on the Joseph W. Jones Ecological Research Center at Ichauway. The gray shaded area indicates the time period when the study area was classified as abnormally dry to extreme drought according to the National Drought Mitigation Center, Lincoln, NE and the vertical dotted line represents the peak rut.

CHAPTER 3

USING PASSIVE CAMERAS TO ASSESS ENVIRONMENTAL AND TEMPORAL INFLUENCES ON ACTIVITY PATTERNS OF WHITE-TAILED DEER

Biggerstaff, M. T., M. J. Cherry, L. M. Conner, C. H. Killmaster, J. T. Johnson, R. B. Chandler, and K. V. Miller. To be submitted to the *Southeastern Naturalist*

Abstract – We used passive infrared cameras to monitor *Odocoileus virginianus* Zimmerman (white-tailed deer) activity patterns in a 1,000 ha study area in southwestern Georgia. We deployed 49 cameras and recorded all occurrences of adult males, adult females and yearling males from January 1, 2015 through December 31, 2015. We quantified the influences of season, diel period, and weather (temperature, wind speed, precipitation) on activity at the annual scale and within each biological season. At the annual scale, diel period was the best predictor of adult female activity, and biological season was the best predictor of adult male and yearling male activity. Adult females were most active during the dusk period, when they were 3.4 times more active than during daytime and 2.2 times more active than during nighttime. Adult male activity peaked during the rut, with 61.4% of all detections recorded during that season. Yearling males were most active during the rut and post-rut periods. Activity rates of females decreased with increased wind speed during the post-rut, but wind was not an accurate predictor of activity during other seasons. During gestation, temperature had a negative effect on female activity. No other environmental variables were accurate predictors of female, yearling male, or adult male activity. We found stronger evidence for temporal influences on activity than environmental influences.

Introduction

Odocoileus virginianus (white-tailed deer) is the most economically important game species in the United States and has been the focus of substantial research efforts. Previous research has shown that weather patterns, biological season, and diel period influence activity patterns, although several studies have reported conflicting results. Knowledge of activity patterns provides valuable information to managers, including harvest susceptibility and how weather events may affect local herds.

White-tailed deer are crepuscular (Kammermeyer and Marchinton 1977, Ockenfels and Bissonette 1982, Rouleau et al. 2002, Webb et al. 2010), and activity rates tend to peak around sunset (Beier and McCullough 1990, Hosey 1980). Small activity peaks may occur at noon and midnight (Michael 1970). Further, white-tailed deer appear to be least active just before the morning crepuscular period, during late morning, and during late evening periods (Hosey 1980, Ivey and Causey 1981, Kammermeyer and Marchinton 1977). Other evidence shows that peaks in activity occur at different diel periods among years (Naugle et al. 1997). Demarais et al. (1989) found that deer are crepuscular during some seasons, but do not have a distinct activity pattern during others. Variations in diel activity patterns have also been reported among demographic groups during September and October (Beier and McCullough 1990).

Seasonality is another important influence on deer activity. Activity of adult males increases prior to the breeding season (Beier and McCullough 1990, Nelson and Mech 1981, Tomberlin 2007) and they are most active during the rut (Tomberlin 2007). Does are more active than males during the gestation and fawning seasons (Beier and McCullough 1990), possibly due to the increased metabolic demands of gestation and lactation (Moen 1978, Robbins 1983, Oftedal 1985, Pekins et al. 1998, Parker et al. 2009).

Weather patterns can also influence deer activity. Progulske and Duerre (1964) reported a negative effect of temperature on activity rates during summer in South Dakota. Further, Beier and McCullough (1990) found that deer activity peaked in Michigan when temperature was between 10°C and 16°C, and activity decreased when temperature deviated from this range. Hawkins and Klimstra (1970) reported a negative correlation with winter trapping success and temperature, and Cartwright (1975) reported a negative correlation between activity and temperature. Others have found no effect of high temperature on activity, but increased activity at temperatures below 0°C for both white-tailed deer (Michael 1968) and *O. hemionus columbianus* (black-tailed deer) (Miller 1970). The effect of temperature on deer activity may be sex- and season-specific (Webb et al. 2010), but Tomberlin (2007) reported that temperature was a reliable predictor of adult buck activity throughout the year.

