POPULATION DEMOGRAPHICS OF NILGAI IN SOUTHERN TEXAS

A Thesis

by

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ABSTRACT

Population Demographics of Nilgai in Southern Texas

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Nilgai antelope (*Boselaphus tragocamelus*) are bovids that are endemic to India and portions of Pakistan and Nepal. They were introduced into South Texas in the 1920's and now have a free-roaming population of approximately 37,000 individuals. There is little known about nilgai population demographics, and their populations appear to be continuing to rise across its introduced range. For this reason, our objectives for this study were to (1) determine where nilgai are found throughout the landscape and quantify the landscape structure around nilgai locations, (2) determine a reliable aging method for aging nilgai in the field, and (3) determine nilgai reproductive capabilities in southern Texas. We collected nilgai point-locations from aerial surveys to assess the landscape structure around observed nilgai locations. We then performed a fine scale landscape analysis that quantified the scale of effect of landscape structures surrounding the nilgai locations and then performed a broad scale analysis that determined nilgai habitat use versus availability. Nilgai harvests were conducted during the summers of 2018-2021. From each harvested nilgai, we took complete dentition photos, collected the central incisors and the right mandible, and assessed the pregnancy and lactation status of each female. If a fetus was present, it was sexed, and the crown-rump length was measured. Our results revealed that, during the wintertime, nilgai were commonly observed on shrublands and woodlands. We were able to determine 13 tooth eruption stages and 6 age classes for female nilgai which can be used to age nilgai in a field-based setting. Overall, out of the sexually mature nilgai cows, 79% were pregnant and 55.5% of those pregnancies were carrying twins. Our results will provide land managers with the tools necessary to properly assess nilgai populations which will be essential in managing and controlling their populations in the future.

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CHAPTER 1.

SCALE OF EFFECT OF VEGETATION STRUCTURE FOR AN INVASIVE UNGULATE DURING WINTER IN A SEMIARID LANDSCAPE: THE CASE OF NILGAI IN SOUTH TEXAS

Abstract

Context: Large ungulate species can have a significant impact on the ecosystem. Knowledge of the spatial structure of vegetation communities can provide important insights about habitat and the development of management strategies to maintain and enhance ecosystem functions. Our goal was to quantify the amount and spatial structure of vegetation configurations around locations where nilgai (*Boselaphus tragocamelus*) were observed and determine potential scales of effect based on the vegetation structure of woody cover.

Objectives: Our objectives were to (1) assess whether there are differences in the landscape structure of where nilgai were observed during aerial surveys and GPS collar locations of nilgai, (2) quantify the scale of effect among vegetation classes where nilgai were observed, and (3) assess whether the landscape structure differed between nilgai sexes and age classes.

Methods: We compared landscape structures at five increasing spatial extents for six class-level landscape metrics based off a classified image of the research site. We then assessed whether there were differences in the landscape structure of nilgai point-locations collected during aerial surveys versus GPS collars. Next, we tested the six metrics using the Kolmogorov-Smirnov Z goodness of fit test for each category that consisted of bulls, cows, and calves. We calculated the

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mean and standard error values for each metric to report the scale of effect within each of the five spatial extents.

Results: The comparison of the data collection methods showed few differences in the landscape structure where nilgai were observed during aerial surveys and the GPS collar point-locations. The scale of effect analysis suggests that nilgai bulls were observed on landscapes consisting of less overall woody cover than areas where cows were observed. Calves were observed in landscape structures that were in between that of bulls and cows. A scale of effect was observed for the patch density and mean patch area class level landscape metrics. The Kolmogorov-Smirnov results showed no significant differences between bull, cow, and calf distribution in 2017 and 2019; however, some comparisons demonstrated differences at the ED landscape metric at most spatial extents.

Conclusion: Nilgai use of landscape structures was largely consistent across all spatial and temporal scales. Small variations in landscape-use could be attributed to changes in temperature and precipitation across survey years. Bulls were observed on landscapes consisting of less woody cover and smaller patches dispersed throughout the landscape, while cows used areas with more woody cover and larger patches that were aggregated together. The methods outlined in this study can be applied to data sets where GPS point-location data is available to gain a better understanding of species-landscape relationships of various wildlife species.

