THERMAL ECOLOGY OF WHITE-TAILED DEER ON SOUTHWESTERN RANGELANDS

A Dissertation

by

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ABSTRACT

Thermal Ecology of White-tailed Deer on Southwestern Rangelands

August 2022

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Temperatures are increasing worldwide, while human activity is removing thermal cover from the landscape. Despite these changes, wildlife and livestock are challenged with maintaining a stable body temperature during extreme temperatures. Behaviors, such as seeking shade, are less energetically costly to animals than physiological responses; shade can reduce radiant heat gain by 30%. However, behavioral changes may lead to competition with other animals on the landscape. Furthermore, all shade is not of equal quality because natural vegetation often produces dappled shade. I used global positioning system collars and operative temperature models in both field and captive experiments to evaluate the relationship between temperature, animal behavior, and woody cover or shade. In chapter 1, I investigated resource selection of white-tailed deer (*Odocoileus virginianus*) and cattle (*Bos spp.*) during summer and assessed deer-cattle competition for shade. I found selection for woody cover throughout the day differed between deer and cattle. Deer and cattle used the same shade resources but avoided each other temporally. In chapter 2, I manipulated shade quality in a captive setting, using woven shade cloth to vary solar obstruction and quantified deer shade preference as temperature fluctuated. Deer selected higher quality shade during hotter temperatures, but shade quality

preference was not clear until ambient temperature was ≥ 29°C. In chapter 3, I evaluated the effects of mechanical brush management on deer movement and quantified resource selection within the treatment area over time. Brush management had minimal effects on deer movement. Deer selected for root-plowed strips during midday compared to brush strips and brush mottes. However, deer selected for brush strips and brush mottes over root-plowed strips at night. In conclusion, shade is important to animals because it decreases operative temperature. Animals use shade to mitigate heat stress during daily temperature extremes, and there is potential for competition with other animals if shade is limited. Understanding the relationship between landscape characteristics and temperature and how animals use the landscape during hotter periods will improve our ability to mitigate the effects of heat stress through management decisions. Land managers should consider thermal cover and wildlife-livestock relationships when designing management plans.

DEDICATION

This dissertation is dedicated to my mother, Tracy Smith, who sacrificed endlessly so that I could pursue my dreams. You taught me to be a good human being and the importance of hard work. Thank you, and I love you.

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CHAPTER 1. INFLUENCE OF HEAT ON RESOURCE SELECTION AND INTERACTIONS OF DEER AND CATTLE ON SOUTHWESTERN RANGELANDS

INTRODUCTION

Heat stress is common in endotherms and has been extensively studied in domestic animals. However, the implications of heat stress in wild animals have only recently begun to be appreciated. Wild animals experience additional stresses, such as meeting nutritional requirements and avoiding predators, which may cause them to behave differently when heat stressed. In addition, behavioral changes of wildlife to mitigate heat stress may increase interactions with domestic animals, potentially affecting their ability to handle extreme heat due to competition for shade resources. Understanding these relationships and how heat influences resource use is important when designing management plans, especially in a changing climate.

Ambient temperatures in arid or semi-arid areas commonly exceed the upper critical temperature of animals (Smith et al. 2017, Milling et al. 2018), causing heat stress (Guthery et al. 2000, Elmore et al. 2017). In South Texas, summer temperatures may exceed 37°C, with average high temperatures > 32°C from June–September (NOAA 2021). Despite copious amounts of research on white-tailed deer (*Odocoileus virginianus*; hereafter deer) including responses to cold temperatures (Moen 1976, Schmitz 1991), behavioral responses to heat are not well understood. Important life history events, such as antler growth, late gestation, and lactation, occur during the hottest times of the year and may further complicate mitigation of heat stress. For example, peak lactation for does occurs during July–August and is considered the costliest life history event for mammals (Oftedal 1985). Bucks accumulate fat reserves during August–

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September to sustain them through rut, which can result in a 40% loss in body mass (Bobek et al. 1990; Deutsch et al. 1990; Miquelle, 1990; Mysterud et al. 2005, Foley et al. 2018).

