HABITAT SELECTION AND SURVIVAL OF WHITE-TAILED DEER FAWNS IN A LONGLEAF PINE ECOSYSTEM

by

MELINDA ANN NELSON

(Under the Direction of Robert J. Warren)

ABSTRACT

This project investigated white-tailed deer (*Odocoileus virginianus*) fawn behavior and survival at the Joseph W. Jones Ecological Research Center in southwestern Georgia, which is an 11,735-ha longleaf pine (*Pinus palustris*) forest. I investigated habitat at fawn bed-sites during the first two weeks of life at multiple habitat levels. Fawns' bed-sites were associated with tall, dense understory vegetation and closed overstory canopies at the microhabitat level, and near edges at the macrohabitat level. Analysis of fawn locations from capture until recruitment into the fall population allowed me to determine that fawn locations were near edges with greater edge density, increased basal area, and far from mixed pine-hardwood habitat. Predation on radio-collared fawns indicated coyotes (*Canis latrans*) were their primary predator with bobcats having minimal effects. The collective data provide more insight into the effect of coyote predation on fawns and how managers can provide abundant habitat for fawns prior to recruitment.

INDEX WORDS: Bobcat, Bed-site, Coyote, *Canis latrans*, Fawn, Habitat, Home range, *Lynx rufus*, *Odocoileus virginianus*, Predation, White-tailed deer

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DEDICATION

I would like to dedicate this thesis to my parents Ted and Betsy, my brother Sam, and my sisters Sarah and Karen. Mom and Dad, your constant fascination with what I do as well as your unwavering support gave me the confidence I needed to persevere and accomplish my dreams. Sam, I can’t tell you how grateful I am for our mutual love for the outdoors and your support throughout this process. Sarah, your patience in listening to my stressed out rants over the phone helped me get through a lot of hard times. Karen, I cannot tell you how grateful I am for your support and encouragement especially within the past year. I love you all!

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is something that I feel every research facility should strive for. Finally, I would like to thank Meg Streich for being an amazing friend during the past year. You were a constant source of comfort and encouragement during a difficult time in my life and again I may likely have given up if it hadn't been for you!

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CHAPTER 1

INTRODUCTION, LITERATURE REVIEW, OBJECTIVES, AND THESIS FORMAT

Introduction

As in many deer species, white-tailed deer (*Odocoileus virginianus*) neonates exhibit a "hiding" strategy during their first few weeks of life as their primary defense against predation. When responding to "alarm stimuli", they exhibit bradycardia and lie prone in "bed sites" under vegetative cover rather than fleeing (Jacobsen 1979). Most comprehensive studies on fawn movements and bed-site selection have been conducted in the midwestern United States (Jackson et al. 1972, Garner et al. 1979, Riley and Dood 1984, Huegel et al. 1986, Gerlach and Vaughan 1991, Grovenburg et al. 2010). Even in these areas, there is still limited information available on aspects of neonatal behavior, such as age-specific behavior, survival, and habitat selection. I have not been able to identify any studies published on neonatal fawn behavior in the Coastal Plain region of the southeastern U.S. Specifically in the fire-maintained longleaf pine (*Pinus palustris*)-wiregrass (*Aristida stricta*) ecosystem, there are inadequate data available on fawn behavior.

The Coastal Plain Physiographic Region of the Southeast provides a diversity of deer habitat with abundant browse and cover. Studies of neonate deer within this region are difficult because its characteristically dense understory allows little opportunity for observation without disturbance. Even so, research conducted within these ecosystems is important because with the lack of available research comes an increased need to understand what specific components are important for its native wildlife as a basis for management recommendations accordingly. The purpose of this study was to gain an understanding of neonatal fawn behavior and survival in a longleaf pine-wiregrass ecosystem. Understanding habitat selection by fawns will allow for more informed forest management. Furthermore, deer management programs should consider all components of a deer's life cycle to best manage herd size and determine management practices such as changes in harvest strategies that could potentially alter these mortality rates (Huegel 1985).

Literature Review

Fawn bed site selection and habitat selection

Habitat quality, which is mainly defined by resource availability, is a significant determinant in the life-history traits of many herbivore species (Pettorelli et al. 2005). During the first few weeks of life when their physical development hinders their ability to outrun predators, white-tailed deer fawns spend up to 80% of their time resting in bed-sites approximately 100m away from their dam (Huegel et al. 1986). The general location of the fawn's bed-site is largely determined by the doe's home range. However, the specific site is chosen by the fawn (Van Moorter et al. 2009). In a study of habitat selection by neonatal black-tailed deer (*O.hemionus columbianus*) in California, Bowyer et al. (1998) found that fawn habitat selection was likely related to the thermal environment and nutritional demands of lactating females rather than risk of predation. Similarly, dams of roe deer (*Capreolus capreolus*) fawns have been shown to select habitat types providing the greatest energetic gain regardless of predation risk (Panzacchi et al. 2010).

In contrast, Alldredge et al. (1991) suggested that bed-site selection may largely be a response to predation pressure. In many areas of the Southeast where the forests are well structured with a dense understory, fawns have the option to select habitat with tall and dense understory vegetation. Such vegetative structure may inhibit air currents from carrying the fawn's scent, which may aid in preventing detection by predators that use olfactory cues (Wells and Lehner 1978). Similarly, roe deer fawns in France selected bed-sites for tall understory vegetation that provided greater visual concealment and better thermal cover, which positively influenced survival (Van Moorter et al. 2009). In Iowa, fawns selected bed-sites with vegetation cover >1m tall (Huegel 1986), and in Oklahoma, Garner et al. (1979) observed that fawns selected bed-sites with greater vertical vegetation height than at random sites.

Fawn survival and cause-specific mortality

Survival of young white-tailed deer fawns is affected by their health at birth, food availability, availability of hiding cover, condition of the dam, and other factors (Jackson et al. 1972). Numerous investigators have documented losses of deer fawns to predation (Huegel 1985, Whittaker and Lindzey 1999, Vreeland et al. 2004, Howze 2009, Kilgo et al. 2012). In the southeastern United States, coyotes and bobcats (*Lynx rufus*) are the most common predators of white-tailed deer fawns (Howze 2009). Coyotes are non-native additions to the fauna of the eastern United States that have recently expanded their range largely through anthropogenic means (Hill et al. 1987). Evidence suggests that coyote (*Canis latrans*) predation on fawns can be high and may be limiting deer populations in this region (Kilgo et al. 2010), largely because fawns are highly vulnerable during the first few weeks of their life.

Kilgo et al. (2012) reported an overall fawn survival rate of 23% in South Carolina, with coyote predation being the dominant cause of fawn mortality. In southwestern Georgia, Howze (2009) reported an overall fawn survival rate of 17% with coyotes also being the dominant cause of all predator-related mortalities. Studies of coyote food habits in the Southeast have found that fawns represent a major food item during the early summer months (Schrecengost et al. 2008, Howze 2009). Alternatively, studies of bobcat food habits suggest that in areas where bobcats and coyotes are sympatric, white-tailed deer are not a major component of bobcat diets (Godbois 2003, Thornton et al. 2004, VanGilder 2008). However, of the studies that have documented levels of bobcat predation in areas of the Southeast where coyotes were not present; Epstein et al. (1983) reported 29% mortality, Boulay (1992) reported ≥60% mortality, and Roberts (2007) reported 57-82% mortality, all of which suggest that coyotes may affect bobcat use of fawns.

Study Area

This study was conducted on Ichauway, the outdoor research facility at the Joseph W. Jones Ecological Research Center (Jones Center) located in Baker County, Georgia. The 11,735-ha research facility is one of the largest privately held tracts of longleaf pine (*Pinus palustris*) forest in the United States. White-tailed deer management objectives on site are to keep the herd well below carrying capacity while maintaining a balanced sex-ratio using selective harvest to influence a diverse age structure (J. W. Jones Ecological Research Center 2012). Spotlight counts and track-counts are conducted yearly to obtain estimates of white-tailed deer and predator abundances across the property.

The climate is characterized by mild, wet, short winters and hot summers with temperatures ranging on average from 11°C during winter to 27°C during summer (Boring 2001). The average annual rainfall is 132 cm. The site is dominated by longleaf pine overstory and associated isolated wetlands. The dominant understory species are old field grasses (e.g., *Andropogon* spp.) on old field sites, and wiregrass (*Aristida beyrichiana*). The Flint River forms 21 km of the eastern property boundary and 24 km of the Ichawaynochaway Creek flows through the middle of the property. Forest management at the Jones Center includes prescribed fire on a 2-year return interval, mechanical removal of hardwoods from the longleaf pine uplands, and longleaf pine restoration in old field sites. Prescribed fire is the primary management tool used to maintain the longleaf pine ecosystem by reducing hardwood encroachment, reducing fuels, and promoting herbaceous cover. Northern bobwhite (*Colinus virginianus*) management practices are implemented on approximately half of the property and include supplemental feeding, food plot maintenance, and limited mesopredator removal. Wildlife food plots are planted in brown top millet (*Urochloa ramosa*), cowpea (*Vigna spp*.), corn (*Zea mays*), grain sorghum (*Sorghum bicolor*), Egyptian wheat (*Sorghum* spp.), and winter wheat (*Triticum aestivum*), (Joseph W. Jones Ecological Research Center 2012).

