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Vegetation Height and Diurnal Period Influenced the Landscape-Use Pattern of Small Ruminants in Woodlands around Summer

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Abstract: Despite the huge potential of using woodlands for small ruminant grazing in the southeast US, unmanaged understory shrubs grown beyond animals' access minimize the utilization of such vegetation. This study aimed to determine the effect of vegetation height and diurnal period on the behavior and distribution patterns of goats and sheep in woodlands around summer. The study was conducted in six woodland plots (0.4 ha each) comprising southern pines and non-pine (non-target) plant species. Non-pine plants in each study plot were assigned to four treatments: cut to 0 m, 0.9 m, or 1.5 m from the ground level or left uncut (control). Cut plant stubs were allowed to regrow to full canopy before stocking animals. Eight Kiko wethers and five Katahdin rams were rotationally stocked in separate plots, and their diurnal (dawn–dusk) behaviors and distribution patterns were monitored when they were in each plot (three plots per animal species) around the summer of 2018. Animal behavior data were analyzed using the general linear model (GLM) procedure with multivariate analysis of variance (MANOVA) in SAS, while animal distribution pattern and weather data were analyzed in SAS using a GLM procedure and the distribution evenness index (DEI) using the Kruskal–Wallis rank-sum test in R. Level of significance was set at 5%. Both animal species visited the control area the least. Wethers browsed predominantly in areas where non-pine plants were cut to 0.9 m from the ground level, and rams grazed mostly in areas where non-pine plants were cut to the ground level, mostly during the post-midday period. Browsing was the dominant feeding behavior of wethers (39% browsing vs. 4% grazing), while rams' feeding behavior was dominated with grazing (24% grazing vs. 12% browsing). Lying was a predominant diurnal behavior in both wethers (46%) and rams (35%), mostly during the midday period. Wethers had a higher value for DEI than rams during the morning and post-midday periods. This study established that (1) the utilization of woodland understory foliage by small ruminants can be increased by lowering plant height, and (2) both vegetation characteristics and diurnal period are important factors for influencing small ruminants' behavior while stocked in woodlands around summer.

Keywords: browsing; distribution; grazing; Katahdin rams; Kiko wethers

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1. Introduction

Woodlands are land areas of at least 0.4 ha with 10% or more coverage by live trees, including other areas that were similarly covered before and have the capacity to be regenerated or planted [1]. Woodlands cover a substantial portion of land (310 million hectares) in the United States and are important for economic and environmental well-being. The southeast US has 31.5 million hectares of woodlands [2]. Alabama ranks second in the Southeast in woodland coverage, with 9.3 million hectares of woodlands, which are dominated by softwood stands (mostly pine-45%) and generated an annual revenue of USD 20 billion from the timber industry in 2017 [3]. Even with multiple intercultural operations, such as thinning and pruning, profitable pine timber harvesting in silvopastures may take from 30 to 50 years or more [4,5]; however, it may take even longer for unmanaged woodlands. Investments in conventional woodland management practices, such as mechanical control and forest fires, are either expensive or unfeasible. The cost of the mechanical method of forest management averaged at USD 370.63/ha, chemical control USD 125.01/ha, and the cost of prescribed fire is estimated between USD 65.80/ha and USD 2471/ha [6,7]. Indeed, forest fire may pose a high risk to neighborhoods, if it escapes from the target area, and also damage the desirable flora and fauna in the burnt area [8]. In areas where forest fire is not feasible or desirable, the use of small ruminants can be a viable option to control the understory vegetation in woodlands.

The integration of woodlands with suitable grazing animals can reduce understory vegetation management costs while serving as an eco-friendly measure for vegetation management [9]. Thinning and goat grazing in Mediterranean woodlands improved tree growth, as indicated by greater tree height and trunk diameter, as opposed to woodlands where such practices were not applied [10]. Goats are one of the suitable animal species for integrating in woodlands, as they consume most of the vegetation available in the system [11] and can also actively graze (feed on grasses and vegetation growing close to the ground surface). Sheep can be another animal species to use in woodlands, since they can change their feeding habits to browsing (eating woody shrubs, vines, and tree leaves) when herbaceous species are limited in the system [12], reaching up to 0.87 m for browsing [13].

Identifying suitable animal species to integrate into woodlands for utilizing the unwanted vegetation and producing marketable quality animals for regular income is important for the sustainable use of the whole system. Woodland grazing can also complement the pasture-based animal production system by expanding the grazing opportunity, increasing diet variety, creating a mild environment, and minimizing gastro-intestinal parasite problems in small ruminants [9]. The expanded grazing opportunity can minimize the existing feed deficit for small ruminants in southeastern states of the US, including Alabama, where farmers must supplement their animals with hay and/ or concentrate feeds for five to six months each year, resulting in a high production cost [14,15]. Sustainably managed woodlands with small ruminants can benefit both timber and small ruminant industries.

The scope of the small ruminant industry in the US is increasing, as the demand for goat and sheep meat has been growing for the past several years at an accelerated rate. Goat and sheep meat imports have increased at an average annual rate of 4% from 2002–2017, goat production increased by 8%, and sheep production decreased by 1% during the same time [16]. The projected increment in goat meat consumers, mostly in Hispanic and Asian populations, by 115% and 143% between 2014 and 2020 [17], respectively, suggest that goat meat demand will increase further. The US imported 143 thousand metric tons of goat and sheep meat in 2017 [18], suggesting that domestic production is not enough to meet the current demand. The negative supply situation in domestic production presents a great opportunity to expand the small-ruminant industry in the US. The sustainable use of woodlands for grazing small ruminants can minimize the production costs.