Some research indicates that wind speed has less impact on deer activity than other weather variables (Newhouse 1973), but its impact may be greater during winter in northern climates (Beier and McCullough 1990, Ozoga and Gysel 1972). However, across regions, deer tend to be inactive when high wind speeds are accompanied by extreme precipitation events (Michael 1970, Severinghaus and Cheatum 1956). On windy days, deer tend to select areas that reduce wind speed (Zagata and Haugen 1974).

Much of the prior research investigating influences of precipitation on white-tailed deer activity focused on drought, flood, or snow events. Observations of the effects of rainfall on deer movements are inconsistent (DeYoung and Miller 2011), although Webb et al. (2009) reported an increase in doe movement tortuosity with increasing rainfall.

It is likely that a combination of weather variables impacts white-tailed deer activity more than any single factor (Progulske and Duerre 1964), and weather impacts may be regionspecific (DeYoung and Miller 2011). Few studies have investigated the effects of a comprehensive weather dataset on activity, so the effects of combined weather variables on white-tailed deer activity remains relatively unknown.

Early studies of deer activity relied on direct observations of deer (Brown 1971, Pledger 1975, Progulske and Duerre 1964, Sparrowe and Springer 1970). Subsequently, Very High Frequency (VHF) telemetry allowed for more intense sampling of individual deer (Beier and McCullough 1990, Hellickson 2002, Hosey 1980, Ivey and Causey 1981, Kammermeyer and Marchinton 1977, Kilpatrick and Lima 1999, Montgomery 1963, Naugle et al. 1997). However, low acquisition frequency and telemetry error limit the value of VHF data relative to modern technologies such as Global Positioning Systems (GPS) telemetry (Cagnacci et al. 2010, Massé and Côté 2013, Tomberlin 2007). However, the high cost of GPS telemetry often results in small sample sizes, thereby limiting sex- and age-specific inferences. Motion-sensitive trail cameras may be a viable cost-effective alternative to GPS collars (Lashley et al. 2018). Further, cameras can be used to monitor the population-level activity rate without relying on a subsample of the population. Therefore, we used a high density trail camera grid to monitor population-level activity patterns of white-tailed deer to investigate diel, seasonal, and weather influences on white-tailed deer activity at annual and seasonal scales.

Field-Site Description

We conducted this study on the Joseph W. Jones Ecological Research Center at Ichauway, a privately-owned property in Baker County, Georgia. Ichauway is comprised of 12,000 ha dominated by longleaf pine savanna. Ichauway is located in the Upper Coastal Plain physiographic region, which is in the southern temperate forest. This area is characterized by mild winters and hot summers. The yearly mean precipitation is 132.4 cm. The longleaf pine forest at Ichauway is fire-maintained with a 1-3 year fire return interval. Food plots and agricultural fields are scattered throughout the property. Wildlife openings are planted in agricultural crops such as corn and grain sorghum and various combinations of food plot species, including oats, wheat, and white clover. Deer are hunted on Ichauway in accordance with Georgia Department of Natural Resources regulations and Jones Center regulations. The white-tailed deer density in this area is approximately 30 deer/km^2 (Johnson, J.T., University of Georgia, Unpublished Data).

Methods

We selected a 1,000 ha study area and divided it into 49 equally sized grid cells (Fig.3.1). We deployed one Uway VH400HD infrared trail camera (HCO Outdoors, Norcross, Georgia, USA) on the closest game trail to the center of each cell, and we ran cameras from January 1, 2015 through December 31, 2015. We monitored cameras monthly to ensure proper function and to download photos. We considered cameras non-operational and replaced them if they failed to take a photo in 7 or more days. We discarded non-independent photos by delineating a minimum 3-minute interval between photographs to minimize recording consecutive detections of the same individual at each camera. We recorded the number of adult females, fawns, yearling males and adult males in each photo.

We divided the year into six biological seasons based on fawn capture data (Nelson et al. 2015) and fetal measurement data (Rutledge B.T., Joseph W. Jones Ecological Research Center at Ichauway, Unpublished Data) from our study site. The timing of the biological seasons were: fawning from June 1 to August 5, rearing from August 6 to October 21, pre-rut from October 22 to November 21, rut from November 22 to January 1, post-rut from January 2 to February 7, and gestation from February 8 to May 31. We defined the diel periods as dawn (one hour before sunrise until one hour after sunrise), day, dusk (one hour before sunset until one hour after sunset) and night. Daily sunrise and sunset times were identified through the use of the 'maptools' package in Program R-3.1.2 (Bivand et al. 2016).

