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Investigating vegetation biophysical and spectral parameters for detecting light to moderate grazing effects: a case study in mixed grass prairie

Research article

Xiaohui Yang[1], Xulin Guo[1]*

1 *Department of Geography and Planning, University of Saskatchewan, Kirk Hall, 117 Science, Saskatoon, SK, S7N5C8, Canada*

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Abstract: Identifying effective vegetation biophysical and spectral parameters for investigating light to moderate grazing effects on grasslands improves management practices on grasslands. Using mixed grasslands as a case study, this paper compares responses of vegetation biophysical properties and spectral parameters derived from satellite images to grazing intensity, and identifies the suitable biophysical and spectral parameters to detect grazing effects in these areas. Biophysical properties including cover, canopy height and Leaf area index (LAI) were measured in three sites with different grazing managements and one benchmark site in 2008 and 2009 in Grasslands PlaceTypeNational Park and surrounding provincial pastures, Canada. Thirteen vegetation spectral indices, calculated by statistically combining different spectral information, were evaluated. The results indicate that canopy height and the ratio of photosynthetically active vegetation cover to non-photosynthetically active vegetation cover (PV/NPV) showed significant differences between ungrazed and grazed sites. All spectral vegetation indices except the canopy index (CI) show significant differences between grazing treatments. Red-Near infrared (Red-NIR) based vegetation indices, such as Modified Triangular Vegetation Index 1 (MTVI1), Soil-adjusted Vegetation Index (SAVI), are significantly correlated to the PV/NPV. Green/Mid-infrared (Green/MIR) related vegetation indices, i.e. Plant Senescence Reflectance Index (PRSI) and Normalized Canopy Index (NCI), show significant correlation with canopy height. Models based on a linear combination of MTVI1 and SAVI were developed for PV/NPV and PRSI and NCI for canopy height. Models that simulated PV/NPV and canopy height show significant correlations with grazing intensity, suggesting the feasibility of remote sensing to quantify light to moderate grazing effects in mixed grasslands.

Keywords: grazing • grassland • spectral indices • vegetation biophysical properties

1. Introduction

Grazing is one of the most common land use forms in grasslands and more than 37.5 million km^2 of the world's arid regions are used for ranching [1]. Managing grasslands, either for conservation or animal production, thus requires a thorough understanding of grazing impacts on grasslands [2]. Grazing effects can be quantified by observing changes in vegetation properties such as vegetation cover, cover fractions, plant species diversity and production, all of which are commonly used for illustrating grazing effects [3–7].

The magnitude of grazing effects varies with grazing in-

*E-mail: xulin.guo@usask.ca

tensity, the length of grazing and grazing regimes applied [8, 9]. Among these factors, grazing intensity has been documented to have the most direct impact on grasslands in the short term [10]. Some studies have shown overgrazing to be harmful for grasslands as it can cause excess defoliation, grass nutrient loss, and pasture degradation [11]. Light to moderate grazing is suggested to be beneficial for grasslands as indicated by the grazing optimization hypothesis [12]. However, no consistent results are reported in existing research in regards to light to moderate grazing effects on grasslands. Patton et al. [13] indicated that moderate grazing in a Kentucky bluegrass-dominated rangeland can maintain a higher level of herbage production as compared to complete rest or overgrazing, while Belsky [14] and Painter and Belsky [15] reported no evidence that herbivory benefits grazed plants. Milchunas et al. [16] found that production was highest in ungrazed treatments, and decreased with increased grazing intensity in short-grass prairie.

The divergence of those results may firstly be explained by the differences in environment moisture of the study sites or the evolutionary history of grazing [17]. On the other hand, the selective behavior of herbivory results in vegetation that is grazed in some places, but left ungrazed in other areas. Limited vegetation information acquired from traditionally used field methods is unable to reflect vegetation condition in grazed sites—especially with large spatial extent, which affects grazing impact investigation.

Remote sensing-based techniques have been widely used in grazing studies to resolve the inherent limitation of field methods regarding their advantages in high temporal frequency and complete spatial coverage [18]. Spectral data are usually combined into spectral vegetation indices that are efficiently correlated with many vegetation biophysical and biochemical properties (e.g. biomass leaf area index, canopy cover, chlorophyll and nitrogen content) [19–25], and therefore have been used as proxies for many vegetation properties. Previous research has investigated grazing impacts based either on interpretation of remote sensing data or by combining them with ground measurements. In some studies, grazing was recognized by analyzing changes in vegetation biophysical properties or spectral indices as a function of distance from the watering point [4, 26]. Others have focused on dealing with assessing or monitoring overgrazing effects or grazing-induced grassland degradation [5]. Few studies have looked at how remote sensing may be utilized to develop complimentary indicators for studying light to moderate grazing impacts. Compared to overgrazing, the impacts caused by light to moderate grazing are less obvious. Thus, the documented vegetation spectral indicators for overgrazing detection may not be effective enough in detecting light to moderate grazing effects; however their assessments are important for allowing comprehensive recognition of impacts and protection from grassland degradation.