Objectives

To better understand fawn behavior and survival from birth until recruitment into the fall population, I established the following objectives.

1. Determine macrohabitat characteristics and microhabitat features associated with fawn bed-sites from birth to about 2 weeks of age.
2. Determine macrohabitat characteristics associated with fawn locations prior to recruitment into the fall population.
3. Determine survival and cause-specific mortality of fawns.

Thesis Format

This thesis was written in manuscript format in which chapters 2, 3 and 4 represent manuscripts submitted for publication. Chapter 1 is an overall description of white-tailed deer fawn behavior and an introduction to the thesis. Chapter 2 describes habitat associated with fawn bed-sites and will be submitted to the American Midland Naturalist. Chapter 3 describes habitat associated with fawn locations and will be submitted to the American Midland Naturalist. Chapter 4 pertains to fawn survival and cause-specific mortality and has been submitted to the

Proceedings of the Southeastern Association of Fish and Wildlife Agencies. Chapter 5 is a summary of all findings and the conclusions of this study.

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CHAPTER 2

HABITAT ASSOCIATED WITH BED-SITES OF WHITE-TAILED DEER FAWNS IN A LONGLEAF PINE ECOSYSTEM

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[1] Nelson, M. A., M. J. Cherry, R. J. Warren, and L. M. Conner. To be submitted to *The American Midland Naturalist.*

Abstract: White-tailed deer (*Odocoileus virginianus*) fawns exhibit a hiding strategy during the first few weeks of life where they rely on vegetation characteristics at bed-sites to provide concealment from predators. Selection of bed-sites occurs at both the macrohabitat level (i.e., the doe's home range) and microhabitat level (i.e., the actual bed-site chosen by the fawn). During the summer of 2012 we identified and sampled fawn bed-sites at the Joseph W. Jones Ecological Research Center in southwestern Georgia. We captured 12 newborn fawns and used radio-telemetry and visual observation to locate fawn bed-sites daily until about 2 weeks of age. We measured microhabitat variables and derived a number of macrohabitat values at bed-sites and paired random points generated within individual fawn seasonal areas of use. We then used logistic regression and an information theoretic approach to assess the influence of these variables at the microhabitat and macrohabitat level on the probability of a site being used as a bed-site. Vertical height of understory vegetation, canopy closure, and understory density at 0.5 m were important at the microhabitat level and distance to edge was important at the macrohabitat level. Following a comparison of our most supported models at each level, there was overwhelming support for the microhabitat model relative to the macrohabitat model. The periodic use of prescribed fire along with increasing access to edges by maintaining a mosaic of habitats would provide fawns with suitable hiding cover.

Introduction

As with many species of ungulates, white-tailed deer (*Odocoileus virginianus*) fawns evolved a hiding strategy, in which they use cryptic coloration and vegetative cover to avoid detection. The success of the hiding strategy depends on interactions between fawn and dam (Huegel *et al*. 1986). To avoid predation, hiders should choose activity patterns that optimally balance movements for feeding and shifting among bed-sites with periods of resting in bed-sites approximately 100 m away from their dam (Huegel *et al*. 1986, Schwede *et al*. 1991). The general location of the bed-site (macrohabitat) is determined by the dam, after which the actual site is chosen by the fawn (Van Moorter *et al*. 2009). Roe deer (*Capreolus capreolus*) does with fawns select habitat types granting the highest energetic gain regardless of its high attractiveness to predators (Panzacchi *et al.* 2010). This behavior suggests that selection of proper hiding cover within the maternal home range may be a better determinant of fawn survival than selection at the landscape scale. However, presence or absence of predation risk within a specified landscape may also be an important determinant in the selection of a bed-site (Van Moorter *et al.* 2009).

In North America, there has been little published research on bed-site selection by white-tailed deer fawns. Fawns in Iowa selected bed-sites with greater vegetation density above 1m compared to random sites (Huegel *et al*. 1986). In South Dakota, fawns selected bed-sites with greater vertical height of understory vegetation which provided greater visual concealment and more shade (Grovenburg *et al.* 2010). To our knowledge there has been no published study on understanding habitat associated with fawn bed-sites in forested regions of the southeastern United States. In many areas of the Southeast, forests are well structured with a dense understory, providing fawns with dense vegetation with ample height. In addition to providing visual obstruction, this vegetative structure may inhibit air currents from carrying the fawn's scent, which may aid in preventing detection by predators such as coyotes (*Canis latrans*) using olfactory or visual cues (Wells and Lehner 1978).

We quantified microhabitat and macrohabitat features associated with white-tailed deer fawn bed-sites in a longleaf pine (*Pinus palustris*) ecosystem. The microhabitat level reflected short-term decisions and observable behavioral plasticity by the fawn, while the macrohabitat level reflected decisions made by the dam and represented a level at which most land management decisions are made (Barbknecht *et al.* 2011). We compared microhabitat and macrohabitat models of bed-site selection to determine which model best predicted bed-site use.

Methods

Study Area

This study was conducted on Ichauway, the outdoor research facility at the Joseph W. Jones Ecological Research Center (Jones Center) located in Baker County, Georgia. The 11,735-ha research facility is one of the largest privately held tracts of longleaf pine (*Pinus palustris*) forest in the United States. White-tailed deer management objectives on site are to keep the herd well below carrying capacity while maintaining a balanced sex-ratio using selective harvest to influence a diverse age structure (J. W. Jones Ecological Research Center 2012). Spotlight counts and track-counts are conducted yearly to obtain estimates of white-tailed deer and predator abundances across the property.

The climate is characterized by mild, wet, short winters and hot summers with temperatures ranging on average from 11°C during winter to 27°C during summer (Boring 2001). The average annual rainfall is 132 cm. The site is dominated by longleaf pine overstory and associated isolated wetlands. The dominant understory species are old field grasses (e.g., *Andropogon* spp.) on old field sites, and wiregrass (*Aristida beyrichiana*). The Flint River forms 21 km of the eastern property boundary and 24 km of the Ichawaynochaway Creek flows through the middle of the property. Forest management at the Jones Center includes prescribed fire on a 2-year return interval, mechanical removal of hardwoods from the longleaf pine uplands, and longleaf pine restoration on old field sites. Prescribed fire is the primary management tool used to maintain the longleaf pine ecosystem by reducing hardwood encroachment, reducing fuels, and promoting herbaceous cover. Northern bobwhite (*Colinus* *virginianus*) management practices are implemented on approximately half of the property and include supplemental feeding, food plot maintenance, and limited mesopredator removal. Wildlife food plots are planted in brown top millet (*Urochloa ramosa*), cowpea (*Vigna* spp.), corn (*Zea mays*), grain sorghum (*Sorghum bicolor*), Egyptian wheat (*Sorghum* spp.), and winter wheat (*Triticum aestivum*), (Joseph W. Jones Ecological Research Center 2012).

Animal capture and monitoring

Between January and April of 2012, we captured adult does assuming they had been bred during the previous rut. We immobilized does with a mixture of xylazine hydrochloride (Rompun®, 2.2 mg/kg body weight) and Telazol® (4.4 mg/kg body weight) (Kreeger *et al.* 2002) delivered via a CO_2-powered dart gun (JMspecial; Dan-inject inc., Borkop, Denmark). We then fitted each doe with a temperature- and photo-activated vaginal implant transmitter (VIT; Advanced Telemetry Systems, Isanti, MN; Cherry *et al. in press*) and a mortality-sensing VHF radio transmitter with GPS capabilities (G2110D; Advanced Telemetry Systems, Isanti, MN). We reversed the xylazine with tolazoline (1.4 mg/kg body weight) (Kreeger *et al.* 2002) after ≥ 120 minutes. We monitored VIT transmissions using a hand-held 3-element yagi antenna and hand-held portable receiver (TRX-2000S; Wildlife Materials, Murphysboro, IL) weekly following doe capture and then twice daily beginning in May to permit identification of parturition sites and to facilitate rapid fawn capture (Cartensen *et al.* 2003, Cartensen-Powell 2005).

We also captured fawns shortly after birth (hereafter, “opportunistic fawns”), using a thermal infrared camera (FLIR Systems, Inc. Wilsonville, OR) to scan woodlands adjacent to secondary roads at night and responding to reports of observations by Jones Center employees. After locating a fawn, it was captured by hand or with a long-handled landing net. Captured fawns were sexed, aged, weighed, and fitted with elastic, breakaway radio-collars with a VHF transmitter (M4210; Advanced Telemetry Systems, Isanti, MN). We used surgical gloves when handling fawns to minimize human scent transfer. We estimated age of opportunistically captured fawns (days) using hoof growth measurement and umbilicus condition (Brinkman *et al.* 2004) as well as body condition and behavior. We handled all deer under the University of Georgia's Animal Use Proposal A2011 03-009-R2.

Data collection

Beginning the day following capture, we identified fawn bed-sites once per day for the first 2 weeks of life. We estimated that 2 weeks was the maximum age where fawns should be as inclined to "freeze" when alarmed by observer presence rather than "flush" (Jacobsen 1979). We located bed-sites by homing with a 3-element, yagi antenna and hand-held portable receiver and then circling suspected fawn locations. Once we were close enough (<10 meters) to determine the fawn's location or visually observe it, we placed flagging around the location and assigned corresponding bearings and distances to allow later sampling of the bed-site. These methods ensured that observer presence minimally influenced fawns' survival and behavior (Alldredge *et al.* 1991).