We received weather data from a datalogger in Camilla, GA, which was operated by the University of Georgia Weather Network (University of Georgia, Athens, GA, USA). The station collected hourly measurements of precipitation, wind speed, and temperature. For analysis, precipitation values were summed within each diel period, while wind speed and temperature were averaged.

We separated data by demographic group, diel period, and biological season. To analyze the effects of environmental and seasonal factors on activity rate, we divided the number of deer photos taken in daily diel periods by the number of operational cameras in that period. We conducted two sets of analyses. One included data from the entire year to assess diel and seasonal variation in activity patterns. The second analysis focused on within-season effects of weather and diel periods on activity patterns. For each analysis, we used linear auto-regressive moving-average (ARMA) models to account for serial correlation in the error terms to relax the assumption that the camera data were independent among days. In the first set of models, we included season and diel periods as predictor variables for each age and sex class. In the second set of models, we assessed activity patterns within each biological season by including temperature, wind speed, precipitation, and the change in each weather variable from the previous diel period and from the previous 24 hours as predictor variables (Table 3.1). We used Akaike's Information Criterion (AIC) to identify the best model in each model set. AIC was also used to select the autoregressive order (p) and moving average order (q) to account for autocorrelation. We then used the best model in each model set to assess the effects of each predictor variable on activity rates. Tukey tests were used for pairwise comparisons. Analyses were conducted using the ‘nlme’ package in Program R-3.1.2 (Pinheiro et al. 2017).

Results

Seasonal and Diel Influences on Activity

We recorded 3,382 observations of adult females, 513 observations of adult males, and 570 observations of yearling males in 2015. The most supported model of female activity patterns included diel period (Table 3.2). Detections during the dawn and dusk periods accounted for 32.4% (n = 1096) of all female detections, but those periods only accounted for 16.7% of time. The mean activity rate of females during the dusk period was greater than during dawn, day, and night (Fig 3.2). While diel period was the best predictor of female activity, biological season also had a significant effect on female activity. Females were most active during the rearing, rut, and post-rut periods, and least active during the gestation period (Fig. 3.3).

The most supported model of adult male activity included biological season, but not diel period (Table 3.2), with highest activity rates occurring during the rut (Fig. 3.3). Overall, 61.4% (n = 315) of adult male detections were recorded during the rut, which only represented 10.9% of the year. The mean activity rate of adult males during the rut was greater than during any other season. While biological season was the best predictor of adult male activity, diel period also had a significant influence on adult male activity at the annual level, with the highest activity rates during crepuscular hours (Fig. 3.2). The average activity rate of adult males during the dawn period was not different than during dusk. However, dawn activity was greater than day and night activity, and dusk activity was greater than day activity.

The most supported model of yearling male activity included biological season but not diel period (Table 3.2), with highest activity rates occurring during the rut and post-rut (Fig. 3.3). Overall, 28.8% (n = 161) of yearling male detections occurred during the rut. Yearling males were most active during the rut and the post-rut. While biological season was the best predictor of yearling male activity, diel period also had a significant effect on activity, with highest activity rates occurring during dawn and dusk periods (Fig. 3.2). Overall, 26.9% (n = 153) of yearling male observations occurred during dusk and dawn periods, which only represented 16.7% of the study period. The mean activity rate for yearling males at dusk was not different from activity at dawn. However, dawn and dusk activity rates were both higher than those from day or night. We selected an autocorrelation structure of order 1 to determine the best predictors of activity at the annual scale.

Within-Season Weather Influences on Activity

During gestation, the most supported model of female activity included average temperature as a predictor variable (Table 3.3) ($t_{450} = -5.761$, $p < 0.01$). With every 1°C that temperature increased, activity rates decreased by 0.002 photos per camera hour. During both the fawning and rearing periods, the most supported model incorporated diel period as a predictor variable (Table 3.3). In the fawning season, the highest activity rates occurred during dusk. However, in the rearing period, there was no significant difference between dawn and dusk activity ($p = 0.05$), but activity was higher in both crepuscular periods than during day or night ($p < 0.01$). The null model had a lower AIC value than any of the models including weather variables during the pre-rut and rut (Table 3.3), and was therefore the most supported model. During the post-rut, the most supported model of female activity included the change in wind speed from the previous diel period as a predictor variable (Table 3.3) ($t_{126} = -4.497$, $p < 0.01$). For every 1 kph increase in wind speed from the previous diel period, female activity decreased by 0.002 photos per camera hour. None of the weather variables explained substantial amounts of variation in adult male or yearling male activity in any biological season, as indicated by the fact that the null model had the lowest AIC value (Tables 3.4 – 3.5). We used an autocorrelation structure of order 1 to determine the best predictors of activity at the seasonal scale.