The goal of this study is to investigate the potential biophysical and spectral parameters to detect light to moderate grazing impacts. Initially, (1) responses of both ground measured vegetation properties and spectral data to grazing treatments were compared; then (2) relationships between grazing-sensitive ground variables and remotely sensed spectral indices were analyzed to test the feasibility of spectral indices as surrogates of ground indicators to detect grazing effects; and finally (3) the performances of identified spectral alternatives were further evaluated with ground grazing intensity data to address the feasibility of remotely sensed spectral parameters for detecting and monitoring light to moderate grazing effects in future studies.

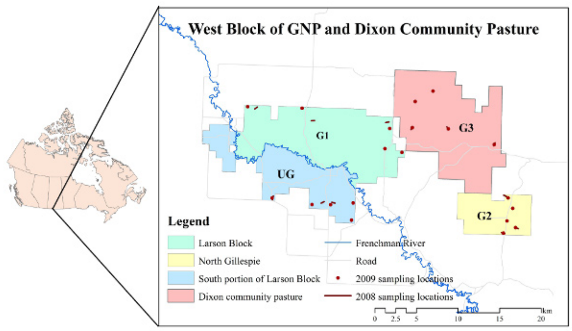
Grazing activities in the mixed grasslands of Grasslands National Park (GNP) and surrounding pastures were examined and used as a case study to achieve the above aims. These areas are excellent sites to investigate the light to moderate grazing effects for several reasons. First, grazing intensities in these areas are light to moderate and are considered lower than the recommended level for the purposes of restoring ecological integrity and maximizing long-term profits [27]. Secondly, a parcel in GNP exists where no disturbances occurred for approximately 23 years, providing a perfect benchmark site for investigating grazing effects. It is hard to find intact reference sites for grazing studies as most grasslands experience disturbances. Finally, although primary knowledge of light to moderate grazing impacts on mixed grasslands in many other regions is known [28–30], the impacts of grazing on this area have not been quantitatively measured and our knowledge about the characteristics of grasslands in this area is very limited.

2. Materials and methods

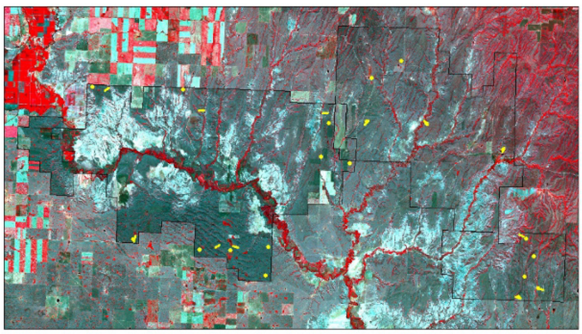
2.1. Study area description

The research was carried out in the Grasslands National Park (GNP) (49°N, 107°W) and surrounding community pastures, Saskatoon, Saskatchewan, Canada (Figure 1). This area is located along the United States border and represents the northern extent of mixed grasslands. The park spans approximately 906 km^2 in area and incorporates two discontinuous blocks, the West and East blocks. Land was first acquired by the park in 1984, and some areas of the park have been under protection from grazing for over 20 years [31].

This region is marked by a continental semi-arid climate



(a)



(b)

Figure 1. Study area, west block of GNP and Dixon community pasture (a) and a false –colour composite of SPOT 5 image (©SPOT image copyright CNES) taken on 28 June 2009 (b).

with dry, cold winters and warm, wet summers. The average temperature in July is 18.3°C, while the average January temperature is -12.4°C. Mean annual precipitation is approximately 325 mm [32]. Approximately half of the annual precipitation occurs in June, July and August. Three broad vegetation-landscape units occur in this area: riparian shrubland, upland grassland and valley grassland [33]. Upland grassland covers approximately two thirds of the park area. The dominant plant communities in upland grasslands are needle and thread (*Stipa comata Trin.& Rupr)*, blue grama grass (*Bouteloua gracilis (HBK) Lang. ex Steud*) and western wheatgrass (*Agropyron smithii Rydb*). Valley grasslands are dominated by western wheatgrass and northern wheatgrass (*Agropyron dasystachym*) along with high densities of shrubs and occasional trees. Common soil types in the park area are chernozemic and solonetzic soils [34].

2.2. Grazing regimes

In order to fully understand light to moderate grazing effects, four sites, namely the North portion of Larson block, the South portion of Larson block, the North Gillespie and the Dixon Community Pasture (hereafter refer as G1, UG, G2 and G3) were selected from within the study area (Figure 1). Three of them (G1, G2 and UG) are within the GNP and one (G3) is outside of the park. The details of grazing activities in all four sites are indicated in Table 1. Even though grazing intensities in the three grazed sites are slightly different they are all light to moderate grazing in that the grazing intensities are lower than the recommended level for this area. The grazing length is different in three grazed sites. Compared to G1 and G2, the length of total grazing time of G3 is longer. So, it is expected that the magnitude of grazing disturbance is relatively large in G3.

Table 1. Grazing regimes of study sites.