To ascertain preferences, we compared bed-sites to random locations for each fawn within its dam's estimated maternal home range. We used ArcGIS 9.3.1 (Environmental Systems Research Institute 2009) and Hawth's Analysis Tools (Beyer 2004) to plot all bed-sites located during the 2-week sampling period for each fawn. We then estimated each fawns' seasonal area of use (SAU) and placed a 100-m buffer around the polygon. Within the buffered area, we generated a number of random points equal to the number of bed-sites we had located for each fawn. We then measured microhabitat characteristics at all bed sites and random points (Table 2.1).

At each bed-site and random point we measured basal area (m^2/ha) using a 10-factor prism. We used a 2.5 m tall vegetation profile board with 0.5-m increments to measure density of understory vegetation (i.e., concealment cover). We placed the board 15 m from the bed-site or random point in the 4 cardinal directions and assigned a number value from 1-5 based upon percentage of obscured segments (1=0-20%, 2=21-40%, 3=41-60%, 4=61-80, 5=81-100%; Nudds 1977). We estimated overstory cover using a spherical densitometer (Geographic Resource Solutions, Arcata, CA) and vertical height of understory vegetation by measuring the median height (centimeters) of the understory vegetation at the estimated bed-site or random location. We calculated a mean measurement for concealment cover and overstory cover from the four cardinal directions. We used ArcGIS 9.3.1 and the land-cover layers in the Jones Center's Geographic Information System to derive macrohabitat attributes for each bed-site and random point (Table 2.1, 2.2). We defined 9 habitat types (Agriculture/wildlife food-plot, urban/built-up, shrub-scrub, young pine, mature pine, hardwood, mixed pine-hardwood, forested wetland, non-forested wetland), two distance variables (distance to edge, distance to road), identified the approximate stand basal area (m^2/ha; 0, <30, 30-60, 60-90, >90) and number of growing seasons since last burn (0, 1, 2, 3, >3) associated with each location.

Statistical Analysis

We created correlation matrices from microhabitat variables to test for pairs of correlated variables ($|r| > 0.60$) (Barbknecht *et al.* 2011), after which highly correlated variables were removed from further statistical analyses. We also performed 2 more separate correlation tests to investigate the relationship between our estimates of understory density at 0.5 m and distance to edge, and vertical height of understory vegetation and distance to edge. Bed-site locations that did not allow us to accurately pair vegetation measurements with our estimates of distance to nearest edge were excluded from analysis.

To assess the influence of both microhabitat and landscape scale variables on bed-site selection, we used logistic regression to produce 2 sets of *a priori* models. We selected variables for each set of models based upon what previous literature determined to be important and used the second order Akaike's Information Criterion (AIC_c) to select the most parsimonious model in each set. We used a Hosmer-Lemeshow goodness-of-fit test to determine if our global models fit the available data ($P > 0.05$ indicated appropriate model fit; Hosmer and Lemeshow 2000). We considered models differing by $\leq 2\ \Delta AIC_c$ from the selected models as competing models (Burnham and Anderson 2000, Grovenburg *et al.* 2010). We then calculated the Akaike weight (w_i) for each model and interpreted w_i as the probability of a model being the best model in the *a priori* set.

We also calculated variable weights as the $\sum w_i$ for each variable to determine variable importance and estimated parameters and unconditional standard errors for important variables in competing models using model averaging (Burnham and Anderson 2000, Conner and Godbois 2003). Through model averaging, we identified the most informative variables because they had confidence intervals (i.e., 1.96 x SE) that did not contain zero. Lastly, using the AICc values from our most-supported microhabitat model and macrohabitat model we calculated and then compared their w_i to determine which spatial scale was a stronger predictor of bed-site selection. We performed all statistical analysis using R 2.15.0 (R Development Core Team 2008).

Results

We implanted 15 adult females with VITs, of which two successfully resulted in the capture of neonates (2 sets of twins). Unsuccessful captures from VITs resulted from equipment malfunction. We also captured 8 fawns opportunistically. The average age at capture for neonates was 2.7 ± 0.57 days ($\bar{x}$ ± SE). From the 12 fawns, we examined a total of 125 bed-sites and 125 paired random sites. The number of bed-sites examined per fawn (10.5 ± 1.2) varied from 3 to 15 due to fawns being captured at different ages and fawns not surviving until the 2-week sampling period had elapsed.

Correlation analyses enabled us to exclude vegetation profile board heights 1.0 m, 1.5 m and 2.0 m from further analysis leaving heights 0.5 m and 2.5 m to be used with the other microhabitat variables in modeling. Also, it also allowed us to identify a significant negative relationship between vertical height of understory vegetation at bed-sites and distance to edge ($|r|$= -0.33, P = 0.0006); and understory density at 0.5 m at bed-sites and distance to edge ($|r|$= -0.20, P = 0.037). Hosmer-Lemeshow goodness-of-fit tests indicated acceptable fit for global models at both the microhabitat and macrohabitat levels (microhabitat: $\chi^2 = 12.42$, P = 0.13, macrohabitat: $\chi^2 = 5.39$, P = 0.71). We developed 2 sets of *a priori* models with 15 models each to define bed-site selection at both levels (Table 2.3 and 2.4).

The microhabitat model with the lowest AIC_c was obtained using basal area, canopy closure, vertical height of vegetation, and understory density at 0.5 m. The weight for this model ($w_i = 0.53$) was approximately 42% greater than the next closest approximating model ($w_i = 0.31$). The macrohabitat model with the lowest AIC_c was obtained using the variable distance to edge. The weight for this model ($w_i = 0.30$) was 53% greater than the next closest approximating model ($w_i = 0.14$). At the microhabitat level, the sum of the w_i for the top 2 models was 0.83

indicating there was a ≥83% chance that one of these models was the best approximating model. The sum of w_i of the top 4 models at the macrohabitat level was 0.70 indicating there was a ≥70% chance one of these models was the best approximating model.

At the microhabitat level the strongest variables were understory density at 0.5 m, vertical height of vegetation, and canopy closure (Table 2.5). The most informative variable at the macrohabitat level was distance to edge (Table 2.6). There was overwhelming support for the microhabitat model relative to the macrohabitat model (microhabitat: w_i =0.999, macrohabitat: w_i =0.001).

Discussion

At the microhabitat level, we determined that taller and denser understory cover, as well as higher shading from canopy closure, were important characteristics at fawn bed-sites. This finding is consistent with other studies on bed-site selection (Huegel *et al.* 1986, VanMoorter *et al.* 2009, Grovenburg *et al.* 2010). Multiple studies have suggested that fawn bed-site selection may largely be a response to predation pressure (Alldredge *et al.* 1991, VanMoorter *et al.* 2009). Following parturition, white-tailed deer fawns are not physically developed and must rely on a hiding strategy to avoid predation. Dense understory vegetation at bed-sites could significantly decrease the probability of visual detection by predators (Grovenburg *et al*. 2010). Concealment for fawns is critical to their survival, especially in the presence of predators such as coyotes (Alldredge *et al.* 1991) and bobcats (*Lynx rufus*) which are their main predators in the southeastern U.S. It seems prudent that bed-sites would be in areas where cover afforded optimal concealment yet did not obstruct vision (Alldredge *et al.* 1991) so fawns could anticipate possible danger. Previous studies have also identified canopy closure as an important variable at fawn bed-sites and reasoned that importance of this may be in providing protection from extreme temperatures (Van Moorter *et al.* 2009).

At the macrohabitat level, bed-sites were within closer proximity to edges in comparison to random sites. Edges provide a variety of cover in the form of increased productivity and structural complexity of vegetation (Said and Servanty 2005, Constible et al. 2006). The significant negative correlation we found between vertical height of understory vegetation, and understory density at 0.5 m at bed-sites with distance to nearest edge would suggest that bed-sites close to edges provided more preferred hiding cover. However, we suggest that fawns' selection for edges also represents a balance between the costs and benefits of accessing hiding cover and risk of predation (Masse and Cote 2012) because edges may increase carnivore efficiency by acting as corridors for movement (Constible *et al.* 2006).

Our most-supported microhabitat model was 99.9% more predictive of fawn bed-site selection than our best landscape model, suggesting that although selection was evident at both scales, measured habitat variables at the microhabitat scale were considerably more important in bed-site selection than were macrohabitat variables. We speculate that this may be due to high-quality forage being sufficiently available at the landscape scale (i.e., the maternal home range). Forest management at the Jones Center includes frequent prescribed burning which promotes high diversity of ground cover and increases nutritional quality of understory plants (Masters *et al.* 1993, Joseph W. Jones Ecological Research Center 2012). Thus, fawns may be able to select for cover at the microhabitat scale without sacrificing the needs of the doe for high quality foraging resources (Barbknecht *et al.* 2011).

Our results emphasize the importance of edges within maternal home ranges of deer in the Southeast while also providing visual concealment and increased shade for fawn bed-sites at the microhabitat level. Further research should also incorporate fawn age as a factor in bed-site selection because preferences related to bed-site selection should change as fawns develop the motor skills necessary to avoid predation by fleeing (Canon and Bryant 1997) and as they forage more.

