Can satellite imagery evaluate the pre-condition of a grazing experiment?

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Abstract

Most studies on grazing effects are based on the assumption that vegetation conditions at experiment sites that are subject to different grazing treatments, are the same prior to grazing, which may not be true. The pre-existing differences in vegetation may be wrongly attributed to the influence of grazing if pre-validation of vegetation conditions at the site is not performed. In this paper, the assumption stated above was verified by comparing vegetation condition between nine experiment units (pastures) in a grazing experiment site set up by Grasslands National Park (GNP) before grazing treatment started. The leaf area index (LAI) was applied to represent vegetation conditions within the grazing experiment site. The vegetation conditions between the nine pastures were compared at different scales and vegetation growing stages. Results indicate that vegetation conditions measured with 1m² sampling scale showed a significant difference among the nine pastures (p<0.1). No significant differences were observed when measurements were conducted with 100m² and 400m² sampling scales (p>0.1). Variation of vegetation conditions of the nine pastures in peak and late growing stages were very consistent. These results indicate that sampling scale plays an important role in vegetation condition assessment. Remote sensing offers data in multi-spatial resolution which provides an efficient way for investigating vegetation condition at different scales.

Keywords: grazing experiment validation, atmosphere transformed soil adjusted vegetation index, leaf area index, mixed grass prairie
Introduction

Grasslands, covering nearly one fifth of the earth’s land, are primarily used for livestock production. More than 37.5 million km² (Dregene 1983) or about 61% of the arid regions of the world are used for ranching (UNEP 1992). One of the primary challenges in rangeland studies has been to understand the effects of herbivore grazing on ecological processes and biophysical factors (Briske et al. 2003). Grazing effects are usually identified by comparing the vegetation response variables (i.e. plant community composition, productivity, forage quality and many others) in sites that are being grazed to those in areas without any disturbances. However, grasslands are inherently heterogeneous because of vegetation characteristics (i.e. productivity, diversity, and composition) that are highly variable across multiple scales (Ludwig and Tongway 1995). These variations are related to different ecological processes such as topography, soil pattern, microclimate and precipitation (Levin 1978; Urban et al. 1987; Crawley 1996; He et al. 2006). Small scale variation in vegetation is related to the heterogeneity of soil (Reynolds et al. 1997). At a large scale, variations of vegetation are controlled by topography or landforms (Sebastiá 2004). These pre-existing variations in grazing response variables may confound interpretation of grazing effects. To reduce the influence of outside factors, other than grazing on vegetation, most of the studies on grazing effects attempt to select sites with similar vegetation and environmental conditions and assume similarity of these conditions in grazed and ungrazed sites prior to the grazing experiment (Fisher et al. 2009).

However, from 1919 to present, none of the grazing trials which looked at variable rate grazing conducted in mixed- and short grass prairie of North American had incorporated a before-treatment sampling period to test whether the vegetation conditions of these sites were the same before the experiment started (Koper et al. 2008). Since the effects of grazing on vegetation depend upon the interaction between the spatial pattern of grazing and pre-existing spatial pattern of vegetation (Adler 2001), assessing before-treatment variation is important to identify post-treatment effects.

Recently, a large manipulative grazing experiment designed to study the ecological integrity of mixed grasslands was started in Grasslands National Park of Canada (GNP). The mixed grasslands located in GNP had been protected from grazing and other disturbances since the land was acquired in the mid 1990s (Henderson 2005). The experiment was set up in 2007 and cattle were introduced into the experiment site in June 2008. This provides a unique pre-treatment period for examining the pre-existing environmental patterns in the experiment site and help further the understanding of grazing effects on this area in future studies.

