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Distance from Night Penning Areas as an Effective Proxy to Estimate Site Use Intensity by Grazing Sheep in the Alps

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Abstract: Livestock site use intensity can vary widely across a grazing area due to several factors such as topography and distance from sheds and water sources. However, an accurate approximation of animal site use should be assessed for each part of the grazing area to apply effective management strategies. In the Alps, shepherds manage sheep through lenient supervision during the day and confining the animals in temporary night penning areas (TNPA) at night. In our case study, we assessed sheep site use over the grazing area with global positioning system (GPS) collars and calculated the sums of inverse distances from all TNPA (unweighted and weighted on the number of penning nights) and from all water sources, as well as the slope, on 118 sample points. We assessed the relative importance of these variables in affecting site use intensity by animals using different sets of models. Both the unweighted and weighted distances from TNPA were found to be the most important factors. The best fitting model accounted for the weighted distance from TNPA and the distance from water, but the latter showed a lower relative importance. Our study suggests that using the distance from TNPA, preferably weighted on the number of penning nights, is an effective proxy to estimate the spatial variability of sheep stocking rate during grazing in the Alps.

Keywords: drinking sources; GIS; grazing behavior; pastures; spatial distribution; stocking rate

1. Introduction

Livestock grazing is useful for the implementation of management strategies that address the restoration, improvement, or maintenance of grassland vegetation [1]. As a basic criterion, the effectiveness of such strategies depends on livestock stocking rate, which can strongly affect nutrient availability, plant species diversity, and vegetation dynamics [2,3]. Stocking rate can be quantified for the entire grazing area as the overall average number of animals per hectare and time unit. However, the overall stocking rate dismisses animal site use intensity, which can have wide variability over the grazing area due to differences in forage quality and quantity, topography (e.g., slope), animal behavior, and the presence of attractive points such as drinking troughs, sheds, and milking areas [4–9]. Animal site use can be measured directly at each site of the grazing area through global positioning system (GPS) collars, visual observations, etc. Otherwise, it can be estimated through indirect measures (proxies) such as the distance from congregation areas like sheds or water sources. These proxies usually assume that animal site use decreases with increasing distances from congregation areas [10]. More specifically, several authors [6,11,12] proved that inverse distances from congregation areas were linearly related to animal site use. However, the reliability of such proxies was rarely validated with direct measurements [5,13] and, to date, no comparative studies have been conducted to assess the different proxies.

In the Alps, a reliable proxy to estimate site use intensity by animals would be particularly useful since pastures are characterized by a high spatial heterogeneity due to changes in topography and vegetation. In these environments, sheep flocks are commonly managed by shepherds in a daily routine, which entails lenient supervision during the day and confinement in temporary areas during the night (temporary night penning areas—TNPA) [14]. TNPA confine flocks to areas of about 1–3 m^2/sheep by means of electrified fences, and they are moved over the grazing area every one-four days, generally located in sites with homogeneous topographic conditions and limited presence of rocks. TNPA help to prevent wolf attacks and, occasionally, contrast shrub encroachment and improve grassland vegetation due to livestock trampling and dung deposition [15,16]. TNPA, as well as water sources, gentle terrains, and milking areas, can therefore be considered the main congregation areas that affect grazing sheep site use in the Alps.

Our study aims to implement a method that uses a GPS/GIS assessment to determine the relative importance of distance from TNPA, distance from water sources, and slope in affecting sheep site use intensity during grazing.

2. Materials and Methods

The study was conducted in the northwestern Italian Alps (45°08′ N, 7°06′ E) in the Site of Community Interest 'Oasi xerotermiche della Valle di Susa—Orrido di Chianocco e Foresto' (SCI IT1110030), an area characterized by a xerothermic and sub-Mediterranean climate with an average annual temperature of 11 °C and an average annual precipitation of 670 mm [17]. Slopes ranged from 4° to 65° (average 28°) and the elevation ranged from 510 to 1260 m a.s.l. The grazing area was characterized by homogeneous seminatural dry grasslands dominated by *Stipa pennata* L., *Bromus erectus* Hudson, and *Festuca ovina* s.l.

From 15 April to 16 May 2015, a flock of 250 Bergamasca (meat breed) sheep grazed over a 45 ha area. Fourteen TNPA (average area: 737 ± 74.0 m^2) were progressively set out over the area and each was used to fence the sheep in for two to three consecutive nights (2.3 ± 0.47; mean ± standard deviation). During the period, four water sources homogeneously distributed over the grazing area were also made available to the sheep.

Ten randomly selected sheep were equipped with GPS collars (Model Corzo, Microsensory SLL, Fernàn Nùñez, Spain; 5 m accuracy) and tracked at 15 min intervals for the entire duration of the experiment. The tracked sheep were dry ewes, two to four years old, weighing approximately 70 kg, and regularly fed on Alpine pastures during the summer. During the study, the flock experienced this specific grazing area for the first time. We assumed the 10 selected sheep as representative of the entire flock, since sheep are a livestock species characterized by a highly cohesive grazing behavior.