Discussion

Our results support previous findings that deer are most active during the crepuscular hours (Beier and McCullough 1990, Hosey 1980, Kammermeyer and Marchinton 1977, Ockenfels and Bissonette 1982, Rouleau et al. 2002, Webb et al. 2010). Further, we found that females are more active during dusk than dawn. As anticipated, biological season was the best predictor of adult male activity, with activity rates being highest during the rut. This significant increase during the rut has been shown in other regions (Tomberlin 2007). Over 61% of all adult male photos occurred during the rut, and the activity rate during the rut was 3.7 times higher than during the post-rut season. Adult male activity was lowest during gestation, with only 10 adult male detections recorded during a 112 day period. Unlike during the rut, adult male home ranges are localized during the gestation season. Males form bachelor groups for most of the year outside of the rut (Brown 1971), so it is possible that none of our cameras intercepted the core area of a bachelor group during that period.

Overall, the within-season analyses revealed few effects of weather factors on female activity. The post-rut and gestation seasons were the only periods in which any weather factor was a better predictor of activity than either diel period or the null model. The change in wind speed from the previous diel period had a negative effect on female activity during the post-rut. In northern deer ranges increased wind speeds negatively affect deer activity in winter (Beier and McCullough 1990, Ozoga and Gysel 1972). Our results suggest that energy conservation during winter may be similarly important in our study area despite comparatively mild winter conditions. During gestation, average temperature had a negative effect on female activity. While most studies have looked at the effects of temperature in cold climates on activity, we observed significant effects in an area with a mild climate. Overall, we conclude that regardless of the environmental conditions we tested, diel period remains the most important influence on female activity.

The lack of significant effects on male activity rates within biological seasons is likely due to the small number of detections recorded outside of the rut. The mean adult male activity rate in all other seasons was only 0.6 photos per day across the grid. Lashley et al. (2018) found that 100 detections are needed within a study period to confidently measure activity rates using trail cameras, and our detections of adult males only reached that threshold during the rut. GPS collars can be programmed for high acquisition rates, and thus can provide much finer detail on deer movement patterns. As such, use of passive infrared camera grids at the camera density we employed does not appear to be an effective way to monitor fine-scale influences on activity rate. However, camera grids can be used to identify coarser-scale movement patterns such as diel and seasonal activity.

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Tables

Table 3.1. Variables that were tested as predictors of white-tailed deer activity at the Joseph W. Jones Ecological Research Center at Ichauway, 2015.

Variable	**Definition**
Diel Period	Period of day (dawn, day, dusk, night)
BioSeason	Biological season
Avg Temp	Average temperature within each diel period
Tempper	Change in temperature from previous diel period
Tempday	Change in temperature from 24 hour mean
Avg Wind	Average wind speed within each diel period
Windper	Change in wind speed from previous diel period
Windday	Change in wind speed from 24 hour mean
Precip	Total precipitation amount within each diel period
Precipper	Change in precipitation amount from previous diel period
Precipday	Change in precipitation amount from 24 hour mean

Table 3.2. The best temporal predictors of female, adult male, and yearling male white-tailed deer activity patterns at the Joseph W. Jones Ecological Research Center at Ichauway.

	K	AICc	ΔAIC	AICcWt	Cum.Wt.
Females					
Diel Period	7	-6824.1	0.00	1.00	1.00
BioSeason + Diel Period	12	-6789.3	34.77	0.00	1.00
BioSeason * Diel Period	27	-6667.3	156.78	0.00	1.00
BioSeason	9	-6634.3	189.81	0.00	1.00
Adult Males					
BioSeason	9	-10516.0	0.00	1.00	1.00
BioSeason + Diel Period	12	-10491.1	24.98	0.00	1.00
BioSeason * Diel Period	27	-10318.9	197.09	0.00	1.00
Diel Period	7	-10283.2	232.83	0.00	1.00
Yearling Males					
BioSeason	9	-10231.6	0.00	1.00	1.00
BioSeason + Diel Period	12	-10216.9	14.71	0.00	1.00
Diel Period	7	-10187.3	44.32	0.00	1.00
BioSeason * Diel Period	27	-10061.2	170.41	0.00	1.00

Table 3.3. The best predictors of female white-tailed deer activity patterns during each biological season at the Joseph W. Jones Ecological Research Center at Ichauway.