Keywords: Scale of effect, landscape metrics, nilgai, ungulates

1. Introduction

The concept of scale has become increasingly important in wildlife studies and provides an important framework to establish the relationship between ecological processes and land cover patterns (Perotto-Baldivieso 2021). The term scale in ecology is used to describe the spatial and temporal aspects of an object, pattern, or ecological process (Turner et al. 1989; Hernandez 2020). Wildlife can be influenced by spatial and temporal scales (Johnson 1980) as they often respond to their immediate environment, but ultimately make decisions dependent on larger landscape conditions (Boyce et al. 2003; Johnson et al. 2004; Northrup et al. 2016). This emphasizes the importance of identifying the scale of the object, pattern, or process before determining a sampling method and analysis to conduct (Hernandez et al. 2020). Otherwise, studies evaluating species-landscape relationships can be misinterpreted if the landscape structures specific to the species are not measured at the scale with the strongest effect on the species (Jackson and Fahrig 2015, Perotto-Baldivieso et al. 2020).

The scale of effect is defined as the spatial extent at which the landscape structure best predicts a species response (Holland et al. 2004). Identifying the scale of effect using class and landscape level metrics can provide important insights into research and management (Brennan et al. 2002). However, the scale of effect is species specific and landscape metrics may respond differently (Moraga et al. 2019). Therefore, quantifying landscape spatial structure with relevant scales is important when looking for a relationship between the species and their surrounding land cover distribution and configuration (Jackson and Fahrig 2012, Perotto-Baldivieso et al. 2020). For example, tree cover had little effect on bat abundance at small spatial scales (~0.2 km radius), but the effect was greater at larger spatial scales (~5 km radius) (Ethier and Fahrig 2011). Studies that do not take the scale into consideration often under-estimate or misinterpret the species-landscape relationship because they use a single spatial extent rather than multiple scales (Moraga et al. 2019). Therefore, when scales are not defined, it is essential to assess landscape variables at several spatial and temporal extents.

Understanding ungulate-landscape relationships is essential because ungulate species are vital components of ecosystems that can shape landscape structures and alter ecosystem functions at several spatial and temporal scales (Hobbs 1996; Apollonio et al. 2017). At larger scales, ungulates provide important ecosystem services such as aiding in nutrient cycling (Murray et al. 2013) and increasing herbaceous cover through seed dispersal (Manier et al. 2007). At smaller scales ungulates often provide a direct food source for predators such as wolves (*Canis* spp.) and coyotes (*Canis latrans*) (Theuerkauf and Rouys 2008; Benson et al. 2017). Many ungulate species are also migratory (Sawyer et al. 2009), therefore addressing factors such as seasonal changes and assessing landscape connectivity at multiple spatial scales would be required to model the species' landscape use (Wisdom et al. 2020).

These ecological concepts can be particularly important when researching the scale of effect of non-native species on the landscape (Wisdom et al. 2020). The expansion of non-native ungulate species in North America has become an increasing concern in wildlife conservation (Krausman and Bleich 2013; Beasley et al. 2018). At large spatial and temporal scales, these non-native species have the potential to degrade landscapes through overexploitation of resources (Wardle et al. 2001) which can often lead to displacement of or competition with native ungulate species for those resources (Baccus et al. 1985; Spear and Chown 2009). The increase in potential transfer of wildlife diseases across large spatial scales can be enhanced with the dispersal of non-native species (Krausman and Bleich 2013). Despite these concerns, many landowners import exotic ungulate species to the United States for sport hunting (Spear and Chown 2009).

Nilgai antelope (*Boselaphus tragocamelus*) are a non-native ungulate species that was first introduced to South Texas in 1924 (Sheffield et al. 1971) for hunting purposes. Since their initial introduction, nilgai have established a free-roaming population consisting of over 37,000 individuals that expands from coastal South Texas to Northeastern Mexico. Nilgai are endemic to almost all of India and portions of Pakistan (Mirza and Khan 1975) and Nepal (Dinerstein 1980). The climate and landscape are similar between their native and introduced ranges (Ables and Ramsey 1972; Sheffield et al. 1983), therefore nilgai populations have thrived in South Texas since their introduction. In their native range of India, nilgai use vegetation communities consisting of scattered shrublands and open grasslands, and they rarely appear in thick forested areas (Blanford 1888; Prater 1980). Based on past studies in South Texas, nilgai are frequently found in open pastures, scrublands, and coastal prairies (Ables and Ramsey 1972; Schmidly 1994; Sheffield et al. 1971, Sheffield 1983). However, these studies do not provide quantitative information about land cover configuration or the time of year the studies took place; therefore, there is a need to determine the effect of landscape configuration on nilgai in South Texas.

In this study, we intended to gain a better understanding of the landscape structure where nilgai were observed in South Texas during the winter. We focused on this species because of the lack of information on nilgai in the United States. Our specific objectives were to (1) assess whether there are differences in the landscape structure of GPS point-locations of nilgai collected during aerial surveys and from collared nilgai, (2) quantify the scale of effect among vegetation classes where nilgai were observed and (3) assess whether the landscape structure differed between nilgai sexes and age classes. To achieve these goals, we hypothesized that (1) the landscape structure around nilgai observations will not differ between data collection methods, (2) the scale of effect will differ among landscape variables and (3) landscape structures will differ among nilgai sexes and age classes. Our results will provide information the on the landscape structure where nilgai were observed during the winter in South Texas and also provide a working framework for future wildlife research focusing on exotic ungulates and vegetation spatial structure.