Conclusions and recommendations

Management practices within forested landscapes of the southeastern U.S. that enhance vertical height of understory vegetation and greater understory density at less than 0.5 m of vegetation height, particularly near edges, would provide neonatal white-tailed deer with abundant hiding cover. In the longleaf pine forest, prescribed fire can help maintain a dense herbaceous understory (Cochrane 2003) to increase availability of hiding cover. Increased canopy closure found in areas on our study site with higher basal area may also provide neonates with more shade. Maximizing access to edge habitat by maintaining a mosaic of habitats would benefit fawns by increasing availability of hiding cover. However, too much emphasis on edge may be detrimental to deer populations due to increased efficiency of carnivore movements. We believe our recommendations are largely applicable throughout the Southeast; however, further investigation is needed on the effect of bed-site selection on neonatal survival.

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Table 2.1. Means and standard errors associated with microhabitat and macrohabitat variables measured at fawn bed-sites and random sites at the Joseph W. Jones Ecological Research Center (Ichauway), Baker County, Georgia, 2012.

	Variable	**Bed-site ($\bar{x}$)**	**SE**	**Random ($\bar{x}$)**	**SE**
Microhabitat level	0.5	4.55	0.07	3.91	0.11
	2.5	2.37	0.11	2.00	0.11
	VH	87.38	5.04	55.30	4.25
	CA	74.40	2.42	69.99	2.54
Macrohabitat level	Edge	23.50	1.97	36.94	3.53
	Road	75.92	5.49	77.06	5.84
	Burn	0.72	0.07	0.68	0.07

Table 2.2. Percent of fawn bed-site and random locations associated with categorical macrohabitat variables at the Joseph W. Jones Ecological Research Center (Ichauway), Baker County, Georgia, 2012.

Variable class		**Bed-site**	**Random**
Landcover	Agriculture/Food plot	4.0	8.8
	Forested Wetland	4.0	9.6
	Hardwood	21.6	10.4
	Mixed pine-hardwood	25.6	33.6
	Mature pine	40.0	32.0
	Shrub/scrub	4.0	2.4
	Urban/Built-up	0.8	1.6
	Non-forested Wetland	0.0	0.8
	Young pine	0.0	0.8
Basal Area (m^2/ha)	0	8.8	13.6
	<30	19.2	8.8
	30-60	19.2	14.4
	60-90	36.0	40.0
	>90	16.8	23.2

Table 2.3. Microhabitat variable combinations used in logistic regression models to predict probability of a site being used as a bed-site at the Joseph W. Jones Ecological Research Center (Ichauway), Baker County, Georgia, 2012.[1]

Model covariates[a]	***k***[b]	**AICc**[c]	**Δ**[d]	w_i[e]
BA+CA+VH+0.5	5	307.69	0.00	0.528
BA+CA+VH+0.5+2.5	6	308.78	1.09	0.306
CA+VH+0.5	4	311.80	4.11	0.068
BA+CA+VH	4	312.69	5.00	0.043
BA+CA+VH+2.5	5	313.02	5.33	0.037
BA+CA+0.5	4	316.13	8.44	0.008
BA+VH+0.5+2.5	5	317.06	9.37	0.005
BA+VH+0.5	4	317.34	9.65	0.004
2.5	2	323.06	15.37	<0.001
0.5	2	323.57	15.88	<0.001
0.5+2.5	3	323.76	16.07	<0.001
VH	2	324.47	16.78	<0.001
BA	2	341.68	33.99	<0.001
CA	2	346.04	38.35	<0.001
Intercept	1	346.59	38.90	<0.001

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[1] [a] BA=Basal area, CA=canopy closure, VH=vertical height of vegetation, 0.5=understory density at 0.5 m, 2.5= understory density at 2.5 m

[b] Number of variables

[c] Akaikes Information Criterion

[d] Difference in AIC relative to minimum AIC

[e] Akaike weight (likelihood/sum of all model likelihoods)

Table 2.4. Macrohabitat variable combinations used in logistic regression models to predict probability of a site being used as a bed-site at the Joseph W. Jones Ecological Research Center (Ichauway), Baker County, Georgia, 2012.[2]

Model covariates	***k***[a]	**AICc**[b]	Δ[c]	w_i[d]
Edge	2	339.19	0.00	0.305
Edge + Burn	3	340.68	1.49	0.145
Edge + Basal area	3	340.87	1.68	0.132
Edge + Road	3	341.09	1.90	0.118
GLOBAL	14	341.46	2.27	0.098
Edge + Road + Burn	3	342.55	3.36	0.057
Edge + Burn + Basal area	4	342.58	3.39	0.056
Edge + Road + Basal area	4	342.77	3.58	0.051
Edge + Road + Burn + Basal area	5	344.53	5.34	0.021
Basal area + Habitat	11	346.06	6.87	0.010
Intercept	1	348.59	9.40	0.003
Habitat	10	349.13	9.94	0.002
Basal area	2	349.41	10.22	0.002
Burn	2	350.47	11.28	0.001
Road	2	350.60	11.41	0.001

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[2] [a] Number of variables
[b] Akaikes Information Criterion
[c] Difference in AIC relative to minimum AIC
[d] Akaike weight (likelihood/sum of all model likelihoods)

Table 2.5. Microhabitat average parameter estimates, unconditional standard errors, 95% confidence intervals, and sum of Akaike weights of predictor variables found in approximating models of fawn bed-sites at the Joseph W. Jones Ecological Research Center (Ichauway), Baker County, Georgia 2012.

Variable	**Estimate**	**SE**	**Lower95%CI**	**Upper95%CI**	$\sum w_i$
Basal area	-0.007	0.004	-0.014	0.000	0.834
Canopy closure	0.016	0.006	0.005	0.027	0.834
Vertical height	0.008	0.003	0.003	0.014	0.834
0.5 m	0.331	0.153	0.031	0.630	0.834
2.5 m	0.004	0.038	-0.071	0.080	0.306

Table 2.6. Macrohabitat average parameter estimates, unconditional standard errors, 95% confidence intervals, and sum of Akaike weights of predictor variables found in approximating models of fawn bed-sites at the Joseph W. Jones Ecological Research Center (Ichauway), Baker County, Georgia, 2012.

Variable	**Estimate**	**SE**	**Lower95%CI**	**Upper95%CI**	$\sum w_i$
Edge	-0.010	0.005	-0.019	-0.001	0.700
Burn	0.018	0.028	-0.037	0.073	0.145
Basal area	-0.008	0.015	-0.038	0.022	0.132
Road	0.000	0.000	0.000	0.001	0.118

CHAPTER 3

HABITAT ASSOCIATED WITH WHITE-TAILED DEER FAWN LOCATIONS IN A LONGLEAF PINE ECOSYSTEM

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[1] Nelson, M. A., M. J. Cherry, R. J. Warren, and L. M. Conner. To be submitted to *The American Midland Naturalist.*

Abstract: Habitat quality has a significant effect on the life-history of wild animals and may be particularly important to white-tailed deer (*Odocoileus virginianus*) fawns by providing cover from predators. Few studies have investigated habitat selection in ungulates prior to recruitment. Therefore during the summers of 2011 and 2012, we investigated habitat components important to white-tailed deer fawns in southwestern Georgia. We monitored radio-collared newborn fawns from capture until fall recruitment to determine the habitats associated with their locations. We then used logistic regression and an information theoretic approach to assess the influence of habitat variables on the probability of a site being used by a fawn. Results suggested that distance to edge, edge density, basal area, and distance to mixed pine-hardwood habitat, were important predictors of fawn locations. Land management practices that emphasize access to edges by maintaining high habitat heterogeneity and the higher canopy closure typical of our study site through manipulation of basal area would provide fawns with more preferred habitat. We also suggest that further investigation is needed to investigate the importance of basal area to fawn use and to further understand habitat selection by lactating does and their fawns.

Introduction

Habitat quality has been identified as a significant determinant in the life-history traits of many herbivore species (Pettorelli et al. 2005). Thus, preferred habitats should provide essential resources; however, prey animals also may select habitats to avoid the risk of predation (Bowyer et al. 1998). White-tailed deer (*Odocoileus virginianus*) fawns exhibit hiding behavior, during which they spend up to 80% of their time resting in locations approximately 100m away from their dam (Huegel et al. 1986) while relying on cryptic coloration and understory vegetation to avoid detection by predators. Therefore, quality habitat for fawns must provide forage for the dam within close proximity to hiding cover for the fawn (Huegel et al. 1986). Although frequency of movement and selection of hiding cover is chosen by the fawn, selection takes place within the maternal home range; therefore habitat available to the fawn is dependent on the mother's habitat selection (Van Moorter et al. 2009).

Few studies have investigated habitat selection of ungulates prior to dispersal or recruitment. Knowledge of fawn behavior could be important in development of effective game management strategies if it affects population processes (Riley and Dood 1984). In a study on habitat selection by neonatal black-tailed deer (*O. hemionus columbianus*) in California, Bowyer et al. (1998) found that fawn habitat was more influenced by thermal environment and nutritional demands of lactating females rather than by predation risk. In a study of white-tailed deer fawn habitat selection and its effect on fawn survival in Pennsylvania, Vreeland et al. (2004) was unable to detect habitat characteristics important to fawn survival within the home range scale, suggesting that landscape-scale characteristics may be more important. Habitat use by white-tailed deer fawns is poorly understood in the densely vegetated southeastern United States (Kilgo et al. 2010), and to our knowledge no studies have investigated fawn habitat selection within this region.