Despite the great scope of utilizing woodlands, only three percent of the total woodland (31.5 million hectares) is grazed in the Southeast [2], without any management applied to the woodland resources. When small ruminants are used in woodlands, their access to only a limited height can be an issue [11–13], as vegetation beyond animals' reach remains unutilized and shades plants present at the lower level, affecting their regrowth after being consumed by animals. This situation triggers a question—how can the non-pine (unwanted) plants present beyond the reach of grazing animals be managed? One of the options would be to cut non-pine plant species to lower heights such that regrowth could be within the reach of grazing animals and then manage the regrowth with the rotational stocking of grazing animals. This idea needs to be tested to determine whether it works and to evaluate how such cutting would influence animals' landscape utilization patterns (time spent and behavior performed in different areas). Understanding animals' behavior and distribution within a landscape is very important to manage any grazing system sustainably [13,19]. An even distribution of animals over the grazing landscape is essential to utilize the available vegetation and recycle the nutrients in the form of animal excreta uniformly within the system. The evenness of animal distribution can be estimated by calculating the distribution evenness index (DEI) [19], which is elaborated in the Materials and Methods section. Uneven animal distribution in grazing lands may cause overexploitation of resources in certain areas while other areas remain underused, leading to unsustainable use of resources. Therefore, a better understanding of animal behavior and distribution pattern in a grazing system is important for landowners and land managers to make management decisions such as the placement of grazing facilities, management of stocking density, and control of predators [19]. Our previous studies during fall in woodlands showed that goats and sheep mostly selected areas within their accessible heights for browsing and grazing during evening hours, while resting activities such as lying and loafing were mostly during afternoon hours, showing the influence of vegetation height and diurnal periods on behavior and distribution patterns of goats and sheep during fall [20]. In this study, we aimed to understand how the vegetation characteristics and time of day influence the behavior and distribution pattern of Kiko wethers (castrated male goats) and Katahdin rams (uncastrated male sheep) in woodlands around summer.

2. Materials and Methods

2.1. Study Site

The study was conducted around summer (June to August) of 2018 in six (6) woodland plots, each of 0.4 ha and fenced on all sides, situated at the Atkins Agroforestry Research and Demonstration Site, Tuskegee University, Tuskegee, Alabama, USA (latitude 32°26′34.0″ N, longitude 85°43′57.4″ W). Study plots consisted of a mixture of longleaf (*Pinus palustris* Mill.) and loblolly (*Pinus taeda* L.) pines, hardwood trees, and many understory plant species. Pine trees were 13 years old, with a tree density of 690 trees/ha, height 8.3 (±0.09 SE) m, and diameter at breast height (DBH) of 12.7 (±0.24 SE) cm. The soil of the study site comprised 78.7%, 21.3%, and 0.1% Cowarts loamy sand, Uchee loamy sand, and Uchee–Cowarts complex, respectively, with the slope ranging from 1 to 25% [21].

2.2. Site Preparation

Prior to applying the cutting treatments, each plot was virtually demarcated into four equal sections (0.1 ha each) with marking flags. During the summer of 2017, non-pine plant species in each plot were either left uncut (control: Zone 1) or cut to the ground level (0 m: Zone 2), 0.9 m from the ground level (Zone 3), or 1.5 m from the ground level (Zone 4); treatments were randomly assigned to each virtual section in each plot. Areas along the fence line (Zone 5) were clear and mostly devoid of woody species or dense ground vegetation; shelters, mineral feeders, and water troughs for animals were installed in this zone (Figure 1). Two shelters and mineral feeders each were installed in each plot such that one of each was located in between the two adjacent sections to promote the uniform distribution of animals across all sections within each plot.

Before stocking animals in each study plot, available vegetation height (grown up to 2.13 m from the ground surface) was measured with a measuring tape in ten randomly selected points in every zone within each plot. At each observation point, the height of all vegetation present within a 1.2 m radius from the center of the observation point was measured (Figure 2). Zone 2 mostly comprised herbaceous species and vines with an average canopy height of 0.8 (±0.03 SE) m. Zone 3 and Zone 4 were dominated by woody species with an average canopy height of 1.4 (±0.03 SE) m and 2.0 (±0.03 SE) m, respectively. Zone 1, unlike other zones, was dominated by woody plants and understory vegetation up to a height of 2.13 (±0.03 SE) m was considered as available for small ruminants based on the maximum browsing height of 1.95 m reported in previous studies with young (6–8 months old) Kiko wethers [22] and assuming a 7.7% higher browsing height for the mature animals used in the current study. Zone 5 did not have much vegetation available for grazing or browsing.

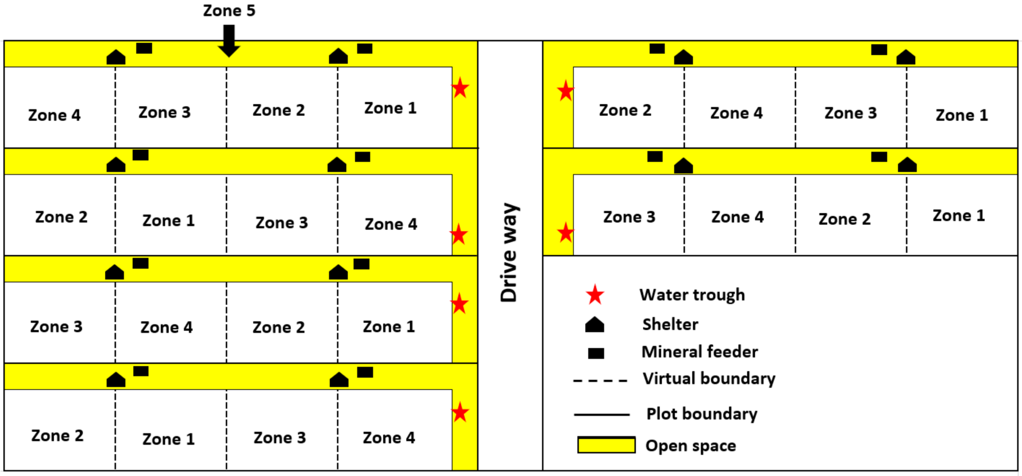

Figure 1. Schematic diagram of research plots showing different zones and locations for shelters mineral feeders and water troughs, June–August 2018, Atkins Agroforestry Research and Demonstration Site, Tuskegee University, Tuskegee, Alabama, USA. Zone 1: Non-pine plants left uncut (control); Zone 2: Non-pine plants cut to the ground level; Zone 3: Non-pine plants cut to 0.9 m from the ground level; Zone 4: Non-pine plants cut to 1.5 m from the ground level; Zone 5: Fence line and driveway where shelters, mineral feeders, and water troughs were located.