2. Materials and Methods

2.1. Study area

This study was conducted on The East Foundation's El Sauz Ranch located in Willacy County, Texas (26°40'N, 97°35'W). The property is a 10,984-ha ranch (Fig. 1.1) that boarders Port Mansfield, Texas. Port Mansfield has an average temperature of 22.7°C (26.7-18.7°C) and receives an average annual precipitation of 659 mm (U.S. Climate Data 2021). The ranch possesses characteristics from three Texas ecoregions: The South Texas Brush Country, Coastal Prairies and Marshes, and the South Texas Sand Sheet. The South Texas Brush Country is known for mostly low-growing thorny vegetation (TPWD 2020). The Coastal Prairies and Marshes ecoregion is known for seagrass meadows and tidal mud flats (Bailey et al. 1994). The South Texas Sand Sheet is known for tallgrass prairies and sand dunes (TPWD 2020). Some common vegetation throughout the study area includes live oaks (*Quercus virginiana*), honey mesquite (*Prosopos glandulosa*), gulf cord grass (*Spartina spartinae*), and seacoast bluestem (*Schizachyrium scoparium*).

2.2. Data Collection

Nilgai location data, provided by the East Foundation, was collected from aerial surveys that were completed annually on our study area on 6 February 2017, 30 January 2018, 6 February 2019, 5 February 2020, and 21 January 2021. The purpose of these surveys is to quantify density estimates of large mammals on the property; however, for the purpose of this study we focused on nilgai location data collected during these surveys. Transects were flown covering 50% of the ranch in each year. During each survey, nilgai were identified by sex and age category (i.e., adult bulls [thereafter 'bulls']; adult cows [thereafter 'cows']; and calves). The number of individuals observed was recorded and a GPS location of the individual or group was taken.

Nilgai GPS collar data was also acquired from a nilgai movement study that was conducted in 2015-2016 (Foley et al. 2017). Thirty nilgai of both sexes were captured and each were fitted with a satellite radio-collar set to record a GPS location every 13-hours (Foley et al. 2017). Collars were remained on the nilgai from April 2015-May 2016. We selected 3 days (February 5-7, 2016) of GPS collar locations to compare with aerial observations because these dates were close to the (21 January-6 February) aerial survey dates. Each 13-hour interval observation for each nilgai was used during this three-day time-period.

We collected the monthly average weather conditions for each survey month. The range of temperatures 7 days prior to each survey date (Fig. 1.2a), and the amount of precipitation received on our study site 30 days prior to each survey date was recorded (Fig. 1.2b; U.S. Climate Data 2021). During the winter, this region experiences temperatures between 10.1°C and 19.4°C in January and between 12.0°C and 21.1°C in February. Average precipitation is 38.5-mm (U.S. Climate Data 2021).

2.3. Scale of effect Analysis

We used NAIP 2016 classified imagery at a 1-m resolution to create a land cover map of our study area using an unsupervised classification in ERDAS IMAGINE 2018 (Hexagon Geospatial, Norcross, GA) following the methods used by Mata et al. (2018). We categorized each image into four land cover classes: woody, herbaceous, bare ground, and water (Fig. 1.1) and obtained overall accuracy ranging between 85.5-89%.

To determine the scale of effect, we measured the spatial extent surrounding each observed nilgai (Moraga et al. 2019). We created circular buffers of 5 different spatial nested extents (20, 40, 60, 80, 100-m) around each observed nilgai location using ArcGIS 10.8 (ESRI, the Redlands, CA; Blackburn et al. 2021). We quantified the spatial structure of each nilgai location across the landscape using class-level landscape metrics (Table 1.1) in conjunction with the woody vegetation class using Fragstats 4.2 (Mata et al. 2018, Blackburn et al. 2021). These metrics included percent woody cover (PLAND, %), edge density (ED, m/ha), mean patch area (MPA, ha), patch density (PD, patches/ha), Euclidean nearest neighbor distance mean (ENN_MN, m), and an aggregation index (AI, %). PLAND values represent the percent of woody cover present. PD and MPA describes the density and mean size of woody patches. Values of ED quantifies the amount of edge per unit area. The ENN_MN represents the mean distance of woody patches to the nearest neighboring woody patch. AI values measures whether woody patches are aggregated or distributed throughout the landscape.