Study site	Grazing intensity (dropping/100 m^2)	Grazing history and strategy	Herbivore
G1	2.0	Year-long (12 month) grazing since 2006	Bison
G2	5.0	Fall grazing (May-September) since 2007	Cattle
G3	12.0	Rotation grazing for at least 100 years	Cattle
UG	0	Protection under grazing more than 20 years	None

Fire is another major factor affecting vegetation structure in grasslands. Uncontrolled wildfire is suppressed in the park areas as it poses a threat to human life, livestock, and natural resources. Prescribed burns are adopted in some places for management purposes. None of the four sites has been known to have experienced fire over past several decades, making grazing the only known disturbance to these sites.

2.3. Vegetation measurement

Field work was conducted from the end of May into early June of 2008 and 2009 in upland grasslands in each of the study sites (Figure 1). Different sampling methods were applied in 2008 and 2009. In 2008, three long transects formed by 128 quadrats with size 50 × 50 cm and 3-meter fixed interval were set up in upland grasslands in each site. Within each quadrat, vegetation variables including various cover components and LAI were collected. Percent cover of green grasses, forbs, shrubs, standing dead litter, mosses, lichens, and bare ground were estimated visually. Plant cover was estimated to the nearest 5% for cover values from 10% to 90% and to the nearest

Table 2. Computation formula of various spectral vegetation indices.

	Index Acronym	Equation	Description and use	Reference
Red-NIR based vegetation indices	NDVI: Normalized vegetation index	$(\rho nir - \rho red)/(\rho nir + \rho red)$	One of most used indices for green biomass estimation.	[38]
	SAVI: Soil-adjusted vegetation index	$(1 + L)(\rho nir - \rho red)/(\rho nir + \rho red + L)$ L=0.5	Minimizes soil brightness-induced variation based on a soil adjusted factor, L.	[39]
	ATSAVI (atmospheric adjusted soil adjusted vegetation index)	$\alpha(\rho nir - \alpha\rho red - b)$ / $(\alpha\rho nir + \rho red - ab + X(1 + a^2))$ X=0.08	Minimizes soil brightness-induced variation. The soil adjusted factors (a and b) need to be investigated for the specific area of interest	[40]
	RDVI: Renormalized difference vegetation index	$(\rho nir - \rho red)/\sqrt{\rho nir + \rho red}$	Suitable for low and high leaf area index values	[41, 42]
	PVI: Perpendicular vegetation index	$(\rho nir - \rho red - b)/\sqrt{1 + a^2}$	Minimizes the soil background influence based on the Euclidean distance to the soil line	[43]
	MTVI1: Modified Triangular vegetation index 1	$1.2[1.2(\rho nir - \rho green) \ -2.5(\rho red - \rho green)]$	Sensitive to leaf and canopy structure change and insensitive to pigment level change	[42]
	MCARI2: Modified chlorophyll absorption ratio index 2	$1.5[2.5(\rho nir - \rho red) - 1.3(\rho nir - \rho green)]$ / $\sqrt{(2\rho nir + 1)^2 - (6\rho nir - 5\sqrt{670}) - 0.5}$	More resistance to chlorophyll influence and sensitive to leaf area index	[42]
Green/MIR related vegetation indices	CI: Canopy index	$\rho mir - \rho green$	Linearize relationships with vegetation biophysical parameters using the MIR and the green bands	[44]
	NCI: Normalized canopy index	$(\rho mir - \rho green)/(\rho mir + \rho green)$	Linearize relationships with vegetation biophysical parameters using the MIR and the green bands	[44]
	RCI: Ratio cover index	$\rho mir/\rho red$	Able to detect canopy moisture condition	[45]
	NDCI: Normalized difference cover index	$(\rho mid - \rho red)/(\rho mir - \rho red)$	Response to canopy moisture condition	[45]
	PD54: Perpendicular difference vegetation index	$(\rho red - \rho green - b)/\sqrt{1 + a^2}$	Robust measure of the total amount of vegetation cover which includes both green and dry materials	[46]
	PSRI: Plant senescence reflectance index	$(\rho red - \rho green)/\rho nir$	Sensitive to Car/Chl ratio, and used to estimate leaf senescence	[47]

1% for cover less than 10% and greater than 90% [35]. LAI was measured using a LiCor-LAI-2000 Plant Canopy Analyzer. In 2009, a stratified random sampling method was used. In the upland grasslands of each study site five locations were selected as five replications. Two 100 m transects were set up in each sampling location perpendicularly at North-South and East-West directions. Taking the cross of the two transects as a start point, six 50 × 50 cm quadrats were placed along four arms. Distances between the quadrats and the start point were 2.5 m, 5 m, 10 m, 20 m, 30 m, and 50 m, respectively. In all, 24 quadrats were set up in each sampling location. Percent cover and LAI were measured for all quadrats using the same methods as those of 2008.

2.4. Dropping counts

In 2008, a row of quadrats with 2-meter intervals was set out perpendicularly to the long transect used for measuring vegetation biophysical properties. One hundred and twenty eight qudrats were set up for each transect, with 384 quadrats for each site. Each quadrat was a rectangle of 10 × 2 m. Since bison or cattle droppings are relatively durable and easily identifiable, they have been used as an indicator of grazing intensity in many studies [36, 37]. We counted the droppings within each quadrat; then the averages for 128 quadrats were used to indicate the grazing intensity for each location. The grazing intensity is expressed as droppings per 100 square meters.