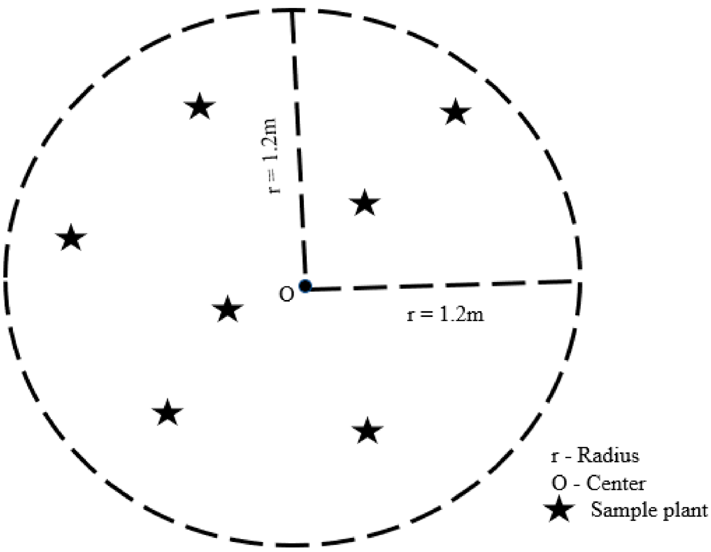

Figure 2. A schematic diagram showing an observation point for the measurement of vegetation height in different zones in woodlands, June–August 2018.

2.3. Study Animals and Their Management

Eight Kiko wethers (48–50 months old) and five Katahdin rams (29–32 months old) were used for the study. The number of animals was determined by estimating the equivalent live weight for each animal species at the beginning of the study. Animals were stocked in the adjacent silvopasture plots before they were brought to the study plots. Animals' FAMACHA score (estimation of the level of anemia in animals caused by barber pole worm (*Haemonchus contortus* (Rudolphi) Cobb.)), body condition score (BCS), live weight, hooves, and the overall health condition were assessed before stocking them in the study plots. Animals had access to clean drinking water and minerals ad libitum. When the vegetation attained the full canopy in the growing season, eight goats and five sheep were randomly allocated to three separate plots per animal species at the beginning of the study, and each animal species was rotated through the assigned plots throughout the study period. Once 50% of the available vegetation within their reach was eaten during the study period of June to August 2018, one set of studies was completed in one plot, and animals were moved to the next plot for the next set of studies. Available vegetation was estimated by visual observations several times during the study and by taking pictures of the photoplots [23] that were established in each zone before stocking animals. These vertical photoplots were 2.1 m high and 0.6 m wide that consisted of 56 equal-sized squares inside (0.15 m $\times$ 0.15 m). Photoplots were used to take pictures and estimate the available foliage in each plot before animals were brought to the plot, when animals were stocked in the plot, and after animals were moved out of the plot (Figure 3). Study animals were cared for following the Tuskegee University Animal Care and Use Committee protocol throughout the study.

(**A**) (**B**)

Figure 3. Photoplots taken (**A**) before bringing animals into the study plots to assess the available vegetation and (**B**) after moving animals out of the plots to estimate the vegetation consumed by Kiko wethers and Katahdin rams stocked in woodlands, June–August 2018.

2.4. Weather Data

Secondary data for air temperature, air pressure, humidity, dew point, wind speed, and visibility for the study site and observation dates were downloaded from an online resource recorded at Auburn-Opelika airport for the Tuskegee Institute, AL, which was the nearest station, located around 34 km from the research site.

2.5. Diurnal Behavior and Distribution Pattern

A study on diurnal (dawn–dusk) behavior and distribution pattern of animals was conducted as described in a previous study [20]. Once animals were stocked in study plots (goats and sheep in separate plots), two days were allocated for them to adjust in each plot. On Day 3, two observers (one for goats and another for sheep) observed the diurnal behavior and distribution pattern of animals and recorded the observations on the pre-structured observation sheets every 10 min. Observations were repeated at each rotational stocking in each study plot, resulting in three observation days per animal species (5 June to 12 August 2018), daily average duration of 13:30 h to 14:30 h, and 516 total observations over the study period. Observation sheets were specific to each study plot, showing different zones, locations of water troughs, mineral feeders, and shelters, and notation for behavior categories such as grazing, browsing, loafing, lying, and debarking [19,20,24]. Observers placed themselves on the adjacent plots in such a way that they could easily observe animals without letting the animals notice the observers. When animals were not visible from the observers' location, they moved quietly and gently to a new location from where they could see animals clearly to avoid animals sensing such movement and the presence of any observer near them. Changing the observation location continued throughout the observation day as needed.

2.6. Data Analyses

Statistical analyses for animal behavior (percentage of total time spent by animals on different behavior categories), distribution pattern (percentage of total time spent by animals in different zones), distribution evenness index (DEI), and weather data were conducted as described in a previous study [20]. Briefly, all observation data were grouped into three diurnal periods: morning (dawn–1100 h), midday (1100–1500 h), and post-midday (1500 h–dusk). This grouping of data into different diurnal periods helped to relate animals' behavior and distribution patterns to the varying weather conditions within a day from morning to evening [19,25]. Since the behavior and weather data were correlated (variables within each data set), multivariate analysis of variance (MANOVA) was used to analyze them [19]. The MANOVA option takes care of the correlation existing among the dependent variables used in the datasets and determines the effects of explanatory variables on the set of dependent variables used in the model at once. Assumption of independence was checked with the residual plots and no issues were found. Animal distribution and vegetation height data were analyzed using general linear model (GLM) procedure with analysis of variance (ANOVA) option in SAS 9.4. The level of significance (α) was set at 5%. The difference among means was assessed using Tukey's multiple comparison test.

Model used for analyzing data:

1. Animal behavior-GLM procedure with MANOVA option in SAS 9.4

$$Y1_{ij}Y2_{ij}Y3_{ij} \ldots Yn_{ij} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + e_{ij}$$

MANOVA h = Animal species, diurnal period, and the interaction between animal species and diurnal period.

where $Y(1\text{–}n)_{ij}$ = value of an observation taken for the ith animal species, in jth diurnal period, (Y1–Yn—behavior categories—grazing, browsing, loafing, and lying), μ = grand mean, α_i = main effect of the ith animal species (i = 1–2), β_j = main effect of the jth diurnal period (j = 1–2), $(\alpha\beta)_{ij}$ = interaction effect of ith animal species and jth diurnal period, and e_{ij} = error associated with the ith animal species and jth diurnal period.