Seeking shade is a simple behavior to avoid extreme temperatures (Renaudeau et al. 2012). Studies of livestock revealed that access to shade can reduce radiant heat gain by 30% (Bond et al. 1967). However, the intensity of natural shade is dictated by the vegetation creating it. Vegetation structure and composition affect microclimatic conditions by influencing the amount of direct solar radiation reaching the ground (Tanner et al. 2021). Vegetation also influences microclimatic conditions through radiative heat transfer and by affecting wind flow (Geiger, 1965; Stoutjesdijk and Barkman, 1987).

Southwestern rangelands are largely working landscapes, where livestock and deer overlap. Range managers are often tasked with managing for deer as well as livestock due to the commercial value of deer hunting. Studies have shown strong temporal separation between the species, which is thought to be attributed to a combination of deer avoiding cattle and differing habitat requirements (Cooper et al. 2008). However, diet overlap between deer and cattle may approach 60% during times of heavy stocking rates (Fulbright and Ortega-Santos 2013) and on highly productive areas (Cooper et al. 2008). In addition, calving typically occurs in the spring, and drought during warmer months may increase diet overlap and lead to deer and cattle living in closer proximity (Fulbright and Ortega-Santos 2013). A combination of the above factors and extreme temperatures coupled with limited or fragmented shade resources could lead to competition for shade.

In addition, vegetation management is focused on mitigating woody shrub encroachment to maintain grasslands for grazing. Animal nutritional requirements are well understood, but shade resources are not. The ecology of shade as a thermal refugium involves a complex interplay between vegetation height and leaf structure, wind, angle of the sun, and animal physiological state. Furthermore, there is potential for competition for shade if high-quality shade resources are limiting. The juxtaposition of foraging areas and shade may influence use of the landscape during the hottest times of the year. My objectives were 1) evaluate deer and cattle selection of land cover types and vegetation characteristics to identify thermal refugia, 2) evaluate the influence of vegetation characteristics on operative temperature, and 3) investigate changes in deer-cattle proximity that may indicate competition for shade resources.

STUDY AREA

I conducted this research on the East Foundation's El Sauz Ranch (26°40'N, -97°35'E; https://www.eastfoundation.net) bordering the community of Port Mansfield, Texas, USA. The site consists of 10,948 ha in the Lower Rio Grande Valley, Coastal Sand Plains, and Laguna Madre Coastal Marshes ecoregions (Bailey et al. 1994). The Coastal Sand Plains ecoregion is made-up of mid- to tallgrass prairies, small ponds, and active sand dunes. The Lower Rio Grande Valley ecoregion contains diverse grasslands, shrublands, and low woodland communities, with mostly Quaternary clay-loams and sandy clay-loam soils. The Laguna Madre Coastal Marshes ecoregion is a hypersaline lagoon system with seagrass meadows and tidal mud flats (Bailey et al. 1994, East Foundation 2007). Port Mansfield had an annual mean rainfall of 64.3 cm and average mean temperature of 23.2°C during 1998–2018 (Prism 2018). Average monthly temperatures for the area are greatest June–August, ranging from 28.3°C to 29.3°C, respectively (NOAA 2021). Common vegetation communities include live oak (*Quercus virginiana*) woodlands, mesquite (*Prosopis glandulosa*) woodlands, gulf cordgrass (*Spartina spartinae*) grasslands, seacoast bluestem (*Schizachyrium scoparium var. littorale*) grasslands, and marshhay cordgrass (*Spartina patens*) grasslands. The average cattle stocking rate on the El Sauz Ranch during 2019–2020 was 1 cow per 58 ha (East Foundation, personal communication). Fresh water tanks are distributed throughout the ranch.