2.5. Image data and processing

SPOT5 multispectral images (©SPOT image copyright CNES) for the study area were acquired on June 1, 2008 and June 28, 2009 with the overpass time as close to the field measurements as possible. The images were geometrically and radiometrically corrected using PCI Geomatics software (10.0). Radiometrics together with atmospheric corrections were done with the ACTOR2 module from PCI Geomatics software package. Twenty eight ground training points collected using GPS were applied to the geometrical correction. The accuracy is 0.35 pixels for the 2008 image and 0.45 pixels for the 2009 image, which represent 3.5 meters and 4.5 meters error on the earth's surface, respectively. Distortions caused by topography were corrected using a digital elevation model (DEM) with 20 m spatial resolution, which was provided by the park.

2.6. Calculation of spectral vegetation indices

To fully consider grassland characteristics (sparse vegetation and accumulated dead materials) in our study area, thirteen commonly used broad band vegetation indices (NDVI, SAVI, ATSAVI, RDVI, PVI, MTVI1, MCARI2, CI, NCI, RCI, NDCI, PD54 and PSRI) were computed in order to select the best candidates. Formulas and notable references for these indices are presented in Table 2. The selected spectral vegetation indices can be roughly grouped into two categories according to their applications from literature. One group is mainly based on red and near-infrared bands (hereafter named Red-NIR-based vegetation index). Vegetation indices in this group include NDVI, SAVI, ATSAVI, RDVI, PVI, MTVI1 and MCARI2. The other group incorporates the green or mid-infrared bands in its calculation, besides the red and near infrared bands. We classified vegetation indices in this group as green and mid infrared (Green/MIR) bands related vegetation index. CI, NCI, RCI, NDCI, PD54 and PSRI were assigned to this group. Theoretically, live green plants have a strong absorption in the red wavelength region and reflectance in near infrared region; therefore, vegetation indices based on red and near infrared wavelength are primarily well correlated with green vegetation properties (e.g. cover, leaf area index, and total biomass) [48]. Green and mid-infrared wavelength relate to leaf water content or senescence [49, 50]; these wavelengths have been used to quantify biophysical characteristics of both green and dead vegetation.

2.7. Statistical analysis

The study was unreplicated like some grazing studies, but our sampling locations are all located in upland grasslands that are topographically very similar and, within each study site, grazing is the primary factor dictating the effects on vegetation. Under similar circumstances, Li et al. (2009) [51] indicated that it is reasonable to assume that experimental error could be represented by sampling errors. Here, we adopted the same assumption for our study. Measurements conducted in 2008 and 2009 were treated as replicates to account for potential correlations and increase the power of statistics. In total, 32 samples (eight for each site), were used in the statistical analysis. All variables were tested for normality before further analysis was conducted. T-test was used for all mean comparisons. For the small sample size a p-value of 0.1 instead of 0.05 is applied to minimize type II error. Differences between sites are considered as significant for $p < 0.1$ only. The Pearson correlation coefficient was calculated to characterize the relationship between spectral indices and biophysical variables. Multiple linear regression analysis - which incorporates more independent variables into the function and improves model prediction capability - was further applied to model these relationships. The forward multiple regression analysis was applied and an alpha value of 0.5 was used to determine a variable's inclusion or removal. The jackknife cross-validation method was applied to validate the developed models which had been shown to be better than split-sample validation, particularly for studies with smaller sample sizes [52]. This approach was implemented by withholding one sample and building the regression model using the data from the remaining samples. The process of removing one sample from the dataset was repeated until all samples had been withheld. Considering that magnitude differences may occur in spectral or biophysical variables, Normalized Root Mean Squared Error (NRMSE) was calculated to indicate the prediction precision of the models for estimating vegetation biophysical variables. NRMSE is computed by the following equation.

$$NRMSE = \sqrt{1 \Big/ n \sum_{i=1}^{n} (x_i - \hat{x}_i)^2} \Big/ (x_{\max} - x_{\min}) \quad (1)$$

Where n is the site number, i is each site sequence, x_i is the measured value and $\hat{x}_i$ is the simulated value calculated from the regression model.

3. Results

3.1. Responses of vegetation biophysical characteristics

Vegetation biophysical parameters showed differences between sites with different levels of grazing (Table 3). More green grass and less dead materials were found in grazed sites. The UG site had a higher canopy height. When comparing biophysical variables of each grazed site with those in the ungrazed site through the T-test, green grass cover was significantly higher in the G2 and G3 sites than that in the UG site ($p < 0.1$). Standing dead cover in UG was significantly higher than in the G1 and G3 sites. No significant differences were found in forb cover and LAI between the grazed sites and the ungrazed site. Canopy height and PV/NPV in the UG site was significantly different from those in the three grazed sites respectively.

3.2. Responses of spectral vegetation indices

Vegetation indices showed variation among the four sites (Figure 2). Greenness-sensitive indices, Red-NIR-based vegetation indices, showed significant differences between UG and G2, G3 ($p < 0.1$) (Table 4). Most Green/MIR-related vegetation indices in G1 and G3 are significantly lower than those in UG. PSRI only showed significant difference between UG and G3.