Understanding spatial movements and habitat selection of fawns will allow for more informed forest management. Furthermore, deer management programs should consider all components of a deer's life cycle to best manage herd size and determine management practices that could potentially alter mortality rates (Huegel 1985). Because there are inadequate data available on fawn spatial movements and behavior within southeastern forested ecosystems, we quantified characteristics associated with white-tailed deer fawn habitat in a longleaf pine (*Pinus palustris*) ecosystem during 2011 and 2012.

Study Area

This study was conducted on Ichauway, the outdoor research facility at the Joseph W. Jones Ecological Research Center (Jones Center) located in Baker County, Georgia. The 11,735-ha research facility is one of the largest privately held tracts of longleaf pine (*Pinus palustris*) forest in the United States. White-tailed deer management objectives on site are to keep the herd well below carrying capacity while maintaining a balanced sex-ratio using selective harvest to influence a diverse age structure (J. W. Jones Ecological Research Center 2012). Spotlight counts and track-counts are conducted yearly to obtain estimates of white-tailed deer and predator abundances across the property.

The climate is characterized by mild, wet, short winters and hot summers with temperatures ranging on average from 11°C during winter to 27°C during summer (Boring 2001). The average annual rainfall is 132 cm. The site is dominated by longleaf pine overstory and associated isolated wetlands. The dominant understory species are old field grasses (e.g., *Andropogon* spp.) on old field sites, and wiregrass (*Aristida beyrichiana*). The Flint River forms 21 km of the eastern property boundary and 24 km of the Ichawaynochaway Creek flows through the middle of the property. Forest management at the Jones Center includes prescribed fire on a 2-year return interval, mechanical removal of hardwoods from the longleaf pine uplands, and longleaf pine restoration on the old field sites. Prescribed fire is the primary management tool used to maintain the longleaf pine ecosystem by reducing hardwood encroachment, reducing fuels, and promoting herbaceous cover. Northern bobwhite (*Colinus virginianus*) management practices are implemented on approximately half of the property and include supplemental feeding, food plot maintenance, and limited mesopredator removal. Wildlife food plots are planted in brown top millet (*Urochloa ramose*), cowpea (*Vigna* spp.), corn (*Zea mays*), grain sorghum (*Sorghum bicolor*), Egyptian wheat (*Sorghum* spp.), and winter wheat (*Triticum aestivum*), (Joseph W. Jones Ecological Research Center 2012).

Methods

Deer capture, handling, and monitoring

During 2011 and 2012, we captured fawns shortly after birth using a thermal infrared camera (FLIR Systems, Inc. Wilsonville, OR) to scan woodlands adjacent to primary and secondary roads at night during May - August. We also captured fawns by responding to reports of sightings by Jones Center employees. During January -April of 2012, we captured adult does assuming they had been bred during the previous rut. We immobilized does with a mixture of xylazine hydrochloride (Rompun®, 2.2 mg/kg body weight) and Telazol® (4.4 mg/kg body weight) (Kreeger et al. 2002) delivered via a CO_2-powered dart gun (JMspecial; Dan-inject inc., Borkop, Denmark). We then fitted each doe with a temperature- and photo-activated vaginal implant transmitter (VIT; Advanced Telemetry Systems, Isanti, Minn; Cherry at al. in press) and a mortality-sensing VHF radio transmitter with GPS capabilities (G2110D; Advanced Telemetry Systems, Isanti, Minn). We reversed the xylazine with tolazoline (1.4 mg/kg body weight; Kreeger et al. 2002) after ≥ 120 minutes.

We monitored VIT transmissions using a 3-element yagi antenna and hand-held portable receiver (TRX-2000S; Wildlife Materials, Murphysboro, Ill) weekly following doe capture and then twice daily beginning in May to permit identification of parturition sites and to facilitate rapid fawn capture (Cartensen et al. 2003, Cartensen-Powell 2005). Captured fawns were sexed, aged, weighed, and fitted with elastic, breakaway radio-collars with a VHF transmitter (M4210; Advanced Telemetry Systems, Isanti, MN). We used surgical gloves when handling fawns to minimize human scent transfer. We determined age of opportunistically captured fawns (days) using hoof growth measurement, umbilicus condition (Brinkman et al. 2004), body condition, and behavior. We handled all deer under the University of Georgia's Animal Use Proposal A2011 03-009-R2.

Beginning the day following capture, we monitored fawns for survival and triangulated fawn locations by recording GPS locations and compass bearings ≥2 times daily. We ceased monitoring fawns during October of each year when we considered them to be recruited into the fall population. In 2012, to satisfy a separate research objective (Chapter 4), we also visually observed fawns and recorded bed-sites from a distance of <10m once daily during their first 2 weeks of life.

Statistical Analysis

We estimated Universal Transverse Mercator (UTM) coordinates of radio-telemetry locations using the program LOAS (Ecological Software Solutions LLC) and removed estimated locations with error ellipses >5 ha. Due to demands on personnel, there were more daytime (68%) than nighttime (32%) locations. To determine if daytime and nighttime locations could be pooled we estimated the distance from each fawn's locations to all habitat features of interest and performed a paired t-test to determine if distances differed between daytime and nighttime locations. Significant differences would necessitate analyzing daytime and nighttime data separately.

Using each fawn's estimated radio-telemetry locations, we calculated a minimum convex polygon (MCP) in ArcGIS 9.3.1 (ESRI 2009) with Hawth's Analysis Tools (Beyer 2004) and placed a 100-m buffer around it. Within the MCP and buffered area, we generated random points equal to the number of radio-telemetry locations. Using ArcGIS 9.3.1 and landcover layers in the Jones Center's Geographic Information Systems database, we derived habitat variables for radio-telemetry locations and random locations. We calculated the distance from fawn and random locations to each of 8 delineated habitat types (agriculture/food plot, hardwood, mixed pine-hardwood, pine, urban/barren, shrub/scrub, wetland, young pine) and recorded the stand basal area (m^2/ha) associated with each location separated into five groups (0, <30, 30-60, 60-90, >90). We defined hard edges as edges between forested and non-forested habitats. We delineated all hard edges and calculated edge density for each point in FRAGSTATS 4.1 using a moving window analysis within a 30 m x 30 m raster cell buffered by 250 m (McGarigal et al. 2012). Calculation of edge density (m/ha) quantified the amount of forested/non-forested edge and standardized it by landscape area (Glennon and Porter 1999). Finally, distance to nearest edge, which included edges between all 8 habitat types, and distance to nearest road were calculated for each point.

To assess the influence of predictor variables on fawn habitat selection, we used logistic regression to evaluate a set of 20 a priori models. We selected variables for our model set based upon what previous literature determined to be biologically important to a fawn. We conducted a Hosmer-Lemeshow goodness-of-fit test to determine global model fit ($P > 0.05$ indicated acceptable fit; Hosmer and Lemeshow 2000) and then used second order Akaike's Information Criterion (AIC_c) to select the most parsimonious model. We considered models differing by ≤ 2 ΔAIC from the best model as competing models (Burnham and Anderson 2000, Grovenburg et al. 2010). We calculated the Akaike weight (w_i) for each model and interpreted w_i as the probability of the *i*th model being the best model in the a priori set.

We also calculated variable weights as the $\sum w_i$ for each variable to determine variable importance. We used model averaging to estimate parameters and unconditional standard errors for important variables included in competing models (Burnham and Anderson 2000, Conner and Godbois 2003). Through model averaging, we identified informative variables as those with 95% confidence intervals that did not include zero. We performed all statistical analysis using R 2.15.0 (R Development Core Team 2008).

Results

We opportunistically captured 12 fawns during 2011 and 8 fawns during 2012. During 2012, we implanted 15 adult females with VITs, of which 2 successfully resulted in the capture of neonates (2 sets of twins). Unsuccessful captures from VITs resulted from equipment failure and malfunction. The average age at capture for neonates was 5.2 ± 0.7 days ($\bar{x} \pm$ S.E.) during 2011 and 2.7 ± 0.6 days during 2012. From the 24 monitored neonates we collected 1,469 telemetry locations with an average error ellipse of 0.31 ± 0.02 ha. Results of the paired t-tests revealed no significant difference ($P > 0.05$ in all cases) between daytime and nighttime points regarding distance to habitat types.

The Hosmer-Lemeshow goodness-of-fit test suggested adequate fit ($\chi^2=13.90$, $P=0.08$) for our global model. Of our 20 a priori models (Table 3.1), the model with the lowest AIC_c was obtained using variables distance to edge, basal area, edge density, distance to agriculture, distance to hardwood, distance to mix pine-hardwood, distance to shrub-scrub and distance to urban/barren. The weight for this model ($w_i = 0.56$) was approximately 63% greater than either of the next closest approximating models. The sum of the w_i for the top 2 models was 0.78 indicating there was a ≥78% chance one of these models was the best approximating model. The most informative variables were distance to soft edge, hard edge density, basal area, and distance to mixed pine-hardwood habitat (Table 3.2).

Discussion

The average parameter estimates and their unconditional standard errors revealed 5 variables that had parameter estimates that convincingly differed from zero. These results suggested that habitat close to edges, positively associated with edge density and basal area, and away from edges of mixed pine-hardwood habitat were strongly associated with fawn locations (Table 3.2).