We randomly generated 160 sample points over the grazing area and assessed the number of GPS fixes within a 30 m buffer zone around each of them as a direct measurement of the site use intensity by grazing sheep [13,16]. The 30 m distance was considered to encompass a zone with homogeneous vegetation and topographic conditions. The sample points were spaced 60 m apart to avoid overlaps between buffers. When a buffer zone exceeded the grazing area, the number of GPS fixes included was weighted by the within-the-grazing-area portion and rounded to the nearest integer value. Forty-two sample points were excluded from further analysis, as they exceeded the boundaries of the grazing area for more than 25% of their buffer zone, so 118 sample points were retained.

According to the following formulas, for each sample point we calculated:

(i) the sum of inverse distances from all TNPA (hereafter 'unweighted distance from TNPA')

$$Unweighted\ d_{TNPA} = \sum_{i=1}^{i=14} \left(\frac{1}{d_i} \right) \tag{1}$$

where d_i is the distance from each TNPA;

(ii) the sum of inverse distances from all TNPA weighted on the number of consecutive penning nights for each of them (hereafter 'weighted distance from TNPA')

$$Weighted\ d_{TNPA} = \sum_{i=1}^{i=14}\left(\frac{n_i}{d_i}\right) \tag{2}$$

where d_i is the distance from each TNPA and n_i is the corresponding number of nights;

(ii) the sum of inverse distances from all water sources (hereafter 'distance from water')

$$d_{water} = \sum_{j=1}^{j=4}\left(\frac{1}{d_j}\right) \tag{3}$$

where d_j is the distance from each water source;

(iv) the slope, which is assessed as the average value of the buffer zone using a 10 m resolution digital terrain model [18].

Geographical analyses were conducted using Quantum GIS version 2.18.26 [19].

To assess the relative importance of (i) distance from TNPA (weighted and unweighted), (ii) distance from water, and (iii) slope in predicting the actual site use intensity by the sheep during grazing, we ran 11 generalized linear models (GLMs). We set the sheep site use intensity (i.e., the count of GPS fixes within each buffer zone) as response variable and set the distances from TNPA and from water as well as the slope in all possible combinations as explanatory variables. We specified a negative binomial error distribution for the GPS count and a logarithmic link function [20]. All explanatory variables were standardized (Z-scores) before performing GLMs to allow for the analysis of effect size by scrutinizing model parameters (β coefficients). Autocorrelation was tested using Pearson's correlation before running the GLMs. Residual deviance, percent of explained deviance (D^2), Akaike information criterion with small-sample correction (AICc), and Bayesian information criterion (BIC) were used to compare the goodness of the model fit. D^2 was calculated according to the following formula:

$$D^2 = \frac{\text{null deviance} - \text{residual deviance}}{\text{null deviance}}$$

where null deviance is the deviance of an intercept-only GLM and residual deviance is the deviance that remains unexplained after the model fit. Statistical analyses were performed using SPSS 25 (SPSS Inc., Chicago, IL, USA).

3. Results

The daily acquisition rate of the GPS devices refers to the total potential of daily fix acquisitions, and was 44.2 ± 2.54% (mean ± standard error). Explanatory variables showed a not significant ($p \geq 0.05$) or weak ($R \leq 0.25$) autocorrelation and all of them were retained in the models. Average values for the response and explanatory variables in buffer zones are provided in Table 1. According to the performed GLMs, the sheep site use was significantly related to the selected predictors (Table 2). More particularly, it was always positively affected by both unweighted and weighted distances from TNPA and the distance from water sources, but negatively by the slope. However, the slope effect was not significant when the distances from TNPA were weighted on the number of penning nights (M7 and M8). Among the explanatory variables, the distance from TNPA had the most influence (highest β coefficients) in all the models, followed by the distance from water and then by the slope. β coefficients increased for the distance from water and the slope in M9, M10, and M11, but their effect size was lower than those of the distances from TNPA.

Table 1. Summary statistics for the dependent and explanatory variables used in the models. Values apply to the 30 m buffer zone around the 118 random points. Numbers in brackets refer to formulas detailed in the Methods section. TNPA refers to temporary night penning areas.

Variable	Minimum	Mean	Maximum
Site use intensity (global positioning system (GPS) count)	0.00	35.14	434.00
Distance from TNPA—unweighted (m^{-1}) (1)	0.01	0.04	0.14
Distance from TNPA—weighted (m^{-1}) (2)	0.03	0.08	0.29
Distance from water (m^{-1}) (3)	0.02	0.10	1.67
Slope (°)	10.92	28.41	43.87

Table 2. Summary of generalized linear models (GLMs) of sheep site use intensity by different sets of explanatory variables. Numbers in brackets refer to formulas in the Methods section. β coefficients and significance levels are provided for each variable as results of the related GLM. Goodness of model fit (best values are highlighted in bold): D^2, explained deviance; AICc, Akaike's information criterion with small-sample correction; BIC, Bayesian information criterion. ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; *ns*, $p \geq 0.05$.