	K	AICc	ΔAIC	AICcWt	Cum.Wt.
Gestation					
Avg Temp	5	-2120.9	0.00	0.63	0.63
Diel Period + Avg Temp	8	-2119.2	1.61	0.28	0.92
Diel Period	7	-2115.5	5.34	0.04	0.96
Fawning					
Diel Period	7	-1410.6	0.00	0.62	0.62
Tempper	5	-1409.2	1.34	0.32	0.93
Avg Temp + Tempper	6	-1405.5	5.02	0.05	0.98
Rearing					
Diel Period	7	-1426.6	0.00	0.98	0.98
Diel Period + Precipday	8	-1416.9	9.73	0.01	0.98
Diel Period + Precip	8	-1416.6	10.00	0.01	0.99
Pre-Rut					
Null	4	-517.2	0.00	0.95	0.95
Diel Period	7	-509.6	7.60	0.02	0.97
Precip	5	-509.0	8.23	0.02	0.99
Rut					
Null	4	-773.6	0.00	0.9	0.90
Diel Period	7	-767.9	5.70	0.05	0.95
Precip	5	-765.9	7.66	0.02	0.97
Post-Rut					
Windper	5	-513.8	0.00	0.63	0.63
Null	4	-512.6	1.20	0.35	0.98
Precip	5	-506.2	7.65	0.01	0.99

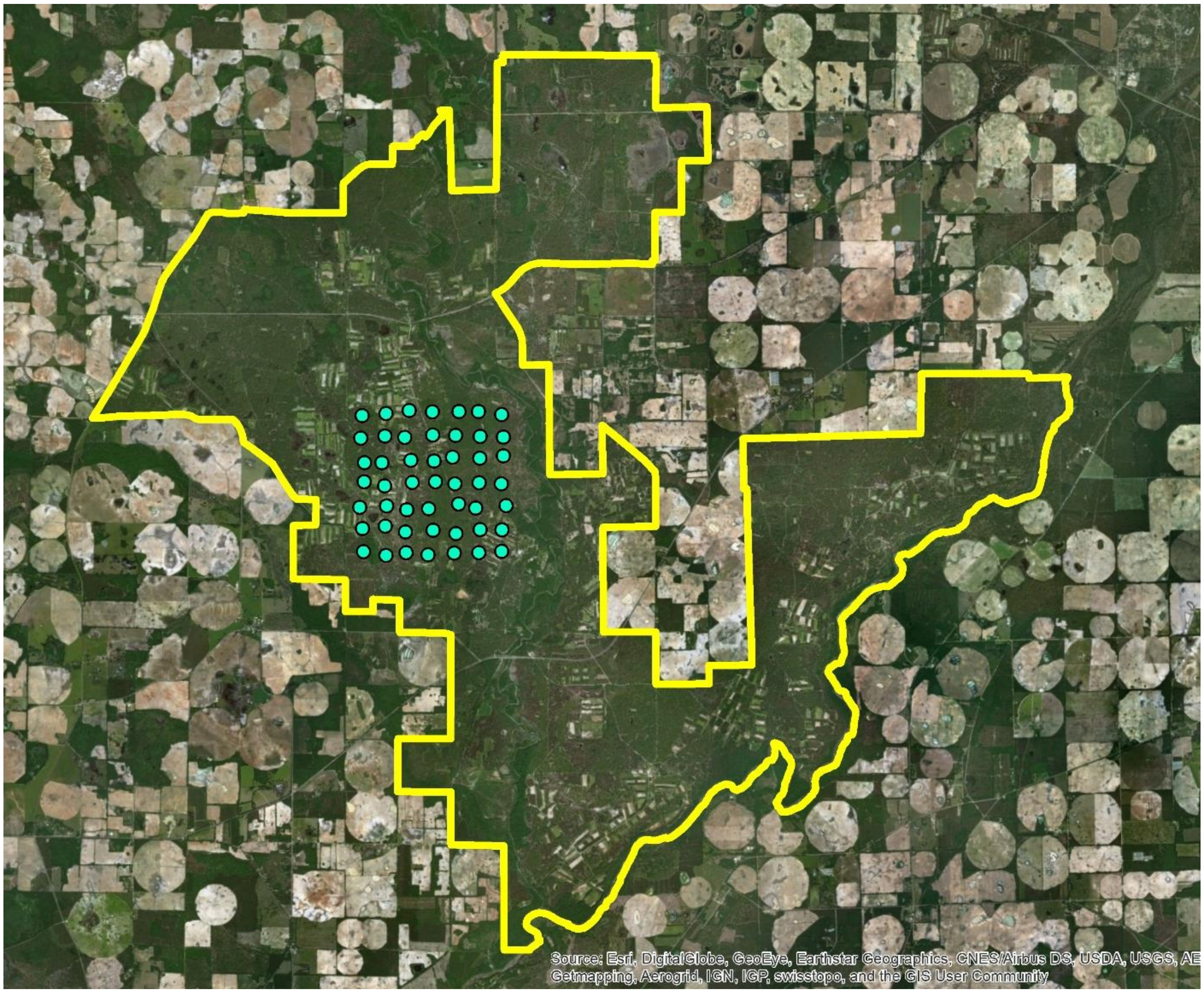
Table 3.4. The best predictors of adult male white-tailed deer activity patterns during each biological season at the Joseph W. Jones Ecological Research Center at Ichauway.