METHODS

Animal Capture

I used a professional capture team and the helicopter net-gun method (Barrett et al. 1982, Webb et al. 2008) to capture 15 male and 15 female deer during March 2019. All deer were ≥ 2 years old based on tooth replacement and wear (Severinghaus 1949, Foley et al. 2021). Each deer was fitted with a global positioning system (GPS) collar (Lotek LiteTrack IRI TL 330) set to record animal location at 30-min intervals (Wiemers et al. 2014). In addition, 10 female cattle in the same area of the ranch were fitted with collars in May 2019. Capture and handling procedures followed ASM Guidelines for wildlife (Sikes 2016) and captures were approved by the Texas A&M University-Kingsville Institutional Animal Care and Use Committee (2018-02-14).

One deer collar slipped off 2 days after initial capture, and there were 2 deer mortalities during July and August. I retrieved 18 deer collars in October 2019 and immediately redeployed those with the 3 collars I retrieved earlier in the year. I maintained the initial sex ratio with all redeployments by placing collars on the same sex of deer on which the collar had originally been deployed. There were 2 deer mortalities within a week of redeployment and another in November 2019. I retrieved and redeployed all cattle collars on different individuals in November 2019. I retrieved 6 more of the 1st deployment deer collars in February 2020 and immediately redeployed those and the 2 mortalities from November; 1 deer mortality occurred 1 week after the February 2020 capture. I retrieved 26 deer collars and the 10 cattle collars for the final time in October 2020. I was unable to retrieve the final 4 deer collars due to battery failure.

Modeling Operative Temperature

To understand how vegetation influences microclimatic conditions and ultimately animal behavior, the influence of ambient temperature, wind, and solar radiation on heat exchange between the animal and its environment must be considered (Porter and Gates 1969, Hetem et al. 2007). The temperature derived from this combination of environmental variables is termed operative temperature. Previous studies have used operative temperature models in the form of black-globe thermometers to study thermal ecology (Bakken 1992, Wiemers et al. 2014). Black-globe thermometers estimate the thermal environment of an animal by integrating the transfer of convective and radiative heat between the environment and the animal (Bakken and Gates 1975, Bakken 1976). To record spatially explicit patterns of operative temperature across the study area (Guthery et al. 2005, Carroll et al. 2016), I constructed operative temperature models (hereafter black-globe thermometers) out of copper spheres measuring 15.24 cm in diameter. I painted the copper spheres matte black and suspended a pendent data logger (HOBO, Cape Cod, MA, USA) in the center to record operative temperature at 30-min intervals, timed to sequence with GPS collar locations (Wiemers et al 2014; Fig. 1.1).

To ensure placement of black-globe thermometers was representative of space use by collared animals, I created a single 95% kernel density estimate (95% KDE) of deer locations on the landscape. This was not necessary for cattle because cattle were confined by livestock fencing, whereas deer could pass over or under the fencing. All deer locations collected from March 2019 to May 2019 were imported into ArcMap 10.1 (Environmental Systems Research Institute, Redlands, CA, USA). I then used 0.5-m resolution 2018 National Agriculture Imagery Program (NAIP, https://naip-usdaonline.hub.arcgis.com/) aerial photographs and ERDAS IMAGINE 2016 (Hexagon Geospatial, Norcross, GA, USA) to perform unsupervised image classification into 4 land cover types: woody cover, grassland, bare ground, and water. These cover types comprised 28, 45, 8, and 19% of the landscape, respectively. I generated random points within the 95% KDE and deployed black-globe thermometers at those points. I allocated 80 thermometers in woody cover and 20 thermometers in grasslands because black-globe thermometers in grasslands likely experience less temperature variation due to the absence of cover. All black-globe thermometers were mounted 0.5 m above the ground to simulate the midpoint between shoulder height of a deer laying down and standing (Fig. 1.1; Wiemers et al. 2014). In May 2020, I repeated this process and moved black-globe thermometers to align with newly collared animals.