Fawn locations were negatively associated with habitat edges and positively associated with edge density. Habitat edges offer a good interspersion of cover and forage for deer (Said and Servanty 2005, Constible et al. 2006, Torres et al. 2011) and may be beneficial for fawns by providing important hiding cover. Fawn bed-sites located near habitat edges on our study site have been significantly correlated with the availability of tall and dense understory vegetation (Chapter 2.). However, we suggest that high edge density associated with fawn locations also represents a balance between the costs and benefits of accessing hiding cover and risk of predation (Masse and Cote 2012) because edges may increase carnivore efficiency by acting as corridors for movement (Constible et al. 2006).

There was a positive relationship between basal area and fawn use. We believe that the greater basal area on our study site is associated with greater canopy closure and speculate that these areas were used because they provided shade. Previous studies have suggested that shade was an important component of fawn habitat by providing protection from high temperatures (Van Moorter et al. 2009). However, as with fawns' use of edge there may also be costs associated with habitat in areas of greater basal area. Although high canopy closure may provide shelter against extreme temperatures, it may mean less food (Mysterud and Ostbye 1999). Longleaf pine ecosystems are typically managed for low basal area, which may be unique to managed pine ecosystems of the Southeast. More research into the importance of this variable within this region may be beneficial.

Fawns used habitat farther from edges of mixed pine-hardwood forests than any other habitat type. These results may represent identification of a correlated variable important to fawn habitat that was not within the scope of our available data. Also likely is that mixed pine-hardwood forests at the Jones Center represent an area with a dense understory that in some situations is impenetrable by prescribed fire (Loudermilk et al. 2011). Although this represents an area that could provide hiding cover for fawns, Cochrane (2003) suggested that the dense understory of mixed pine-hardwood forests would promote high prey populations to benefit bobcats (*Lynx rufus*). Bobcats are known predators of fawns at the Jones Center (Howze 2009, Chapter 4); therefore, fawns may have stayed farther away from this habitat as a predator avoidance behavior.

Although our analysis did not discriminate between needs of mother and young (Bowyer et al. 1998), based on previous research, it is clear that a trade-off exists between predation risk for fawns and availability of forage for lactating does. Mothers of roe deer (*Capreolus capreolus*) fawns have been known to select habitat types granting the highest energetic gain regardless of predation risk (Panzacchi et al. 2010). Riley and Dood (1984) found that forage area used by mule deer does influenced cover use by their fawns. On our study site, our results suggested that high access to habitat edges may provide greater availability of hiding cover for fawns and possible forage for does, but also may represent areas with increased predation risk. Fawns’ selection for greater basal area can represent areas with increased protection from extreme temperatures, but may also lack optimal food resources.

Management Implications

Management practices within pine ecosystems of the southeastern United States that promote preferred habitat characteristics for fawns should be encouraged. These include manipulation of understory vegetation through prescribed fire and manipulation of canopy closure through selective overstory thinning. Fawn association with well-defined edge habitat suggests that maintaining habitat heterogeneity in managed forests may be important in providing more hiding cover. Although fawns locations in our study were strongly associated with increased basal area, more investigation may be needed before the relationship between fawn use and basal area is fully understood because basal areas of forests at the Jones Center are maintained relatively low. Finally, we think studies that attempt to identify habitat selection of fawns and their dam within the Southeast (i.e., quantifying the influence of does over their fawn's habitat selection) would be valuable.

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Table 3.1. Variable combinations used in logistic regression models to predict probability of a site being used by a fawn at the Joseph W. Jones Ecological Research Center (Ichauway), Baker County, Georgia, 2011-2012[3].

Model Covariates[a]	k[b]	**AIC_c**[c]	**ΔAIC**[d]	w_i[e]
E + ED + BA + AG + PH + H + SC + U	9	3939.12	0.00	0.565
E + ED + BA + PH + H + SC + U	8	3941.10	1.98	0.210
GLOBAL	13	3941.25	2.13	0.195
E + ED + BA + AG + PH + H + U	8	3945.10	5.98	0.028
E + ED + AG + PH + H + SC + U + W + YP	10	3952.15	13.03	0.001
E + ED + AG + PH + H + SC + U	8	3954.10	14.98	<0.001
E + R + ED + AG + PH + H + SC + U	9	3956.12	17.00	<0.001
ED	2	4035.01	95.88	<0.001
AG	2	4045.01	105.88	<0.001
PH	2	4045.01	105.88	<0.001
P	2	4055.01	115.88	<0.001
R	2	4066.01	126.88	<0.001
E	2	4068.01	128.88	<0.001
SC	2	4074.01	134.88	<0.001
Intercept	1	4077.00	137.88	<0.001
H	2	4078.01	138.88	<0.001
BA	2	4079.01	139.88	<0.001
W	2	4088.01	148.88	<0.001
YP	2	4090.01	150.88	<0.001
U	2	4092.01	152.88	<0.001

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[3] [a] E= Distance to edge, ED= Edge density, R=Distance to road, BA=Basal area, AG=Agriculture, PH=Mixed pine-hardwood, H=Hardwood, P=Pine, SC=Shrub-scrub, U=Urban, YP=Young pine, W=wetland

[b] Number of variables

[c] Akaikes Information Criterion

[d] Difference in AIC relative to minimum AIC

[e] Akaike weight (likelihood/sum of all model likelihood)

Table 3.2. Average parameter estimates, unconditional standard errors, 95% confidence intervals, and sum of variable weights (**$\sum w_i$**) of predictor variables found in strongest competing models associated with fawn locations at the Joseph W. Jones Ecological Research Center (Ichauway), Baker County, Georgia, 2011-2012.

Variable	**Estimate**	**SE**	**Lower95%CI**	**Upper95%CI**	**$\sum w_i$**
Distance to Edge	-0.003	0.0008	-0.005	-0.002	0.775
Basal Area	0.101	0.0247	0.053	0.150	0.775
Edge density	0.004	0.0007	0.003	0.005	0.775
Hardwood	0.001	0.0002	0.000	0.001	0.775
Mixed pine-hardwood	0.004	0.0005	0.003	0.005	0.775
Shrub/scrub	-0.001	0.0002	-0.001	0.000	0.775
Urban/barren	-0.001	0.0007	-0.002	0.001	0.775
Agriculture/food plot	-0.001	0.0003	-0.001	0.000	0.565

CHAPTER 4

SURVIVAL AND CAUSE-SPECIFIC MORTALITY OF WHITE-TAILED DEER FAWNS IN A LONGLEAF PINE ECOSYSTEM IN SOUTHWESTERN GEORGIA

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[1] Nelson, M. A., M. J. Cherry, M. B. Howze, R. J. Warren, and L. M. Conner. Submitted to the *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies*

Abstract: Managing white-tailed deer (Odocoileus virginianus*)* populations requires an understanding of fawn survival and cause-specific mortality. In the past several decades, anthropogenic influences have enabled coyotes (Canis latrans) to expand their range into the eastern United States. Coyotes are thought to be a significant source of fawn mortality and can be a limiting factor in some deer populations. Therefore, we captured and radio-collared 47 fawns to quantify their survival and cause-specific mortality at the Joseph W. Jones Ecological Research Center in southwestern Georgia during 2007, 2008, 2011 and 2012. Fawn survival to 20 weeks of age (i.e., opening of firearms season) was 29.0%. Coyote predation accounted for 52.4% of all fawn mortalities and 68.7% of all fawn predation events. Our study provides further evidence that coyote predation is a substantial source of fawn mortality in the southeastern U.S.

Key words: Coyote, Fawn, Predation, Recruitment, White-tailed deer

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Survival of newborn fawns is affected by their health at birth, food availability, availability of hiding cover, condition of the dam, predator abundance, and other factors (Jackson et al. 1972). Numerous investigators have documented losses of deer fawns to predation (Vreeland et al. 2004, Lomas and Bender 2007, Kilgo et al. 2012) which is typically the main source of mortality across studies and landscapes (Roberts 2007). In the southeastern United States, a number of studies have been confined to areas where coyotes (Canis latrans) were absent (Epstein et al. 1983, Boulay 1992, Roberts 2007). Due to anthropogenic influences, within the last few decades coyotes have expanded their range into the eastern United States (Hill et al. 1987). This has required white-tailed deer (Odocoileus virginianus) herds in the Southeast to cope with increased predation pressure from coyotes (Kilgo et al. 2012). Coyote predation on fawns may be limiting growth of certain deer populations in the Southeast (Kilgo et al. 2010), especially when white-tailed deer populations are below carrying capacity (Ballard et al. 2001).

Coyotes are a generalist species and, when available, fawns can be a major food item in their diets in the Southeast (Thornton 2004, Schrecengost et al. 2008, Howze 2009). Blanton and Hill (1989) found that in areas with a high deer density, fawns were a staple in coyote diets; whereas, in areas with a low deer density, fawns were less abundant in their diets. These results suggest that coyotes readily exploit seasonal food items as they become available, and may selectively prey on fawns rather than other less energetically beneficial prey items (Blanton and Hill 1989, Schrecengost et al. 2008). Managing white-tailed deer requires an understanding of fawn survival and sources of mortality (Pusateri Burroughs et al. 2006). Therefore, we quantified fawn survival and cause-specific mortality during 2007-2008 and 2011-2012 in southwestern Georgia.