2. Weather data-GLM procedure with MANOVA option in SAS 9.4

$$Y1_iY2_iY3_i = \mu + \alpha_i + e_i$$

MANOVA h = Diurnal period.

where $Y_i(1\text{–}3)$ = value of weather variables for the ith diurnal period (i = 1–3), μ = grand mean, α_i = main effect of ith diurnal period, and e_i = error associated with ith diurnal period.

To determine the effect of Zones and diurnal periods on animal distribution, the animal distribution data were analyzed using the GLM with ANOVA option in SAS 9.4. Zones and diurnal periods were independent variables and animal distribution patterns were dependent variables. For the analysis of vegetation height, zones were the independent variables and vegetation height was dependent variable.

Similarly, DEI, which is a measure of uniformity of animal distribution patterns in a grazing landscape, was calculated as described previously [20] by using the equation presented below [26].

$$DEI = \left(- \sum_{i=1}^{z} pi \ln pi \right) / \ln z$$

where pi = the proportion of wethers or rams present in a particular zone at a given observation point in time, z = the number of zones in the study plot. A value of 0.001 was assigned to zones with no animals at the specific observation time to make the mathematical calculations feasible.

The set of DEI data was assigned to three different diurnal periods (morning, midday, and post-midday), as done with the other data sets, and analyzed to determine the effect of animal species on the distribution evenness using the Kruskal–Wallis rank-sum test [27], a non-parametric analysis method in R v 3.4.4, as the data did not meet the criteria for normal distribution required for a parametric analysis method. Multiple means were compared by using the Dunn test. An animal species (goat and sheep) comparison for DEI was analyzed separately for each diurnal period (morning, midday, and post-midday) by using the model presented below:

$$H = \frac{12}{n(n+1)} \sum_{i=1}^{k} \frac{R_i^2}{n_i} - 3(n+1)$$

where H = test statistic, n_i (i = 1, 2, 3, . . . , k) = sample size for each of the k groups (k = 1–2 for animal species and k = 1–3 for diurnal periods), R_i = the sum of ranks for group (animal species or diurnal periods as applicable).

3. Results

3.1. Weather Parameters

Of all the diurnal periods, the highest humidity ($p < 0.01$) and lowest wind speed ($p < 0.05$) occurred in the morning (Table 1). Air temperature, air pressure, dew point, and visibility were not different among the diurnal periods.

Table 1. Weather parameters for different diurnal periods of behavior observation days at the study site, June–August 2018.

Weather Variables	Diurnal Period		
	Morning (Dawn–1100 h)	Midday (1100–1500 h)	Post-Midday (1500 h–Dusk)
	LS Means ± SE		
Air temperature (°C)	24.6 ± 1.57	26.6 ± 2.03	28.3 ± 1.81
Air pressure (mm hg)	30.1 ± 0.02	30.1 ± 0.03	30.0 ± 0.03
Humidity (%)	75.1 ± 2.64 ^{a,**}	53.2 ± 3.40 ^{b}	61.4 ± 3.04 ^{b}
Dew point (°C)	19.5 ± 0.75	19.5 ± 0.96	20.1 ± 0.86
Wind speed (Km/h)	8.5 ± 0.68 ^{b}	11.6 ± 0.88 ^{a,*}	9.9 ± 0.79 ^{a,b}
Visibility (Km)	14.8 ± 0.58	16.1 ± 0.75	16.1 ± 0.67

^{a,b} LS means with different superscripts in a row differ (* $p < 0.05$, ** $p < 0.01$). Km/h—Kilometers per hour; Km—Kilometers; LS means—Least square means; SE—Standard error.

3.2. Vegetation Height

Zone 1, the control area, had the tallest understory vegetation followed by Zones 4, 3, and 2 ($p < 0.01$) during the study period (Figure 4). Lower vegetation heights in cutting treatments, mostly in Zones 2 and 3, could provide animals with greater access to available plants compared to areas with higher vegetation heights, such as Zones 1 and 4.

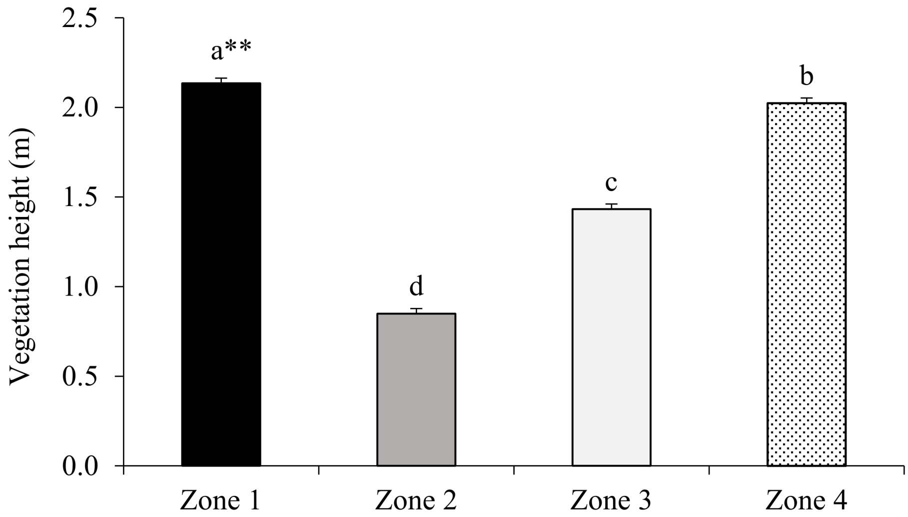

Figure 4. Understory vegetation heights (LS means ± SE) in different zones in woodlands, June–August 2018, Atkins Agroforestry Research and Demonstration Site, Tuskegee University, Tuskegee, AL, USA (^{a,b,c,d} LS means with different superscripts between different study zones differ, ** $p < 0.01$). Zones 1 to 4 are defined in Figure 1.