Vegetation Characteristics

I indexed vegetation height and density within the 95% KDE using light detecting and ranging (LiDAR) because these vegetation characteristics likely represent shade. I downloaded LiDAR point cloud data from Texas Natural Resources Information System (TNRIS, http://www.tnris.org). These data were obtained via aerial flyover by the United States Geological Survey in 2018 and were collected at 70-cm resolution (USGS 2018). I classified the vegetation data at 1-m intervals using LP360 software (GeoCue, https://geocue.com/software/lidar-software/) into the following classes: 0–1 m, 1–2 m, 2–3 m, 3–4 m, 4–5 m, and > 5 m above ground (Devore et al. 2016, Ewald et al. 2014). I calculated canopy height using the difference between digital elevation models (DEMs) and digital surface models (DSMs; Barnes et al. 2016). I calculated vegetation density using point density of the LiDAR data and quantified the horizontal structure of all vegetation. Using point density may result in vegetation density > 100% cover. I quantified the vertical structure of vegetation to calculate canopy cover. I created all vegetation rasters at a 5 m × 5 m spatial resolution.

Analyses

I completed all analyses using the statistical computing language R (R Core Team 2020) and created plots with the ggplot2 package (Wickham 2016). I cleaned collar data by removing improbable fixes (e.g., those outside the research area) and those with a dilution of precision (DOP) > 10 (Brook 2010, Hooven et al. 2022).

Resource Use and Selection

To determine resource selection, I first used GPS locations to calculate home ranges for individual deer and cattle using the adaptive Local Convex Hull (LoCoH; Calenge 2006) method in the adehabitatHR package (Getz et al. 2007). The adaptive LoCoH creates local hulls until reaching a predefined distance (α). For α, I used the maximal distance between any 2 fixes for an individual (Reinecke et al. 2014) except when it resulted in "orphaned holes", at which point I increased (α) to between 1*α to 2*α until there were no "orphaned holes" (Costello et al. 2014). I used the 90% contour of the α-LoCoH to identify animal's home range (Getz et al. 2007). I chose this method due to its ability to account for hard boundaries to movement, such as the coastline or cattle fences (Reinecke et al. 2014).

Next, I filtered the data to June–September 2019 and 2020, the hottest months of the year. I resampled the vegetation rasters to 10 m × 10 m to account for collar error and built a correlation matrix using the stats package (www.r-project.org, ver. 3.6.0) to assess correlation among vegetation characteristics canopy height and vegetation density at each 1-m interval. I removed an individual vegetation feature if it was > 70% correlated (Pearson's correlation coefficient) with another feature and scaled and centered all continuous variables. I then calculated proportional use of woody cover and grasslands for both deer sexes and cattle. I evaluated third-order selection (Johnson, 1980) of male and female deer and cattle for categorical variables woody cover and grasslands and continuous variables % canopy of woody cover and vegetation density at different heights. I fit resource selection functions (RSF) using conditional logistic regression in the lme4 package (Bates et al. 2015). I estimated relative probability of selection at 3 time periods: midday (09:00 to 16:59), night (21:00 to 03:59), and crepuscular periods (04:00 to 08:59 and 17:00 to 20:59; Wiemers et al. 2014, Morano et al. 2019). To account for availability of each land cover type, I tested ratios of 1 used location to different numbers of random locations. There was no appreciable change in coefficient estimates when increasing from 3 to 10 random locations so I settled on a ratio of 1 used location to 10 random locations. I designated deer as a random intercept to control for individual variation. I included woody cover as my model reference level to evaluate selection for categorical land cover types.

Vegetation Characteristics and Operative Temperature

To determine the relationship of % canopy of woody cover and vegetation density with operative temperature, I resampled the LiDAR-derived vegetation measurement rasters to 1 m × 1 m resolution. I then created a 5-m buffer around each black-globe thermometer and calculated mean % canopy cover and vegetation density at each height within that buffer. I removed an individual vegetation feature if it was > 70% correlated (Pearson's correlation coefficient) with another feature. I used generalized linear models (GLM) in the stats package (www.r-project.org, ver. 3.6.0) to analyze the influence of vegetation characteristics on operative temperature at the 3 time periods.

Deer-cattle Proximity

To determine the potential for deer and cattle to compete for shade resources, I first visually identified individuals with overlapping 90% α-LoCoH home ranges. If 2 individuals' home ranges overlapped, they were included in the analysis. I then filtered the data to include