Study Area

This study was conducted on Ichauway, the outdoor research facility at the Joseph W. Jones Ecological Research Center (Jones Center) located in Baker County, Georgia. The 11,735-ha research facility is one of the largest privately held tracts of longleaf pine (Pinus palustris) forest in the United States. White-tailed deer management objectives on site are to keep the herd well below carrying capacity while maintaining a balanced sex-ratio using selective harvest to influence a diverse age structure (J. W. Jones Ecological Research Center 2012). Spotlight counts and track-counts are conducted yearly to obtain estimates of white-tailed deer and predator abundances across the property.

The climate is characterized by mild, wet, short winters and hot summers with temperatures ranging on average from 11°C during winter to 27°C during summer (Boring 2001). The average annual rainfall is 132 cm. The site is dominated by longleaf pine overstory and associated isolated wetlands. The dominant understory species are old field grasses (e.g., *Andropogon* spp.) on old field sites, and wiregrass (*Aristida beyrichiana*). The Flint River forms 21 km of the eastern property boundary and 24 km of the Ichawaynochaway Creek flows through the middle of the property. Forest management at the Jones Center includes prescribed fire on a 2-year return interval, hardwood removal from the longleaf pine uplands, and longleaf pine restoration. Prescribed fire is the primary management tool used to maintain the longleaf pine ecosystem by reducing hardwood encroachment, reducing fuels, and promoting herbaceous cover. Northern bobwhite (*Colinus virginianus*) management practices are implemented on approximately half of the property and include supplemental feeding, food plot maintenance, and limited mesopredator removal. Wildlife food plots are planted in brown top millet (*Urochloa ramose*), cowpea (*Vigna* spp.), corn (*Zea mays*), grain sorghum (*Sorghum bicolor*), Egyptian wheat (*Sorghum* spp.), and winter wheat (*Triticum aestivum*), (Joseph W. Jones Ecological Research Center 2012).

Methods

During 2007, 2008, 2011, and 2012, we captured fawns shortly after birth using a thermal infrared camera (FLIR Systems, Inc. Wilsonville, OR) to scan woodlands adjacent to primary and secondary roads at night from May through August. We also captured fawns by responding to reports of fawn sightings by Center employees and, during 2012, with the aid of vaginal implant transmitters. Between January and April 2012, we captured adult does assuming they had been bred during the previous rut. We immobilized does with a mixture of xylazine hydrochloride (Rompun®, 2.2 mg/kg body weight) and Telazol® (4.4 mg/kg body weight) (Kreeger et al. 2002) delivered via a CO_2-powered dart gun (JMspecial; Dan-inject inc., Borkop, Denmark). We fitted each doe with a temperature- and photo-activated vaginal implant transmitter (VIT; Advanced Telemetry Systems, Isanti, Minn; Cherry at al. in press) and a mortality-sensing VHF radio transmitter with GPS capabilities (G2110D; Advanced Telemetry Systems, Isanti, Minn). We reversed the xylazine with tolazoline (1.4 mg/kg body weight; (Kreeger et al. 2002) $\geq$ 120 minutes post-injection.

We monitored VIT transmissions using a hand-held 3-element yagi antenna and hand-held portable receiver (TRX-2000S; Wildlife Materials, Murphysboro, Ill) weekly following doe capture and then twice daily beginning in May to identify parturition sites and to facilitate rapid fawn capture (Cartensen et al. 2003, Cartensen-Powell 2005). Captured fawns were sexed, aged, weighed, and fitted with elastic, breakaway radio-collars with a VHF transmitter (M4210; Advanced Telemetry Systems, Isanti, MN). We used surgical gloves when capturing fawns to minimize human scent transfer. We estimated age of opportunistically captured fawns (days) using hoof growth measurement and umbilicus condition (Brinkman et al. 2004) as well as body condition and behavior. We handled all deer under the University of Georgia's Animal Use Proposal A2011 03-009-R2.

The greatest probability of mortality occurs during the first few weeks of a fawn's life (Cook et al. 1971, Howze 2009, Kilgo et al. 2012). Therefore, we intensified monitoring efforts during that time to ensure accurate estimation of time-of-death and facilitate identification of mortality sources. From capture until approximately 6 weeks of age, we monitored fawn survival $\geq$ 2 times per day. After 6 weeks of age, we monitored fawns $\geq$ 5 times per week. We ceased monitoring fawns during October of each year when we considered them to be recruited into the fall population. During 2012, to satisfy a separate research objective, we also visually observed fawns from approximately 10 meters during their first 2 weeks of life.

We identified cause-specific mortality using field methods based on identification of signs of trauma, external hemorrhaging, scattering of remains, and caching behavior (White 1973, Garner et al 1976, Epstein et al. 1983). Due to the intensity of our monitoring efforts we believe there was little possibility that our determination of cause of death was based upon scavenging rather than predation (Kilgo et al. 2012). To support this, Kilgo et al. (2012) found that DNA identification confirmed all determinations of probable coyote predation in fawns based on collected field evidence. The two main predators of white-tailed deer fawns on our site were coyotes and bobcats (Lynx rufus) (Howze 2009). Therefore, we classified all predation mortalities as caused by “coyote”, “bobcat”, or “unknown predator”. Mortalities not classified as predation events were classified as “other”, which included deaths attributed to emaciation, or an unknown cause.

We estimated fawn survival from capture until recruitment into the fall population (i.e., opening of firearms hunting season) using the Kaplan-Meier method modified for staggered entry based on their birth date (Pollock et al. 1989) and right-censored fawns that experienced premature transmitter failure (Kane et al. 2007). To determine if we could pool survival estimates obtained during different years, we compared years with the least and greatest survival estimates using a χ^2 test (Pollack et al. 1989) in SAS 9.3 (SAS Institute Inc., Cary, NC, USA).

Results

We captured and radio-collared 47 fawns during the study. Five fawns were captured using VITs during 2012. There was minimal variation in average age at capture of neonates among years (Table 1). During 2007 and 2011, two fawns (four fawns total) were right censored because they prematurely shed their radio-collars.

Kaplan-Meier survivorship did not vary (χ^2=2.32, P=0.128) between the year with the greatest (2011) and least (2012) survival estimates (Table 1.). Our pooled survival estimate was 29.0% ± 9.3% ($\bar{x}$ ± SE; Figure 1). Coyotes were the primary source of mortality. Of 21 mortality events, coyotes were responsible for 11, bobcats for 2, unknown predator for 3, and other for 5. Of the mortality events classified as other, 1 was caused by emaciation and we were not able to determine a mortality cause for 4. Predation accounted for 76.2% of all fawn mortalities with coyotes being responsible for 68.7% of those predation events; coyotes killed 52.4% of all fawns that died during our study.

Discussion

In most studies where coyotes occur, coyote predation has been identified as the most important source of white-tailed deer fawn mortality (Blanton and Hill 1989, Ballard et al. 1999, Pusateri Burroughs et al. 2006). Similar to other studies in the Southeast, coyote predation had the greatest influence on fawn survival, accounting for 52.4% of all mortalities on our study site. In an exurban area of Alabama, Saalfeld and Ditchkoff (2007) found that coyote predation was the leading cause of fawn mortality, accounting for 41.7% of fawn deaths. In the Coastal Plain of South Carolina, Kilgo et al. (2012) found that coyote predation definitively accounted for 37% -80% of all fawn mortalities. The results of our study represent another important data point demonstrating the importance of coyotes in the dynamics of white-tailed deer populations in the southeastern United States.

In contrast, bobcats were responsible for only 9.5% of mortalities. Studies of bobcat food habits suggest that in areas where bobcats and coyotes are sympatric, white-tailed deer are not a major component of bobcat diets (Godbois 2003, Thornton et al. 2004, VanGilder 2008). Similar to our results, a recent study in South Carolina reported that bobcat predation only accounted for 8.5% of fawn mortalities with coyote predation being the dominant cause of mortality (Kilgo et al. 2012). Of the studies that have documented levels of bobcat predation in areas of the Southeast where coyotes were not present; Epstein et al. (1983) reported 29% mortality, Boulay (1992) reported ≥60% mortality and Roberts (2007) reported 57-82% mortality, which suggests that coyotes may affect bobcat use of fawns.

Due to lack of evidence at mortality sites, we could not determine the cause of 18.8% of fawn predations. However, we speculate most of these predations were canid predation, either coyote or perhaps feral dogs (Canis familiaris) because in the majority of these instances no carcass was found and we observed only tooth marks on a radio-collar (Pusateri Burroughs et al. 2006).

During capture, four fawns showed signs of red imported fire ant (Solenopsis spp.) bites. Of those fawns, two subsequently died shortly thereafter of unknown causes. Although the role of fire ants in the deaths of these two fawns is uncertain, it has been hypothesized that fire ants may locally impact white-tailed deer recruitment (Allen et al. 1997). Irritation from fire ant stings may cause neonatal fawns to increase their movements which could make them more susceptible to predation during the most critical period in their lives (Mueller and Forbes 2001).

Most (66.7%) mortalities occurred within the first 2 weeks of life, and all but two mortalities occurred during the first 30 days of life. Further, 82% of coyote predations, 100% of bobcat predations and all unknown predations occurred during the first 30 days of life. These results support the findings of other studies suggesting that white-tailed deer fawns are most vulnerable to predation during their first few weeks of life (Whittaker and Lindzey 1999, Pusateri Burroughs et al. 2006, Kilgo et al. 2012). Also consistent with previous studies, only 9.5% of predations occurred after 30 days of life suggesting that once fawns survive their first few weeks of life, predation mortality is low and survival until recruitment into the fall population is relatively high (Pusateri Burroughs et al. 2006).