3.3. Relationships of spectral indices with canopy height and PV/NPV

Pearson correlation coefficients were computed between spectral vegetation indices and canopy height, and PV/NPV (Table 5). Not all vegetation indices were significantly correlated with these two biophysical properties. Compared to Green/MIR-related vegetation indices, Red-NIR-based vegetation indices showed weaker negative correlations with canopy height, with r values around 0.3 ($p < 0.1$, $n = 32$). Among all Green/MIR-related vegetation indices, PRSI had the highest correlation with

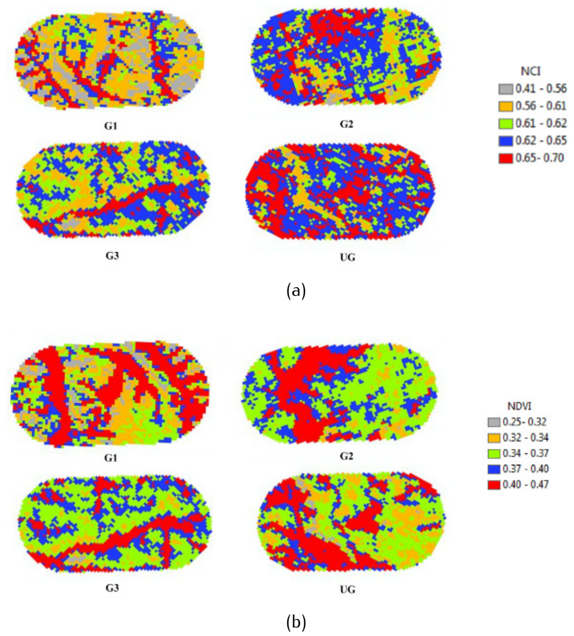


Figure 2. Variation of vegetation indices in four sites. (a) An example of NCI. (b) An example of NDVI. NCI and NDVI are derived from the 2009 SPOT image.

canopy height. On the other hand, for PV/NPV, Red-NIR-based vegetation indices were more highly correlated than Green/MIR-related vegetation indices. MTVI1, MCARI2 and PRSI showed the highest correlations with PV/NPV with r values around 0.6 ($p < 0.1$, $n = 32$).

3.4. Models of canopy height and PV/NPV

Since both Red-NIR-based and Green/MIR-related vegetation indices showed significant high correlation with canopy height and ratio of green grass cover to standing dead cover, multiple regression analysis that can incorporate more than one independent variable was applied to improve the model prediction using grazing-sensitive biophysical variables as dependent variables and spectral indices as independent variables. Significant linear relationships were found between spectral indices with canopy height and PV/NPV ($p < 0.1$, $n = 32$) (Table 6). The model developed for PV/NPV is better than that for canopy height as it has relative higher r^2 (0.5) and lower NRMSE (0.16) (Table 6). Jackknife cross-validation was further applied to test the accuracy of the developed model. Model simulated values versus measured values are depicted in Figure 3.

Table 3. Comparison of vegetation characteristics between grazed and ungrazed sites.

Measured variables	Mean				p-value		
	G1	G2	G3	UG	G1-UG	G2-UG	G3-UG
Green grass cover %	11.55±5.18	14.80±4.79	11.66±2.18	9.23±2.04	0.27	**0.02***	**0.04***
Standing dead cover %	32.12±7.19	41.80±15.37	24.43±12.37	49.56±12.73	**0.00***	0.29	**0.00***
Forb cover%	3.20±2.07	3.49±0.80	4.51±2.13	3.16±1.37	0.96	0.56	0.15
LAI	0.46±0.31	0.58±0.37	0.39±0.29	0.74±0.26	0.21	0.52	0.17
Canopy height	10.32±1.03	10.67±3.10	9.02±1.57	12.96±1.66	**0.00***	**0.09***	**0.00***
PV/NPV	0.35±0.14	0.37±0.10	0.60±0.36	0.19±0.06	**0.01***	**0.00***	**0.02***

*p<0.1

Table 4. Comparison of the spectral indices between grazed and ungrazed sites.

Spectral indices		Mean				p-value		
		G1	G2	G3	UG	G1-UG	G2-UG	G3-UG
Red-NIR based vegetation indices	NDVI	0.33±0.04	0.38±0.02	0.37±0.03	0.33±0.04	0.89	**0.01***	**0.04***
	SAVI	0.19±0.04	0.22±0.02	0.22±0.03	0.18±0.04	0.54	**0.02***	**0.03***
	ATSAVI	0.12±0.04	0.15±0.02	0.15±0.03	0.10±0.05	0.62	**0.02***	**0.03***
	RDVI	0.19±0.03	0.21±0.02	0.21±0.03	0.18±0.03	0.58	**0.02***	**0.03***
	PVI	0.048±0.01	0.057±0.01	0.059±0.01	0.042±0.01	0.43	**0.04***	**0.03***
	MTVI1	0.11±0.03	0.13±0.02	0.14±0.03	0.10±0.03	0.49	**0.04***	**0.03***
	MCARI2	0.10±0.03	0.12±0.01	0.13±0.03	0.09±0.03	0.55	**0.03***	**0.03***
Green/MIR related vegetation indices	CI	0.26±0.03	0.25±0.03	0.26±0.02	0.26±0.02	0.95	0.73	0.93
	NCI	0.61±0.01	0.63±0.01	0.61±0.01	0.63±0.01	**0.00***	0.94	**0.00***
	RCI	3.15±0.15	3.32±0.08	3.25±0.09	3.36±0.12	**0.01***	0.48	**0.07***
	NDCI	0.52±0.02	0.54±0.01	0.53±0.01	0.54±0.01	**0.01***	0.50	**0.07***
	PD54	-0.035±0.0008	-0.035±0.003	-0.033±0.001	-0.034±0.0006	**0.10***	0.58	**0.01***
	PSRI	0.12±0.02	0.12±0.01	0.10±0.01	0.13±0.02	0.53	0.18	**0.02***