	K	AICc	ΔAIC	AICcWt	Cum.Wt.
Gestation					
Null	4	-4527.4	0.00	1.00	1.00
Tempday	5	-4512.9	14.53	0.00	1.00
Precip	5	-4512.9	14.54	0.00	1.00
Fawning					
Null	4	-2242.6	0.00	1.00	1.00
Precip	5	-2228.8	13.87	0.00	1.00
Avg Wind	5	-2224.3	18.37	0.00	1.00
Rearing					
Null	4	-2406.2	0.00	1.00	1.00
Precip	5	-2393.4	12.76	0.00	1.00
Tempper	5	-2388.5	17.71	0.00	1.00
Pre-Rut					
Null	4	-836.4	0.00	0.99	0.99
Precip	5	-825.2	11.22	<0.01	1.00
Avg Temp	5	-823.9	12.54	<0.01	1.00
Rut					
Null	4	-900.3	0.00	0.99	0.99
Precip	5	-890.5	9.89	0.01	1.00
Avg Wind	5	-886.7	13.63	0.00	1.00
Post-Rut					
Null	4	-971.2	0.00	0.98	0.98
Avg Wind	5	-963.2	8.04	0.02	0.99
Precip	5	-960.4	10.83	<0.01	1.00

Table 3.5. The best predictors of yearling male white-tailed deer activity patterns during each biological season at the Joseph W. Jones Ecological Research Center at Ichauway.

	K	AICc	ΔAIC	AICcWt	Cum.Wt.
Gestation					
Null	4	-3620.5	0.00	0.99	0.99
Precip	5	-3607.9	12.64	<0.01	1.00
Avg Temp	5	-3607.9	12.65	<0.01	1.00
Fawning					
Null	4	-2035.8	0.00	1.00	1.00
Precip	5	-2022.9	12.85	0.00	1.00
Tempper	5	-2020.4	15.39	0.00	1.00
Rearing					
Null	4	-2153.7	0.00	0.99	0.99
Windper	5	-2142.8	11.00	<0.01	1.00
Precip	5	-2141.6	12.15	<0.01	1.00
Pre-Rut					
Null	4	-820.9	0.00	0.97	0.97
Avg Temp	5	-812.3	8.64	0.01	0.99
Tempday	5	-811.4	9.52	0.01	0.99
Rut					
Null	4	-1004.2	0.00	0.99	0.99
Precip	5	-994.87	9.37	0.01	1.00
Avg Wind	5	-991.35	12.89	0.00	1.00
Post-Rut					
Null	4	-849.8	0.00	0.99	0.99
Precip	5	-840	9.80	0.01	0.99
Windper	5	-837.2	12.61	0.00	1.00

Figures



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AE
Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 3.1. The 1,000 ha camera grid, represented by blue dots, at the Joseph W. Jones Ecological Research Center at Ichauway.