Generalized Linear Model	Distance from TNPA	Distance from Water	Slope	Residual Deviance	D^2 %	AICc	BIC
M1: Distance from TNPA (unweighted) (1)	1.43 ***	-	-	111.5	63.1	892.7	898.1
M2: Distance from TNPA (unweighted) (1) + distance from water (3)	1.41 ***	0.18 **	-	102.6	66.0	885.9	894.0
M3: Distance from TNPA (unweighted) (1) + slope	1.40 ***	-	−0.20 *	109.2	63.9	892.5	900.6
M4: Distance from TNPA (unweighted) (1) + distance from water (3) + slope	1.36 ***	0.21 **	−0.21 *	100.4	66.8	885.8	896.5
M5: Distance from TNPA (weighted) (2)	1.47 ***	-	-	107.4	64.5	888.6	894.0
M6: Distance from TNPA (weighted) (2) + distance from water (3)	1.43 ***	0.21 **	-	99.2	67.2	**882.5**	**890.6**
M7: Distance from TNPA (weighted) (2) + slope	1.44 ***	-	−0.12 *ns*	106.5	64.8	889.7	897.8
M8: Distance from TNPA (weighted) (2) + distance from water (3) + slope	1.39 ***	0.23 **	−0.15 *ns*	**98.2**	**67.5**	883.6	894.4
M9: Distance from water (3)	-	0.76 ***	-	282.6	6.5	1063.8	1069.2
M10: Slope	-	-	−0.62 ***	267.8	11.4	1048.9	1054.4
M11: Distance from water (3) + slope	-	0.96 ***	−0.63 ***	243.3	19.5	1026.6	1034.7

Lower AICc and BIC scores were obtained in models including distances from TNPA and specifically, in models based on weighted distances (M5, M6, M7, and M8). The lowest values in terms of residual deviance and D^2 were performed by M8, which considered weighted distance from TNPA, distance from water, and slope, although this latter variable was not significant. The same model deprived of slope (M6) showed the best fit according to AICc and BIC values.

4. Discussion

All GPS devices worked as expected with a satisfactory acquisition rate. However, the harsh morphology of the study area (i.e., very rocky, rough, and a steep mountainous environment) had a negative effect on the accuracy of GPS fix acquisition. This determined that the signal bounced off of a considerable proportion of GPS fixes out of the study area borders, so these were excluded from the analyses.

The present research highlighted the remarkable relationships that exist among site use intensity by grazing sheep and specific environmental/management predictors, namely, distance from night penning areas, distance from water, and slope. As expected, site use intensity was inversely related to the slope and directly related to the distance from TNPA and water sources in all GLMs we performed [5,21]. Specifically, the models that included the distance from TNPA (both unweighted and weighted, i.e., from M1 to M8) explained remarkable percentages of deviance (>63%, higher than shown in Putfarken et al. and in Dorji et al. [13,22]), which proved the pivotal role of TNPA in affecting sheep distribution during grazing. Instead, the distance from water sources and the slope showed a weaker influence, as demonstrated by their lower β coefficients. This was also observed in models based only on these variables (M9, M10, and M11), which had the lowest explained deviances, confirming the findings of other authors [13,22]. Nevertheless, unlike our study, previous studies did not compare different regressive models that consider environmental and management variables.

The models that included distances from TNPA (M1 to M8) also achieved the best fitting results in terms of AICc and BIC, which varied within a range of 10 points. Therefore, according to Burnham and Anderson [23], all of them can be considered as having comparable reliability. The limited differences among the models including the unweighted and weighted distances from TNPA may be due to the low variability in the number of penning nights among TNPA used in Equation (2), which resulted in distributions with a high similarity. Nevertheless, M6 (weighted distance from TNPA + distance from water) can be considered as the best fitting model as it presented the lowest AICc and BIC scores. Moreover, in this model, the relative importance of distance from water was lower (β coefficient was sevenfold smaller) than that of the weighted distance from TNPA, suggesting that the implementation of predictive models that include the distance from water sources could be of limited effectiveness. This finding was in contrast to the results of the study by Putfarken et al. [13], which highlighted a higher relative importance of the distance from the drinking trough as compared to the distance from the sheep shed. Nevertheless, in their trial study, they tested the effects of only one drinking trough and one sheep shed in different management conditions (i.e., higher stocking rate, longer grazing season, lowland mesotrophic grasslands, and with a cow and sheep mixed grazing system). Moreover, the distance of a given site from all available water sources could be difficult to assess in some situations, e.g., when linear water sources like mountain streams are available for livestock over the grazing area. Therefore, according to our results, the distance from TNPA, preferably weighted on the number of penning nights (Equation (2)), can be reasonably considered as the main driver and a suitable and easily measured proxy to estimate the spatial variability of sheep stocking rate during grazing.

Future research should avoid some shortcomings still evident in our study, such as (i) the short duration of the experiment, (ii) the low grassland forage variability related to the occurrence of one vegetation community, (iii) the limited number of tracked animals (avertible by selecting rotating collared sheep), and (iv) the lack of information about animal behavior activity (i.e., resting, grazing, and traveling categories). Nonetheless, the approach we propose, which is based on a comparison among different models including environmental and management predictors, could also be applied for other livestock species and categories, shepherding managements, vegetation types, and environments.

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