*p<0.1

3.5. Spectral vegetation indicators and grazing intensities

The relationships of grazing intensities with model simulated canopy height and PV/NPV are depicted in Figure 4. Grazing intensity showed a significant positive relationship with PV/NPV ($p = 0.00$, $n = 12$) and a negative relationship with canopy height ($p = 0.05$, $n = 12$).

4. Discussions

4.1. Vegetation biophysical parameters for detecting light to moderate gazing effects

Grazing intensity is commonly considered a primary, if not the most important, factor influencing grasslands [8]. Unlike under heavy grazing or overgrazing, where dramatic changes in vegetation (such as decline in vegetation cover and biomass or increase bare ground) can be easily ob-

Table 5. Correction between grazing-sensitive biophysical variables and spectral indices.

Vegetation indices		Canopy height		PV/NPV	
		r	p	r	p
Red-NIR based vegetation indices	NDVI	-0.31	**0.09***	0.48	**0.00***
	SAVI	-0.30	**0.10***	0.55	**0.00***
	ATSAVI	-0.31	**0.09***	0.54	**0.00***
	RDVI	-0.30	**0.10***	0.55	**0.00***
	PVI	-0.28	0.11	0.57	**0.00***
	MTVI1	-0.34	**0.06***	0.60	**0.00***
	MCARI2	-0.34	**0.06***	0.60	**0.00***
Green/MIR related vegetation indices	NCI	0.41	**0.02***	-0.27	0.14
	RCI	0.14	0.46	0.03	0.87
	NDCI	0.13	0.48	0.04	0.81
	PD54	-0.37	**0.04***	0.19	0.31
	PSRI	0.52	**0.00***	-0.60	**0.00***

*p<0.1, number of samples (n) =32

Table 6. Modeling relationships between grazing-sensitive variables and spectral indices.

Biophysical indicators	Models	r square	Adjusted r square	NRMSE	Correlation between independent variables (r)
Canopy height	-25.44+58.71×PRSI+47.19×NCI	0.37	0.33	0.18	0.21
PV/NPV	1.5+27.6×MTVI1-22.11×SAVI	0.50	0.46	0.16	0.99

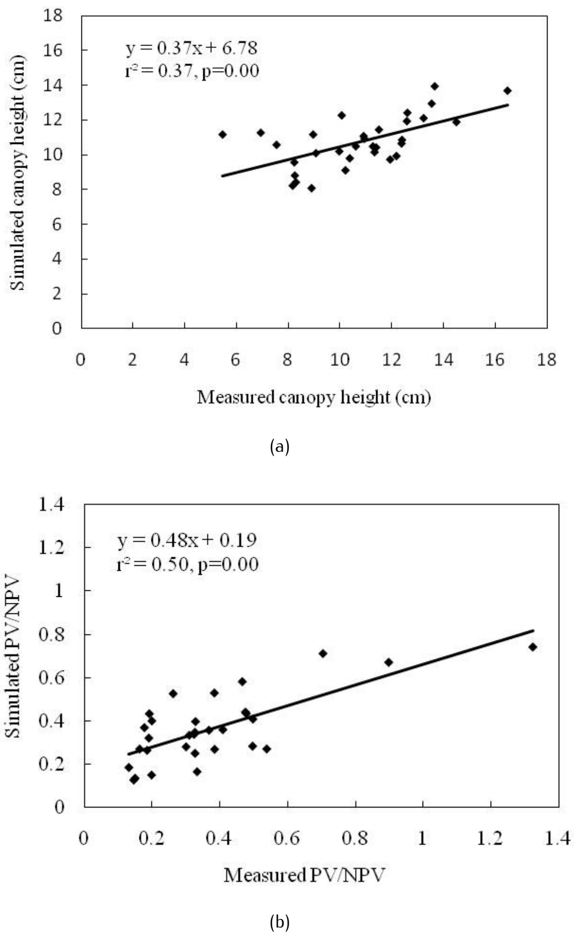


Figure 3. Model simulated values and measured values.