Management Implications

The impact of coyotes on deer populations in the Southeast may depend on deer population density (Kilgo et al. 2012). The estimated deer density at the Jones Center is 8.8 deer/km^2 (Joseph W. Jones Ecological Research Center 2012). This density is well below biological carrying capacity, thus the deer population may be more vulnerable to suppression through predation (Ballard et al. 2001). Our research demonstrates that coyote predation can be a major source of mortality in neonatal white-tailed deer during their first few weeks of life. Because data on the long-term effects of coyote predation on white-tailed deer are limited, more research is needed to clarify this relationship. When predators are limiting white-tailed deer populations, reducing harvest of females may be necessary to offset losses to coyote predation (Kilgo et al. 2012).

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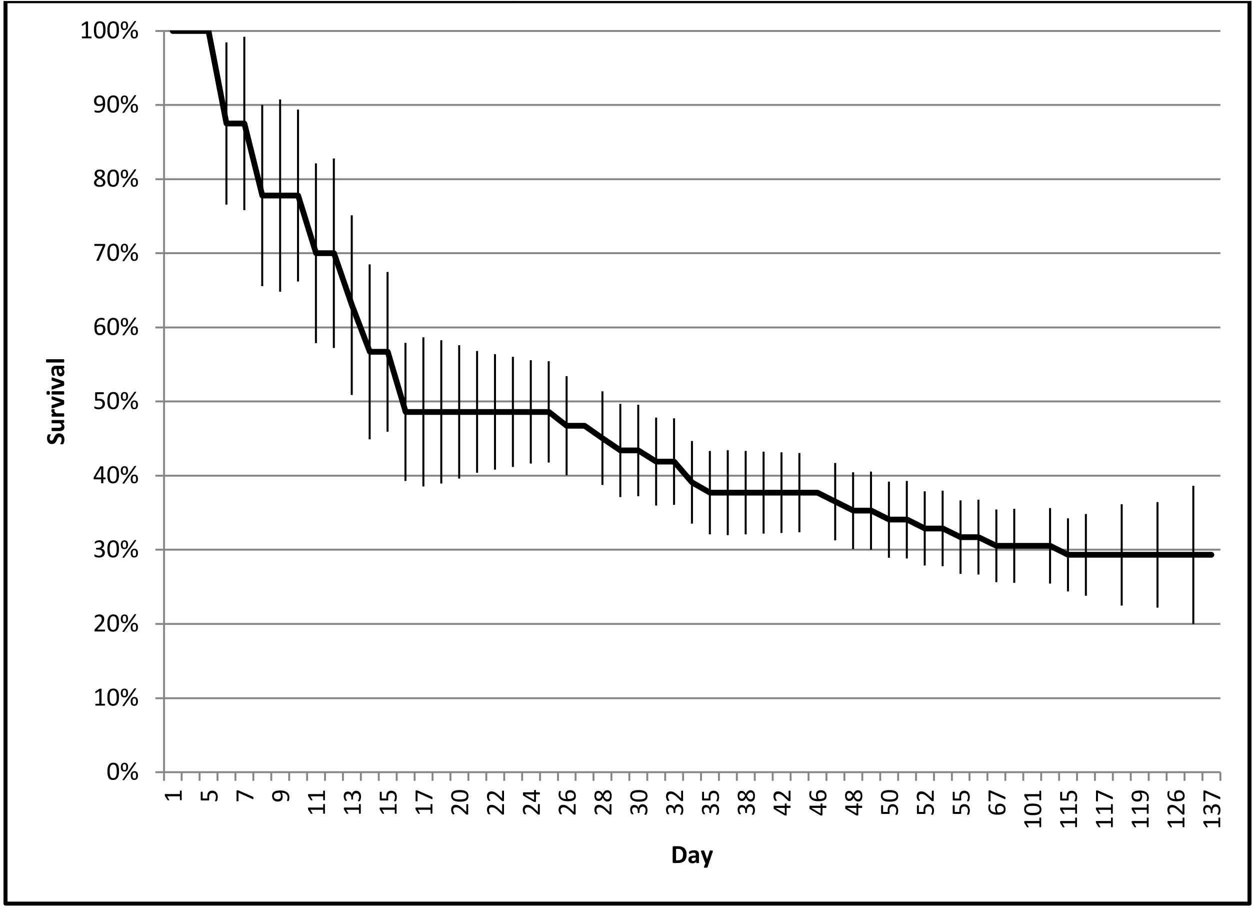
Table 4.1. Number of fawns captured (n), average estimated age (days ± SE) at time of capture, and estimated fawn survival (percent ± SE) until hunting season for white-tailed deer fawns at the Joseph W. Jones Ecological Research Center (Ichauway), Baker County, Georgia.

Year	**n**	**Age**	**Survival**
2007	8	4.4 ± 0.50	0.267 ± 0.13
2008	13	4.2 ± 0.60	0.222 ± 0.07
2011	13	4.5 ± 0.60	0.675 ± 0.14
2012	13	3.1 ± 0.70	0.205 ± 0.08

Figure 4.1. Survivorship curve of radio-collared white-tailed deer fawns from capture until October (the beginning of the firearm deer hunting season season) at the Joseph W. Jones Ecological Research Center (Ichauway), Baker County, Georgia. Data are pooled for years 2007, 2008, 2011, and 2012). Vertical bars represent standard errors.



CHAPTER 5

SUMMARY AND MANAGEMENT IMPLICATIONS

Summary and Management Implications

This project was implemented to better understand white-tailed deer (*Odocoileus virginianus*) fawn behavior and survival in a southwestern Georgia longleaf pine (*Pinus palustris*) forest. I have not been able to identify any previous studies on fawn behavior in the Coastal Plain ecosystem of the southeastern United States. I investigated habitat characteristics at fawn bed-sites during the first two weeks of life, habitat associated with fawn locations until recruitment into the fall population, and cause-specific mortality and survival until recruitment into the fall population. Understanding habitat selection of fawns will allow for more informed forest management. Also, managing white-tailed deer requires an understanding of fawn survival and sources of mortality (Pusateri Burroughs et al. 2006) in order to create management practices to potentially alter mortality rates.

My results allowed me to determine that white-tailed deer fawn bed-sites were associated with tall, dense understory vegetation, and closed canopies at the microhabitat level, and near edges at the macrohabitat level. My results also suggested that microhabitat characteristics were much stronger predictors of fawn bed-site locations than macrohabitat characteristics. Tall, dense understory vegetation at bed-sites could significantly decrease the probability of visual detection by predators (Grovenburg et al. 2010) and canopy closure may provide shade (Van Moorter et al. 2009). Edges correlated with tall and dense understory vegetation provide abundant hiding cover for fawns (Said and Servanty 2005, Constible et al. 2006) but may also represent areas with greater predation pressure.

Fawn locations until recruitment were determined to be close to edges with greater edge density, increased basal area, and far from mixed pine-hardwood habitats. Similar to my results describing fawn bed-sites, fawn locations were near edges, with increased edge density probably for the availability of hiding cover in these areas. Higher basal area was probably important because the increased canopy closure provided protection from extreme temperatures. However, more investigation into the costs and benefits associated with habitat with higher basal area may be useful because, although canopy closure provides shelter against high temperatures, forage availability is generally reduced under dense canopies (Mysterud and Ostbye 1999). Lastly, edges of mixed pine-hardwood forest may have been important in fawn habitat due to a correlated variable I was not able to identify. Also, this habitat may have been avoided because its dense understory vegetation could foster high prey populations which would promote higher populations of predators such as bobcats (*Lynx rufus*) (Cochrane 2003).

The pooled Kaplan-Meier survival rate of fawns at the Jones Center was consistent with other studies done in the southeastern U.S. The majority of fawn mortalities occurred within the first two weeks of life, and all but two mortalities occurred during the first 30 days of life. My results support other studies that suggest fawns may be most vulnerable to predation during their first few weeks of life (Whittaker and Lindzey 1999, Pusateri Burroughs et al. 2006, Kilgo et al. 2012). Overall, coyote (*Canis latrans*) predation had the greatest influence on fawn survival. Bobcats, which are the only other documented predator of white-tailed deer fawns in southwestern Georgia (Howze 2009), had little impact on fawn survival. Studies of bobcat food habits suggest that in areas where bobcats and coyotes are sympatric, white-tailed deer are not a major component of bobcat diets (Godbois 2003, Thornton et al. 2004, VanGilder 2008). Because data on the long-term effects of coyote predation on white-tailed deer are limited, more research is needed to clarify this relationship.

The impact of predation on white-tailed deer populations in the Southeast may depend on deer density (Kilgo et al. 2012) with populations that are maintained well below carrying capacity being the most vulnerable to suppression (Ballard et al. 2001). Providing abundant hiding cover for fawns could be achieved through land management practices such as prescribed fire and maintenance of a mosaic of habitat types which promote an herbaceous understory while creating edge (Cochrane 2003). However, to reduce the chance of fawns being detected by predators that may use edges as travel corridors, emphasis should be placed on providing areas with tall and thick understory vegetation, which would be hiding cover for fawns.

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