The primary objective of this study is to verify the assumptions proposed for most grazing studies that vegetation conditions are same among experiment units through examining the vegetation conditions in experiment area in GNP prior to grazing treatment. To achieve this goal, LAI is measured and used as an indicator of vegetation condition in the experiment site. LAI, defined as one-half the total green leaf area per unit of ground surface area (Chen and Black 1992), determines canopy water interception and carbon gas exchange between vegetation and the environment. Past researches have found that LAI highly correlates with many vegetation biophysical properties such as biomass, canopy height and ground cover (Guo et al. 2005; He et al. 2009) and is also an indicator of vegetation vertical structure. Thus, it has been broadly used to describe or quantify vegetation condition. On the other hand, considering the scale dependence of vegetation conditions, it is essential to examine vegetation condition at multiple scales. To quantify vegetation conditions at a smaller scale, field methods are feasible; however, it is commonly recognized as a time-consuming and expensive when applied to measure vegetation conditions at a large scale. LAI can be easily derived from remote sensing providing an efficient way to quantify vegetation conditions at a large scale. In this study, conditions of vegetation between pastures, at different scales, is assessed by comparing LAI collected from different sampling scales. Small scale LAI is measured with field method and large scale LAI is derived from remote sensing image. Vegetation condition at different growing stages is also investigated through comparing LAI collected in peak and late stages.

Methods

Experimental site description

The study was conducted in the East Block of GNP in Saskatchewan, Canada (lat 49°01’00˝N, long 107°49’00˝W), which is located in southern Saskatchewan along the Canada-United States border (Figure1). This area falls within the Great Plain which is characterized by semiarid climate with approximately 350mm of annual precipitation and 347mm of annual evapo-transpiration (Coupland 1992; Kottek et al. 2006). The experimental area is 26.5km² in size, comprising nine experiment units (pastures) which were constructed specifically for the experiment. Each pasture occupies nearly 300ha and incorporates similar landscapes, vegetation communities and natural water source locations. (Henderson 2005). Four major vegetation types are found at the experiment site: upland, slope and valley grasslands along with riparian shrub communities. Experiment pastures are dominated by upland and valley grasslands with some riparian shrub and slope grasslands also present but to a lesser extent (Michalsky and Ellis 1994). The upland grassland is composed primarily of grass or sedges and low percentage of shrub. The dominant native grass species in the uplands are needle-and-thread (Stipa comate Trin. & Rupr), blue grama grass (Bouteloua gracilis (HBK) Lang. ex Steud) and western wheatgrass (Pascopyrum smithii Rydb) (Fargey et al. 2000). Valley grassland is characterized by a high abundance of shrub such as silver sagebrush (Artemisia cana) and snowberry (Symphoricarpos albus) as well as grass including wheatgrass (Pascopyrum spp.) and bluegrass (Poa spp.). The major soil type in the experiment site is Chernozemic or typical grassland soil commonly associated with solonetizic or saline soils (Zhang and Guo 2007). The surface horizon of grassland soil is dark and fertile due to accumulations of organic matter over time from grass and herb roots (Westworth and Associated Ltd 1994). In June 2008, cows...
were introduced to six of the pastures which resulted in an average of twenty to seventy percent of annual forage utilization, the remaining three pastures were used as ungrazed control sites (Koper et al. 2008).

Data collection and pre-processing

Field work was conducted at the peak growing season, June 2007, in nine designated pastures inside of the grazing experiment site. Ten sampling plots were set up in each pasture, with six located in upland communities and four in valley communities. LAI measurements were collected using LiCOR-LAI-2000 Plant Canopy Analyser at each sampling plot using 1×1m quadrats. In each quadrat, one above canopy reading and six below canopy readings were recorded. The value of LAI for each sampling site was the average of these six values. Three SPOT multispectral images were acquired for the years of 2005 (June 22nd, SPOT4, 20m), 2006 (July 22nd, SPOT5) and 2007 (June 20th, SPOT5). Geometric and radiometric corrections, including atmospheric corrections were applied to all images. The images were geometrically corrected by a geo-coded image which was further corrected using ground training sites, with accuracy better than 0.3 root mean square error (RMSE), representing approximately three meters error in ground for SPOT5 image and six meters for SPOT4 image. Distortion caused by topography was corrected using a digital elevation model (DEM), found in the GNP GIS database. Radiometric and atmospheric corrections were done with the ACTOR2 module from the PCI Geomatics software package.