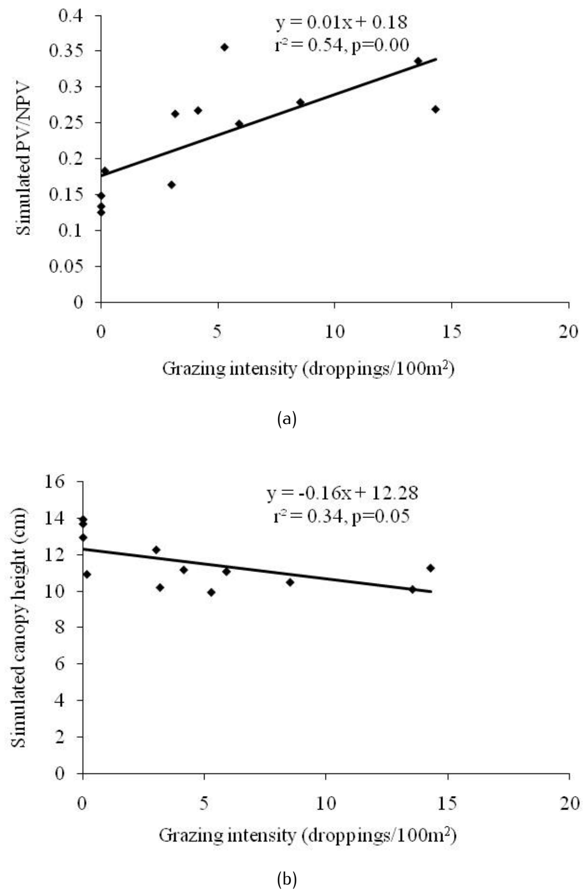


Figure 4. Grazing intensity and spectral indices.

served, we did not find any obvious changes in LAI under light to moderate grazing intensity. Instead, we found that the percentage of vegetation component was modified by light to moderate grazing in that the grazing significantly reduced the standing dead cover but increased green grass cover and PV/NPV. Reduction of dead materials (standing dead and fallen litter) in grazed grasslands has been reported in previous studies [53–55], where grazing reduced dead materials through defoliation, trampling or shredding of the litter into small particles, accelerating their decomposition. Dead materials are the major component of vegetation in this area, accounting for about 67.6% of total biomass in the early growing season (May) and 47.0% in the peak growing season (June to July), respectively [56]. Dead materials intercept heat and water flow at the soil surface [57, 58]. Removal of dead materials by grazing modifies the micro-environment of plants and the soil, and consequently affects vegetation community structure and function. More green grass cover as a result of grazing may be the consequence of a reduction in dead material. First, the reduction in dead material increases light intensity at the grass crown and simulates development of new tillers [55, 58]. Second, less dead materials may increase the soil temperature, which would promote grass green-up earlier [59]. Shorter canopy height in a grazed site is partially attributed to defoliation by grazing. An alternative explanation may be the consequence of reduced water available for plant growth due to the reduction of dead materials [58].

Even though we found that green grass cover, standing dead cover, canopy height and PV/NPV are more sensitive to grazing than other tested vegetation biophysical variables, only PV/NPV and canopy height showed significant differences between all grazing treatments. The absence of significant differences in green grass cover between UG and G1, and standing dead cover between UG and G2 indicates that despite the importance of grazing intensity in determine the magnitude of grazing impacts, the length of grazing treatment may also contribute to the outcome of interaction between herbivore and vegetation. Masbiri et al. [60] indicated that two criteria must be met for grazing effects to be detected: the effects must be larger than the variability in the system and they must reach this size during the period of observation. Compared to G3, the length of grazing treatment in the G1 and G2 sites are relatively short. It is possible that changes in green grass cover in G1 and standing dead cover in G2 have not accumulated to a level that would clearly indicate grazing effects if not the grazing treatment itself dose not produce effects. From this aspect, we identified PV/NPV and canopy height as the best suitable vegetation biophysical parameters for detecting light to moderate grazing effects in these areas. Although we used two years of data to increase the power of our analysis, the sample size may still be a potential factor influencing the detection of grazing effects, especially for studies based on ground sampled vegetation variables. Fortunately, this limitation could be overcome by using contemporary remote sensing indicators. That is why we think it is important to investigate the correspondent spectral parameters for detecting grazing effects in our study area.

4.2. Remote sensing of light to moderate grazing effects

To explore the suitable spectral indices for investigating light to moderate grazing effects, two factors needed to be taken into account: the sensitivity of the spectral parameter itself to grazing treatment, and the performance of the identified spectral candidate as a proxy of a vegetation biophysical indicator for detecting grazing effects. Previous studies have successfully identified grazing impacts using vegetation biophysical variables retrieved from remote sensing data as indicators. In these studies, NDVI and other chlorophyll-based indices have been used to characterize vegetation biophysical indicators such as grass biomass, canopy height and vegetation cover [22, 61]. Numata et al. [61] pointed out that the success of using remote sensing to detect grazing effects depends on grassland phenology and background substrates. They explain that if the studies were conducted at a stage where greenness is the dominant vegetation component, grazing effects are better represented by greenness variation, and chlorophyll-sensitive vegetation indices such as NDVI are more appropriate for vegetation estimation or grazing detection. For a site dominated by dry, green grass (senescent grass), grazing effects are more represented by attributes of senescent grass (quantities, brightness and water content) rather than greenness variation. Numata et al. [61] found that the Normalized Difference Infrared Vegetation Indices (NDII5 and NDII7) are suitable for monitoring grazing effects on grasslands during the dry season, as they show higher correlation with ground biomass than NDVI and SAVI.