3.3. Animal Behavior in Different Zones

Animal behavior was different across zones ($p < 0.05$). Animals lied down mostly in Zone 5 ($p < 0.01$) and used other zones for feeding (Table 2). Wethers browsed predominantly in Zone 3 (Figure 4) (44% of the total browsing time; $p < 0.05$) and grazed mostly in Zone 2 (50% of the total grazing time; $p < 0.01$). Rams grazed predominantly in Zones 2 (38% of the total grazing time) and 3 (29% of the total grazing time) while browsing mostly in Zone 2 (45% of the total browsing time), followed by Zones 1 and 3 (27% of the total browsing time in each) ($p < 0.05$). Animals spent most time on feeding activities in Zones 2 and 3 (wethers—70%, rams—69%).

Table 2. Diurnal (dawn–dusk) time spent by Kiko wethers and Katahdin rams in woodland, June–August 2018.

Animal Species	Zone	Behavior Category			
		Grazing	Browsing	Loafing	Lying
		LS Means ± SE (%)			
Kiko wethers	1	0 ± 0.3^{b}	1 ± 1.4^{c}	0 ± 0.6^{c}	0 ± 1.5^{c}
	2	$2 \pm 0.3^{a,**}$	11 ± 1.4^{b}	3 ± 0.6^{b}	7 ± 1.5^{b}
	3	0 ± 0.3^{b}	$17 \pm 1.4^{a,*}$	0 ± 0.6^{c}	0 ± 1.5^{c}
	4	$1 \pm 0.3^{a,b}$	10 ± 1.4^{b}	$2 \pm 0.6^{b,c}$	$3 \pm 1.5^{b,c}$
	5	$1 \pm 0.3^{a,b}$	0 ± 1.4^{c}	$7 \pm 0.6^{a,*}$	$36 \pm 1.5^{a,**}$
Katahdin rams	1	2 ± 1.1^{c}	$3 \pm 0.7^{a,b}$	1 ± 1.1^{c}	1 ± 1.4^{c}
	2	$9 \pm 1.1^{a,*}$	$5 \pm 0.7^{a,*}$	$15 \pm 1.1^{a,**}$	9 ± 1.4^{b}
	3	$7 \pm 1.1^{a,b}$	3 ± 0.7^{a}	3 ± 1.1^{c}	0 ± 1.4^{c}
	4	$3 \pm 1.1^{b,c}$	$0 \pm 0.7^{b,c}$	0 ± 1.1^{c}	0 ± 1.4^{c}
	5	$3 \pm 1.1^{b,c}$	0 ± 0.7^{c}	9 ± 1.1^{b}	$26 \pm 1.4^{a,**}$

^{a,b,c} LS means with different superscripts in a column for each animal species differ (* $p < 0.05$, ** $p < 0.01$). Zones 1 to 5 are defined in Figure 1.

3.4. Animal Distribution in Different Zones

Vegetation height had an effect on the distribution of both animal species in the landscape ($p < 0.05$). Wethers spent the predominant time in Zone 5 (44%, $p < 0.0001$), while rams spent the predominant time in Zones 2 (37%) and 5 (36%, $p < 0.05$) (Figure 5). Zone 1 was the least visited area by wethers, while Zones 1, 3, and 4 by rams. Both animal species visited Zone 1 the least.

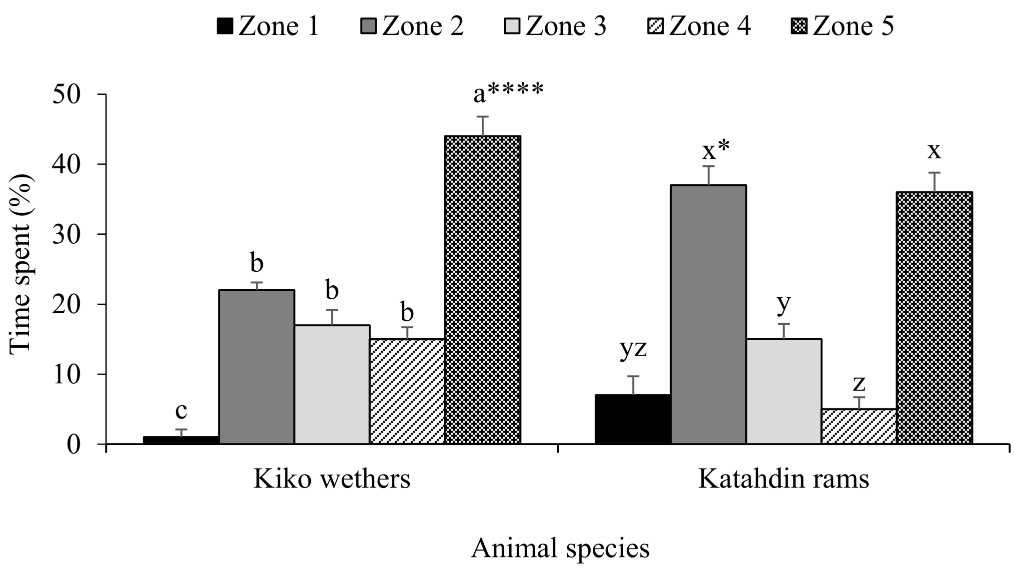

Figure 5. Diurnal (dawn–dusk) time (LS means ± SE) spent by Kiko wethers and Katahdin rams in different zones in woodlands, June–August 2018 ($^{a,b,c\ x,y,z}$ LS means with different superscripts within each animal species differ; * $p < 0.05$, **** $p < 0.0001$). Zones 1 to 5 are defined in Figure 1.

3.5. Influence of Diurnal Period on Animal Behavior

The diurnal period influenced the feeding and lying behavior of both species ($p < 0.05$). Grazing ($p < 0.05$) and browsing ($p < 0.0001$) behaviors of wethers were concentrated during the post-midday period and lying during the midday period ($p < 0.05$) (Table 3). Similar behavior was shown by rams, with most time spent on grazing ($p < 0.0001$) during the post-midday period and lying during the midday period. However, rams browsed mostly in the morning ($p < 0.05$).

Table 3. Diurnal (dawn–dusk) time spent by Kiko wethers and Katahdin rams in woodlands, June–August 2018.