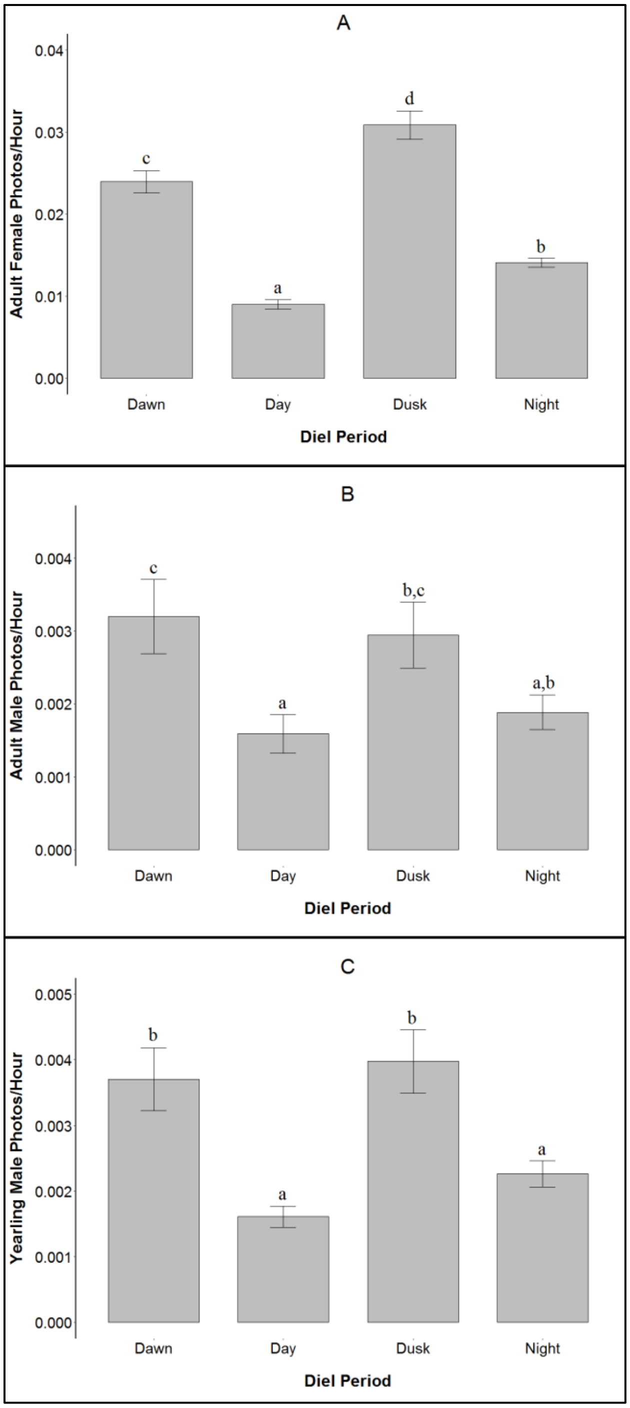


Figure 3.2. The number of photos per camera hour (± SE) of adult female (A), adult male (B), and yearling male (C) deer by diel period recorded on a 1,000 ha camera grid at the Joseph W. Jones Ecological Research Center at Ichauway during 2015. Periods with the same letter are not statistically different (P<0.05, Tukeys).