2.4. Statistical Analyses

To compare the GPS collar locations to the aerial survey observations, we used a generalized linear model to determine if there were differences in the landscape structure where nilgai were recorded between the two methods. The model used an all-pairs comparison of least square means to determine if there were differences between years and bulls, cows, or calves. The year 2016 represents the GPS collar data and the years 2017-2021 represents the aerial survey observations. The model analyzed each metric in each spatial extent by comparing 2016 to each other year (5 comparisons) and then comparing bulls, cows, and calves in each of those 5 comparisons (15 total comparisons per metric; 90 total comparisons per spatial extent).

We compared landscape structure metrics between bull, cow, and calf locations for each spatial extent using the Kolmogorov-Smirnov Z goodness of fit test with a 0.05 level of significance (Perotto-Baldivieso et al. 2011; Blackburn et al. 2020). We calculated the mean and standard error values for each metric to report the scale of effect within each of the 5 spatial extents (Moraga et al. 2019). These results allowed us to assess whether there were differences in the landscape configuration between of each compared category. All statistical analyses were conducted using SPSS version 27.0 (IBM Corp, Armonk, NY). We reported the z-statistics and corresponding p-values in the Supplementary Information (Appendix A-E).

3. Results

The comparisons between GPS collar data and aerial survey location data showed 12 out of 90 comparisons with significant differences at the 20-m scale, and 20 differences out of 90 comparisons (Table 1.2) for the 40-m, 80-m, and 100-m spatial scales. The 60-m spatial extent showed 18 differences among the 90 total comparisons. The PD and ED metrics accounted for most of the variation between GPS collar locations and aerial survey locations among all years and within all spatial extents.

Only two of the six class-level landscape metrics showed a significant scale of effect: PD and MPA (Fig. 1.3). The PLAND values show that cows were observed in areas with a greater amount of woody cover (43-55% woody cover) than bulls (35-40% woody cover) in each year, with calves using areas with the amount of woody cover between bulls and cows (40-43% woody cover). In 2020 and 2021, the PLAND values for cows increased by approximately 10% compared to previous years. The PD fluctuated each year within each category of bulls, cows, and calves. In 2017 and 2020, bulls were observed in areas with a higher PD (7,223-8,895 patches/ha) than cows (5,451-8,702 patches/ha), however, cows in 2018 (10,281 patches/ha) and calves in 2018, 2019 and 2021 (7,008-11,258 patches/ha) were observed in areas with greater PD than bulls. The overall PD values stabilized at the 40-m scale in each category.

In 2017, bulls utilized areas with a higher MPA (0.041 ha) than cows or calves (0.011-0.031 ha). Cows were observed using higher MPAs (0.021-0.071 ha) than bulls and calves (0.009-0.047 ha) in 2018, 2020, and 2021, and calves used areas with higher MPAs (0.057 ha) than cows and bulls (0.019-0.036 ha) in 2019. The overall MPA steadily increased at small scales until 60-m in 2017, 40-m in 2018 and 2019, 60-m in 2020, and 40-m in 2021. After these scales, the MPA decreased in each year and category (Fig. 1.3). Bulls had a slightly greater ENN_MN [3.05 – 4.11 m] value in 2018 and 2021 than cows and calves [2.55 – 3.76 m]. Cows were observed in areas with slightly higher AI values [73.88 – 85.10 %] than bulls and calves [68.76 – 83.10 %] in 2017, 2018, 2020, and 2021. There was no significant difference in AI values for any category in 2019. There were no differences in distribution between any of the compared categories at any spatial extent in 2017 (Appendix A) and 2019 (Appendix C). In 2018, the bulls-cows comparison showed differences in distribution in PLAND across all spatial scales, ED at 80-m, and ENN_MN at >60-m (Appendix B). In 2020, the bulls-cows comparison showed differences in distribution in PLAND, MPA, and AI across all spatial scales, and PD at >60-m (Appendix D). In 2021, comparisons of both bulls-cows and bulls-calves showed differences in distribution (Appendix E). The differences for bulls-cows occurred in PLAND, ED, MPA, and ENN_MN at all spatial scales, and in the AI at 20-60-m. The differences for bulls-calves occurred in PLAND at 20-m, ED at all spatial scales, and ENN_MN at >60-m.

In 2016, seven days prior to the location records that were used, the study site experienced above average temperatures (28.3°C; Fig. 1.2a). 2016 also had less cumulative precipitation 30 days prior (3.3-mm; Fig. 1.2b). Our study site also experienced above average temperatures in 2017 and 2019 (26-27°C; Fig. 1.2a) but with average amounts of precipitation (29.2-mm [2017] and 47.5-mm [2019]; Fig. 1.2b) in January and February. In 2018, 2020, and 2021 temperatures (-2-