Vegetation indices that combine reflectance from two or more bands can overcome most atmospheric and backgrounds influence, and enhance the ability to measure ground information. For this study area, previous information indicated that atmosphere transformed soil adjusted vegetation index (ATSAVI) (Baret and Guyot 1991) showed superior result compared to other indices (normalized difference vegetation index, perperricular vegetation index, soil-adjusted vegetation index, etc.) when used to predict ground LAI (He et al. 2006). Therefore, ATSAVI was computed to use as a proxy of LAI collected with large sampling scale. ATSAVI was calculated with the equation below:

\[
ATSAVI = \frac{a \times (NIR - a \times RED - b)}{a \times NIR + RED - a \times b + \lambda(1 + a^2)}
\]

where \(NIR\) is the reflectance in near infrared band, \(RED\) is the reflectance in the red band and \(X\) is the soil line adjustment factor with a default value 0.08. \(a\) and \(b\) are the slope and intercept of the “soil line” with corresponding values, of 1.22 and 0.03 respectively (Zhang 2006).

Data analysis

We overlaid the pasture polygons on top of SPOT images. Spectral data was extracted from a 3×3 pixel area centered on each field location. The median of these nine pixel values was used to eliminate extreme values. To examine vegetation con-
dition among pastures in different scales, LAI collected with different sampling scales, namely 1m$^2$, 100m$^2$ and 400m$^2$, were applied. LAI with 1m$^2$ sampling scale was measured in the field. ATSAVI derived from satellite images were used as surrogate for LAI collected with 100m$^2$ or 400m$^2$ sampling scales. LAI and ATSAVI data were tested for normality before any further statistic analysis was performed, to ensure that the data were normally distributed. The capability of ATSAVI to characterize vegetation conditions instead of LAI at a large scale, was verified by investigating the relationship between ATSAVI and LAI. A linear regression analysis was applied to describe the relationship between LAI and ATSAVI (He et al. 2006). To test the vegetation condition in different time, vegetation conditions measured in 2006 and 2007 which represent the peak and late vegetation growing stages, were examined. The analyses were based on data from six pastures, because three pastures are covered by haze in the 2006 image. Given that upland and valley grasslands are dominated by different plant communities, comparison of vegetation conditions between pastures was conducted for upland and valley grasslands separately. Analysis of variance (ANOVA) was performed to analyze the differences among pastures in the grazing experiment site (SPSS 16.0). Differences were considered statistically significant when $p<0.1$.

**Results**

**Relationship between LAI and ATSAVI**

Leaf area index shows a significant positive correlation with ATSAVI with 41% of its variation could be explained by ATSAVI (Figure 2). The result indicates the applicability of ATSAVI as a proxy of LAI for quantifying vegetation conditions at a large scale.

**Vegetation condition and sampling scale**

We find significant differences in both upland and valley vegetation, as measured by LAI collected with a 1m$^2$ sampling frame, between pastures (Table 1). In upland communities, LAI is shown as the highest in pasture 1 and a significant difference is found between pasture 1 and 6 other pastures ($p<0.1$), pastures 6 and 7 showed no significant difference. For valley grassland, differences occur between pastures 1 and 3, 4 and 5 ($p<0.1$). The results vary when the observation scale increases from 1m$^2$ to 100 m$^2$ or 400 m$^2$. No significant difference in vegetation condition is detected among pastures either in upland, or valley grasslands with a 100 m$^2$ sampling unit. Similar results are obtained when using a 400 m$^2$ sampling unit.

**Vegetation conditions and vegetation growing stages**

Vegetation conditions of the peak and late growing seasons in six pastures, represented by ATSAVI, are shown in Figure 3. The highest ATSAVI in peak growing season for upland grasslands is in pasture 2 with pasture 3 having the lowest value. This variation pattern of ATSAVI does not change with vegetation growing stages.

**Table 1**: Comparison of vegetation conditions between pastures with different sampling scales. Value within the same column followed by different letters (a,b,c,d) is significant at $p<0.1$.