Animal Species	Diurnal Period	Behavior Category			
		Grazing	Browsing	Loafing	Lying
		LS Means ± SE (%)			
Kiko wethers	Morning (Dawn–1100 h)	1 ± 1.1^{b}	33 ± 3.9^{b}	15 ± 2.0	52 ± 4.0^{b}
	Midday (1100–1500 h)	3 ± 1.2^{b}	19 ± 4.6^{b}	9 ± 2.3	$69 \pm 4.7^{a,*}$
	Post-midday (1500 h–Dusk)	$8 \pm 1.1^{a,*}$	$63 \pm 4.2^{a,****}$	10 ± 2.1	20 ± 4.3^{c}
Katahdin rams	Morning (Dawn–1100 h)	19 ± 3.1^{b}	$18 \pm 2.2^{a,*}$	34 ± 3.3	29 ± 4.4^{b}
	Midday (1100–1500 h)	14 ± 3.7^{b}	4 ± 2.6^{b}	23 ± 3.9	$59 \pm 5.1^{a,****}$
	Post-midday (1500 h–Dusk)	$40 \pm 3.4^{a,****}$	11 ± 2.3^{b}	27 ± 3.6	23 ± 4.7^{b}

^{a,b,c} LS means with different superscripts in a column for each animal species differ (* $p < 0.05$, **** $p < 0.0001$).

3.6. Influence of Diurnal Period on Animal Distribution

The time of day influenced the time spent by both species in different zones ($p < 0.05$) (Table 4). In Zones 1 ($p < 0.05$) and 3 ($p < 0.0001$), wethers spent the most time during the post-midday period, while in Zone 5, they spent most time during the midday period ($p < 0.05$). Similarly, rams spent the most time in Zone 1 ($p < 0.05$) in the morning, Zone 3 during the post-midday period ($p < 0.01$), and Zone 5 ($p < 0.001$) during the midday period. Wethers were distributed more evenly in the post-midday period, with a distribution evenness index (DEI) value of 0.16 vs. the morning (DEI—0.08; $p < 0.01$) and midday periods (DEI—0.05; $p < 0.0001$).

Table 4. Diurnal (dawn–dusk) time spent by Kiko wethers and Katahdin rams in woodlands, June–August 2018.

Animal Species	Diurnal Period	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
		LS Means ± SE (%)				
Kiko wethers	Morning (Dawn–1100 h)	0 ± 0.6^{b}	27 ± 4.0	8 ± 3.2^{b}	19 ± 3.3	45 ± 4.3^{b}
	Midday (1100–1500 h)	0 ± 0.8^{b}	19 ± 4.7	3 ± 3.7^{b}	14 ± 3.8	$64 \pm 5.1^{a,*}$
	Post-midday (1500 h–Dusk)	$3 \pm 0.7^{a,*}$	20 ± 4.3	$40 \pm 3.4^{a,****}$	11 ± 3.5	26 ± 4.6^{c}
Katahdin rams	Morning (Dawn–1100 h)	$12 \pm 2.5^{a,*}$	40 ± 4.8	13 ± 3.4^{ab}	7 ± 2.1	28 ± 4.4^{b}
	Midday (1100–1500 h)	6 ± 3.0^{b}	31 ± 5.6	6 ± 3.9^{b}	1 ± 2.4	$55 \pm 5.2^{a,****}$
	Post-midday (1500 h–Dusk)	3 ± 2.7^{b}	39 ± 5.1	$23 \pm 3.6^{a,**}$	5 ± 2.2	29 ± 4.7^{b}

[a,b,c] LS means with different superscripts in a column for each animal species differ (* $p < 0.05$, ** $p < 0.01$, **** $p < 0.0001$). Zones 1 to 5 are defined in Figure 1.

3.7. Effect of Animal Species on Diurnal Behavior

Diurnal behaviors were significantly different between Kiko wethers and Katahdin rams throughout the study period that lasted for 13:30 to 14:30 h ($p < 0.01$). Wethers (46%) and rams (35%) showed predominantly lying behavior (Figure 6). Wethers lied down for a longer time than rams ($p < 0.01$). Browsing was the dominant feeding behavior of wethers (39%), which was much higher than that of rams ($p < 0.0001$). In contrast, grazing was the dominant feeding behavior of rams (24%), and was much greater than that of wethers ($p < 0.0001$). Rams loafed for a longer time (28%) compared to wethers (11%) ($p < 0.0001$). Animals did not debark pine trees during the study. The DEI of wethers was significantly higher than rams during the morning ($p < 0.01$) and post-midday periods ($p < 0.0001$) (Figure 7).

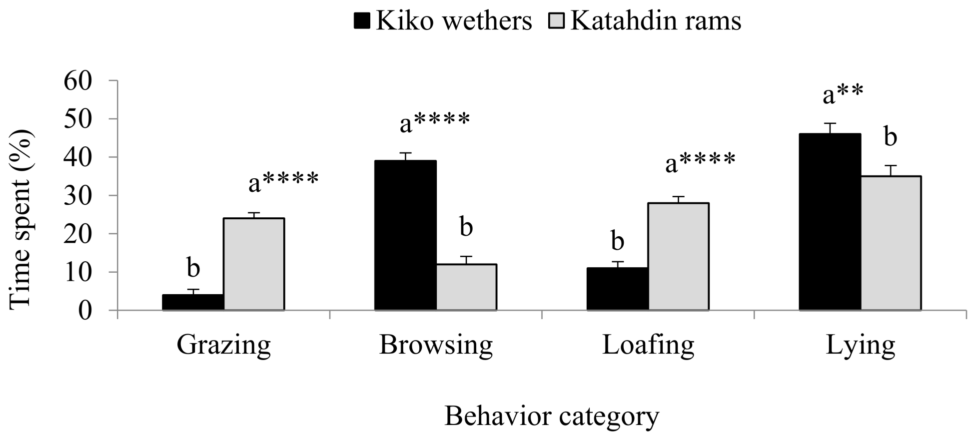

Figure 6. Diurnal (dawn–dusk) time (LS means ± SE) spent by Kiko wethers and Katahdin rams in woodlands, June–August 2018 ([a,b] LS means with different letters within each behavior category differ; ** $p < 0.01$, **** $p < 0.0001$).