In the case of this study, senescent grass was the dominant vegetation component and grazing effects were expressed by variations in green grass and senescent grass, so both greenness- and senescence-related vegetation indices were applied and tested. It is expected that most vegetation indices are sensitive to grazing. Regarding their performances for predicting biophysical variables (canopy height and PV/NPV), the negative relationships between Red-NIR-based indices and canopy height were reasonable because canopy height is determined by the height of standing dead cover in the study area. A 49% variation in canopy height is attributed to standing dead cover (data not shown). Standing dead grass has a masking effect on green grass and therefore weakens the contrast between red and near-infrared bands. It is expected that the more standing dead grass there is, the smaller the Red-NIR vegetation indices values [45]. Most Green/MIR-related vegetation indices show significant correlation with canopy height, and only PSRI is significantly correlated to the PV/NPV. The less significant correlation of Green/MIR-related vegetation indices with PV/NPV may be due to their sensitivities to the effects from background substrate. The effects of background substrate on performance of vegetation indices have been documented in many studies [38, 40, 62]. Depending upon whether the background is litter or soil, the spectral signature for the vegetation canopy will change, and the performances of vegetation indices to characterize grass will be affected. For vegetation conditions such as mixed grasslands, litter and microphytic communities (lichen and moss) are the permanent background substrate. In the same study area, Zhang's study (2008) [45] indicated that the relationships between vegetation indices (such as NDVI and soil reflectance corrected vegetation indices) and vegetation biophysical variables were hampered by accumulated litter and biophysical soil crust.

Models developed for canopy height and PV/NPV solve the difficulties in detecting, mapping or monitoring grazing effects due to insufficient sampling coverage, especially for studies with large spatial extent like our study sites. Variations explained by the models were substantial, 37% for canopy height and 50% for PV/NPV—a bit lower than the values reported in other studies. Numata et al. [61] found that Normalized Difference Index (NDII5) derived from Landsat Thematic Mapper 5 (TM5) can explain 42% variation in grassland canopy height. In addition to grassland phenology and background substrate, there are other unexplained variations that may prevent higher r^2 values in our study. One possible factor may be that the phenology changes in vegetation of around one month between field sampling and satellite image acquisition in 2009 were not accounted for. Even though the models showed moderate goodness of fit, they are significant. Developed models were further applied to quantifying the grazing intensity. As expected, simulated canopy height decreases while grazing intensity increases due to defoliation or trampling disturbances by herbivore. According to intermediate disturbance hypothesis grazing at intermediate intensity levels benefits grasslands because of increased structural and compositional heterogeneity. PV/NPV is a measure of grassland structure and composition. The increased PV/NPV along with increased grazing intensity in our study supports the intermediate disturbance hypothesis. The good relationship between grazing intensity and simulated canopy height and PV/NPV supports the feasibility of remote sensing indicators for detecting light to moderate grazing effects.

For further analysis in future studies, there are some issues to be considered. First, there is still room to improve the model predictability for canopy height and PV/NPV. In this study, we tested spectral indices based on the electromagnetic spectrum in visible and infrared portions. Remote sensors operating in other regions of the electromagnetic spectrum (i.e. the microwave region [63]), and finer spectral resolutions (e.g. hyperspectral remote sensing [64]), have been shown to be good for this particular application. Second is the model application. Sampling limitations prevented us from measuring the vegetation biophysical variables at peak growing season. Therefore, a model developed for the early growing season may not be expanded for the detection of grazing effects in other growing stages without validation. Finally, grazing intensity was characterized by herbivore droppings. We assumed a 1:1 ratio between bison droppings and cattle droppings, a proportion which needs further analysis in order to validate it.

5. Conclusions

In this study, ground biophysical variables and spectral indices of an ungrazed site and three grazed sites under light- to moderate intensity-grazing were compared in order to investigate the potential for using these parameters to characterize light to moderate grazing effects on mixed grasslands. Ground biophysical variables, canopy height and PV/NPV were more sensitive to light to moderate grazing within various grazing periods and were determined to be the most reasonable biophysical indicators of grazing effects when compared to the rest of the biophysical variables considered. Developed models for these two grazing-sensitive biophysical indicators based on linear combination of different spectral variables (PSRI and NCI; MTVI1 and SAVI) and their abilities to quantify grazing intensity prove the feasibility of remote sensing-driven models to detect grazing effects under light to moderate grazing intensities in mixed grasslands.

For more accurate quantification of light to moderate grazing effects using spectral vegetation indices-driven models, especially for improving the model predictability for canopy height or PV/NPV, radar or high spectral resolution remote sensing data are needed. In addition, since we used a single date satellite image and field data, the consistency of these results should be tested at a different time to investigate whether remote sensing-driven models provide the best estimate for light to moderate grazing effects over longer time periods. Temporal analysis using high temporal resolution sensors such as MODIS or AVHRR will be able to address this question.

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