<table>
<thead>
<tr>
<th>Pastures</th>
<th>1m×1m (LAI)</th>
<th>10m×10m (ATSAVI)</th>
<th>20m×20m (ATSAVI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Upland</td>
<td>Valley</td>
<td>Upland</td>
</tr>
<tr>
<td>1</td>
<td>0.98±0.30a</td>
<td>0.75±0.08a</td>
<td>0.52±0.09a</td>
</tr>
<tr>
<td>2</td>
<td>0.67±0.14abcd</td>
<td>0.79±0.40ab</td>
<td>0.57±0.10a</td>
</tr>
<tr>
<td>3</td>
<td>0.50±0.13bcd</td>
<td>0.42±0.12b</td>
<td>0.49±0.05a</td>
</tr>
<tr>
<td>4</td>
<td>0.42±0.19bc</td>
<td>0.86±0.56ab</td>
<td>0.49±0.08a</td>
</tr>
<tr>
<td>5</td>
<td>0.36±0.12b</td>
<td>0.49±0.11b</td>
<td>0.47±0.04a</td>
</tr>
<tr>
<td>6</td>
<td>0.82±0.19ad</td>
<td>0.80±0.47ab</td>
<td>0.51±0.05a</td>
</tr>
<tr>
<td>7</td>
<td>0.74±0.17ac</td>
<td>0.80±0.32ab</td>
<td>0.51±0.02a</td>
</tr>
<tr>
<td>8</td>
<td>0.63±0.20bcd</td>
<td>0.58±0.34ab</td>
<td>0.52±0.07a</td>
</tr>
<tr>
<td>9</td>
<td>0.57±0.23bcd</td>
<td>0.87±0.48ab</td>
<td>0.50±0.05a</td>
</tr>
</tbody>
</table>

Figure 2: Relationship between LAI and ATSAVI:

\[ y = 1.52x - 0.13 \quad (r^2=0.41) \]
growing stages, indicated by that consistent ATSAVI patterns among all six pastures are found between peak and late growing seasons. Variation pattern of ATSAVI in valley grasslands in two growing stages are also consistent with the highest ATSAVI in pasture 2 and the lowest in pasture 9.

**Discussion**

Our work demonstrates several important principles in the design of experiments in which time and space contribute significantly to treatments. First, it is correct to assume that experimental units will differ from each other even prior to the application of treatments (Koper et al. 2008). Substantial variation was found in LAI measurement at a smaller scale, however, the differences diminished as sampling scale increased. This is no surprise given the inherent scale-dependent characteristic of vegetation conditions. The variations in vegetation conditions measured at the small sampling scale, among pastures are due to inherent within site/pasture heterogeneity in soil properties, for example, soil moisture and nutrient elements (Reed et al. 1993, He et al. 2007). Therefore, if this sampling scale is applied for comparison of vegetation condition among pastures in post grazing experiment, the pre-existing differences needed to be taken into consideration for accurate interpretation of grazing effects. With a large sampling scale, portion of site variation could be contained within a sample. Inter-samples variations are decreased and the possibility of detecting differences between pastures is increased (Wiens 1989). Sampling at a large scale (100m² and 400m²), we did not find differences in vegetation conditions among pastures prior to grazing treatment, implying that effects of grazing on vegetation condition could be isolated accurately if the same sampling scales are employed in post grazing treatment.

Second, incorporating multi-scale observation methods into experimental design is essential for acquiring comprehensive information on vegetation condition within the study site. We only investigated vegetation condition based on three sampling scales. Using a gradient sampling frame allows for identifying the suitable sampling scale for measuring vegetation conditions. In this research, both field and remote sensing methods were applied for quantifying vegetation conditions at different scales. Vegetation conditions at a small scale could be easily quantified using field methods, but field methods are limited in obtaining representative data for revealing variation at a larger scale. Remote sensing is a valuable data source for characterizing vegetation condition at multiple scales as it is available from a range of satellite sensors and covers a broad extent. Our approach to use archived, remotely sensed images to quantify vegetation condition is one that we feel could prove valuable in a number of field settings.

Third, remote sensing may not be the ideal tool to completely replace ground measures of vegetation conditions, due to its failure to capture all the information or achieve the desired level of accuracy. However, remote sensing can serve researchers with baseline information, particularly for the experiment with large-scale extent where a full suite of variables is impractical to measure prior to treatment applications. The biophysical changes that are readily detected by light reflectance provide a relatively quick overview of potential compositional and structural variation of a grass sward (Guo et al. 2004). Thus, this relatively inexpensive method could be used to focus pre-sampling efforts appropriately. As well, they can provide an accurate, quantitative assessment of treatment induced change if they are measured both prior to and following treatment application in an a priori design.

**Management Implications**

Comparing sites spatially has been considered as a means to study the grazing effects for a long time. Understanding the vegetation condition among sites prior to experiment design is essential for researchers or land manager to interpret vegetation change post treatment. In light of the scale dependence of vegetation condition found in our study the influence of post grazing
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