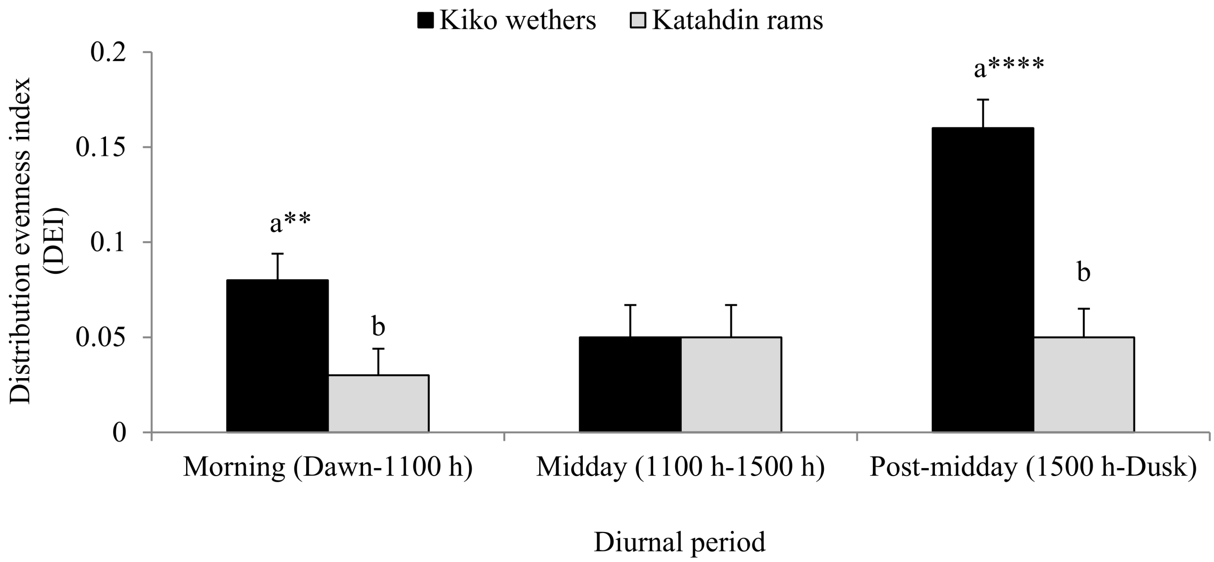

Figure 7. Distribution evenness index (DEI) (LS means ± SE) of Kiko wethers and Katahdin rams in woodlands, June–August 2018 ([a,b] LS means with different letters within each diurnal period differ; ** $p < 0.01$, **** $p < 0.0001$).

4. Discussion

4.1. Influence of Vegetation Height on Animal Behavior and Distribution

We found a significant influence of the height of understory vegetation in woodlands on the behavior and landscape-use pattern of Kiko wethers and Katahdin rams in this study. Wethers browsed mostly in Zone 3, which was dominated by woody species with an average vegetation canopy height of 1.4 m. Wethers grazed for a very short time, mostly in Zone 2, which had plenty of herbaceous species grown to an average height of 0.8 m from the ground surface. A longer time spent by wethers on browsing (44% of total feeding time) versus grazing (0%) in areas where the vegetation canopy was available to an average height of 1.4 m, which shows the importance of lowering and maintaining the non-timber (non-pine) vegetation within the comfortable reach of goats in woodlands. Although there was an abundance of browse vegetation in Zone 4, where the average canopy height was 2.0 m, goats spent much less time (41%) browsing here compared to Zone 3. The time spent by goats on browsing in Zone 1, where no manual intervention was made in altering the non-pine vegetation height, was much lower (94%) than the time they spent in Zone 3 on browsing. Similar findings were reported in our previous study during fall [20]. With these findings, the current research revealed that maintaining the browse vegetation at an appropriate height provides comfortable access to animals and promotes the utilization of such vegetation in woodlands. In our previous study, we demonstrated that goats and sheep consumed foliage from an average maximum height of 1.6 m and 1.1 m, respectively, in woodlands [28]. Even though the browsing behavior of goats has been reported as a dominant feeding behavior, with some possible reasons for such behavior explained in previous studies [24,29,30], the current study is the first to determine the effect of vegetation height on the browsing behavior of goats in woodlands.

Similar to wethers, rams' preference for feeding and non-feeding behavior was influenced by the height of understory vegetation while stocked in woodlands. Rams preferred Zones 2 and 3 for feeding activities as these zones had shorter vegetation canopy height, 0.8 m and 1.4 m, respectively, compared to Zones 1 and 4. Rams spent 69% of their total feeding time in these zones, where 67% of the total feeding time was spent on grazing and 33% on browsing. Although grazing as the dominant feeding behavior of sheep has been reported in previous studies [24,31,32], their preference for certain areas based on the vegetation height is the novel finding of the current study. Additionally, the findings of the current study emphasize the value of mixed species grazing (goats and sheep) to utilize the diversified vegetation available in woodlands that is managed to promote understory vegetation growth and utilization, and minimize the competition of non-pine vegetation with pine trees. Zone 1 was the least visited area by both animal species because of its denseness with woody plant species and the most foliage remaining beyond the reach of animals. The areas with sparse vegetation, shelters, and watering facilities (Zone 5) were used by animals for lying or resting. These results indicate that openness and the availability of ample vegetation within the reach of animals are important for the efficient use of understory foliage in woodlands. This finding has presented a new insight for tremendously improving woodland grazing strategy, which involves lowering the height of non-timber species to desirable levels and maintaining the regrowth within the reach of grazing animals. By implementing this new management approach, producers can derive additional benefits over the conventional practice of woodland grazing that only includes rotational stocking of animals after developing grazing facilities to harvest the existing understory vegetation without any management of non-timber or timber species. While individual animal behavior were not accounted for in this study, we believe the results are applicable to similar animal populations, environmental conditions, and grazing systems, as used in the current study.

4.2. Influence of Diurnal Period on Animal Behavior and Distribution

Diurnal periods had a significant effect on feeding and lying activities of goats and sheep. Feeding activities were concentrated mostly during the post-midday period. Several researchers have reported similar findings from studies conducted in different grazing systems, such as woodlands [20], silvopastures [19,24,33], and the Mongolian steppe [34]. Goats grazed for less time in the morning due to less conducive environmental conditions (cooler temperature, higher humidity, and possible dew) as compared to evening hours [19]. In the current study, the morning temperature was lower while the humidity was higher than during other parts of the day. Similar to the results reported by previous studies [19,20,24], animals grazed until late evening in the current study. Lying behavior was predominant during the midday period, which could be because of the direct sunlight falling on the ground (perpendicular or close to that angle) thereby creating less or no shading in the grazing lands vs. during morning or post-midday hours. The direct sunlight during the midday period might have caused discomfort in grazing animals, leading them to rest in the shade and/ or shelters. Previous studies conducted in woodlands during fall [20] and in silvopastures during the cool-season-grazing period have reported similar results [19,24].