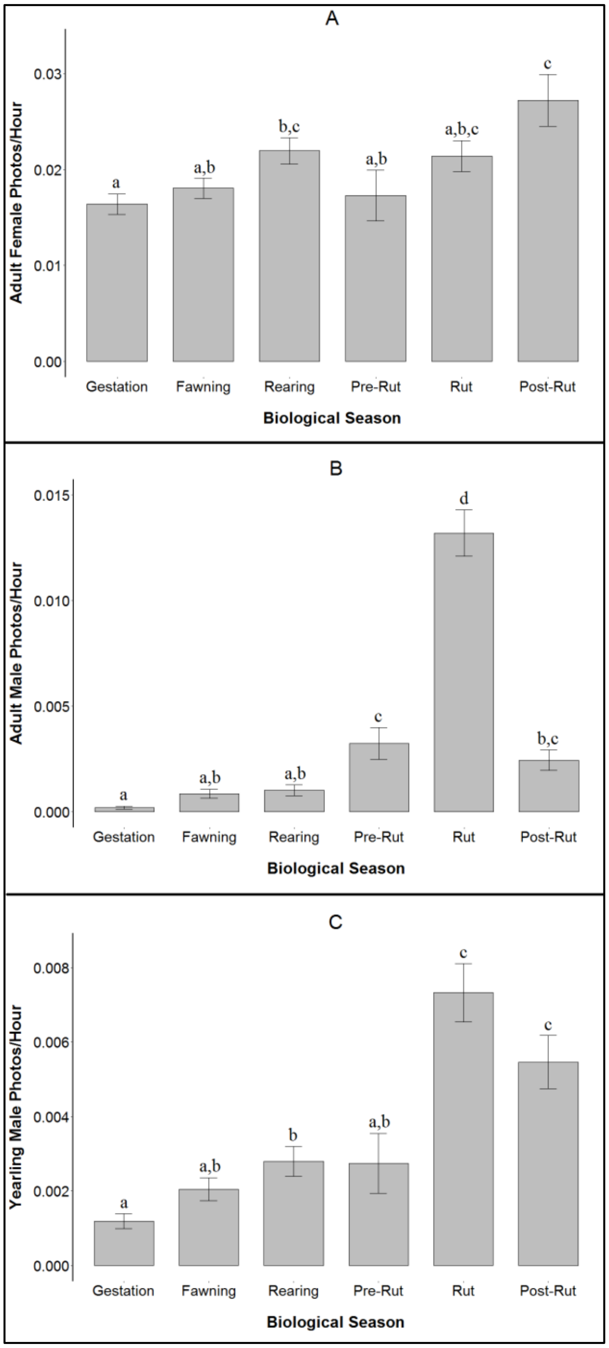


Figure 3.3. The number of photos per camera hour (± SE) of adult female (A), adult male (B), and yearling male (C) deer by biological season recorded on a 1,000 ha camera grid at the Joseph W. Jones Ecological Research Center at Ichauway during 2015. Periods with the same letter are not significantly different (P<0.05, Tukeys).

CHAPTER 4

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

During 2015 – 2016, I used a grid of 49 trail cameras on a 1,000 ha study site in southwestern Georgia to monitor activity patterns of white-tailed deer. From October 18, 2016 – December 27, 2016, an extreme drought took place throughout much of the Southeast. This provided me with the unique opportunity to identify potential effects of the drought on white-tailed deer activity.

I monitored activity from September 18, 2015 – January 19, 2016, and a similar period in 2016 – 2017, to determine the effects of drought. During these periods, I accumulated 3,323 adult female detections, 1,291 adult male detections, and 699 yearling male detections. The activity rate of each demographic group was higher prior to the drought in 2016 than at the same time in 2015. The difference in female activity was greater during the drought period than prior to the drought, suggesting that the drought led to an increase in female activity. My results suggest that the decrease in forage quality and quantity, mixed with the high nutritional needs of females during that time, resulted in increased activity rates.

The difference in male activity was not greater during the drought period than before the drought, which is likely due to the natural increases in activity associated with the rut. It appeared that the males were responding more to socio-sexual cues than to the drought.

To identify potential temporal and environmental influences on white-tailed deer activity, I collected 3,382 observations of adult females, 513 observations of adult males, and 570 observations of yearling males in 2015. I used biological season, diel period, and weather measurements from a University of Georgia Weather Network (Athens, GA) station as predictor variables. At the annual scale, diel period was the best predictor of female activity, with the highest activity rates occurring at dusk. Biological season was also a significant predictor of female activity, with highest activity during the rearing, rut, and post-rut seasons. Biological season was the best predictor of adult male and yearling male activity, with highest yearling male activity rates occurring during the rut and post-rut and highest adult male activity rates occurring during the rut. Diel period was another significant predictor of adult male and yearling male activity, with highest activity rates occurring during dawn and dusk.

I then investigated environmental and temporal influences on activity within each biological season. Outside of the rut period, I likely observed too few detections of adult males to determine within-season influences on activity. Their behavioral responses to sexual cues during the rut appears to be a better predictor of activity than any environmental factor. I only found two significant environmental effects on adult female activity within biological seasons. During gestation, as temperature increased, female activity rates decreased. Also, during the post-rut, the change in wind speed from the previous diel period was the best predictor of activity. If the wind speed had increased since the previous diel period, female activity was likely to be low.

My study indicates that high density passive trail camera grids can be used to monitor coarse effects on population-level activity rates of white-tailed deer. I successfully observed an increase in female activity during an extreme drought. I also concluded that, outside of the drought period, diel period is the primary driver of female deer activity and biological season is the main influence on male deer activity regardless of environmental conditions.