Another reason for the lying behavior of animals during the midday period could be because of the higher wind speed during this time versus the morning period in the current study. Goats preferred indoor conditions under light (0.5 m/s) to medium (4 m/s) windy conditions [35]. In addition, a high temperature (26.6 °C) could have caused more lying behavior of animals during the midday period, as this temperature was above the thermoneutral zone of goats (10–20 °C) and towards the upper limit of sheep (21.1–31.1 °C) [36]. Similarly, a predominant lying activity for goats and sheep was reported during the midday period when the humidity was lower than reported in the current study (47.3%) and the temperature was 24.5 °C [24]. Goats were distributed most evenly during the post-midday period, when their feeding activities were predominant. This might have resulted from their dispersal in search of their preferred foliage. A previous study has reported goats' greater DEI in the spring vs. winter and during midday vs. morning in silvopastures due to more conducive weather conditions in the former season and diurnal period [19]. These authors showed higher DEI values occurring during the diurnal periods, when animals were exhibiting greater feeding activities. Understanding diurnal variation in behavior of goats and sheep could benefit small farmers, who have small woodland holdings and few animals, by targeting animal intergation in such grazing facilities during their active feeding periods, thereby saving time and management costs.

4.3. Species Effect on Behavior and Distribution Pattern

Wethers browsed for a longer time (69%) compared to rams, while rams grazed for a longer time (83%) than wethers. Browsing as a dominant feeding activity of goats and grazing for sheep have been reported in several studies conducted in non-woodland systems, showing goats' browsing activity ranging from 45% to 63% of the total observation time, while sheep browsed for 12% to 18% of the total observation time [13,24,37,38]. Similarly, in another study, goats browsed for 75% of the total feeding time and sheep grazed for 73% of the total feeding time, while they co-grazed in rangelands dominated by shrubs and herbaceous annual grasses [39]. The difference in the foraging behavior of goats and sheep could be due to difference in their anatomical structures. In general, goats have mobile upper lips and prehensile tongues that allow them to select leaves of browse species [30], while the short lips and broad muzzle in sheep facilitate the intake of grasses and forages growing close to the ground [32]. The current and previous study findings support the fact that when there are different types of vegetation available, goats are more inclined to browse, and sheep are more inclined to graze as compared to each other irrespective of the grazing system. The different foraging behavior of sheep and goats indicates that co-grazing of these species would be more effective to utilize the grazing lands with diverse vegetation than grazing with either of the species alone.

Time spent loafing remained less (61%) for Kiko wethers than Katahdin rams in this study. This could be because of rams traveling more within the landscape searching for their preferred vegetation. However, the availability of sufficient woody plants in study plots for goats to browse might have minimized their time spent searching for the foliage of their choice. In contrast to the finding of the current study, a study reported that goats loafed for a longer time than sheep with or without confinement in silvopasture plots [24]. These authors mentioned that there were plenty of planted herbaceous forages in silvopasture plots, where sheep spent the most time grazing, and woody species outside the silvopasture plots, where goats traveled to browse when the silvopasture plot gate was left open (non-confinement). Goats lied down for a longer time (24%) compared to sheep in the current study. This could be because of sheep spending more time searching for food. Wethers were spread across the landscape more evenly in the morning (63%; $p < 0.01$) and post-midday (69%; $p < 0.0001$) periods than rams. This could be because of a stronger flocking behavior of sheep than goats. Another reason for goats' more even distribution could be because of their greater preference for a wide range of plant species available throughout the landscape, causing them to spread more widely in the grazing land [40] compared to sheep. Similar to the findings of the current study, greater DEI values for wethers than rams were reported when they were grazed in woodlands separately [20] or co-grazed in silvopastures [24].

Animals did not debark pine trees in the current study. However, debarking behavior of Kiko wethers on southern pine trees has been reported [19,24] when they were rotationally stocked in silvopasture plots. Nevertheless, sheep did not debark any pine trees in silvopastures [24]. Contrary to the findings of these authors, sheep debarked the younger stand of pine trees (2–4 years old) heavily (35%) in low tree density plots and less (<5%) in denser stands [41]. In the current study, pine trees were 13 years old and there were various understory woody species, giving animals plenty of variety to choose from. The results of the current study show that it is safe to rotationally stock Kiko wethers and Katahdin rams in woodlands containing 13-year-old or older stands of southern pines and numerous understory woody plant species with abundant foliage available for grazing animals.

5. Conclusions

Understory vegetation height and diurnal period highly influenced the behavior and distribution patterns of animals in woodlands. Wethers selected areas with more browse species available within their easy reach (1.4 m) for browsing, while rams grazed mostly in areas with more herbaceous species mixed with woody species available at a low height (0.8 m). Animals visited the area with densely populated woody plants with limited foliage available within their reach the least. Open space (dry and sparsely vegetated) with shelters, mineral feeders, and watering facilities was mostly preferred by animals for lying or resting. Animals preferred to browse and graze during the post-midday period and lie down in the midday period. Neither of the animal species debarked pine trees. This study has established that small ruminants can efficiently utilize understory vegetation in woodlands available within their reach and located in areas they can easily move through compared to areas with dense woody species growing beyond their reach. Such a landscape-use pattern of animals confirms the importance of lowering the height of non-timber plants and maintaining their regrowth within the reach of grazing animals to increase the utilization of woodland-understory vegetation. The current study also found a strong diurnal periodicity of animals when performing different behaviors and utilizing various areas with diverse vegetation characteristics and facilities in woodlands. While individual animal behavior were not accounted for in this study, we believe the results are applicable to similar animal populations, environmental conditions, and grazing systems, as used in the current study.

Author Contributions: U.K. designed the experiment. S.B. and S.P. collected behavior and distribution data. S.B. and U.K. performed statistical analyses and interpreted the results. S.B. prepared the manuscript and U.K. reviewed and edited it. S.B. and U.K. finalized the manuscript. All authors have read and agreed to the published version of the manuscript.

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