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Research Paper

Estimating aboveground green biomass in desert steppe using band depth indices

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ARTICLE INFO

Article history:
Received 4 May 2014
Received in revised form
22 July 2014
Accepted 21 August 2014
Published online 15 September 2014

Keywords:
Desert steppe
Aboveground green biomass
Hyperspectral remote sensing
Band depth indices
Continuum removal

Estimation of aboveground green biomass is essential for evaluating grassland productivity and functioning. This study aimed to explore the potential of band depth indices for estimating aboveground green biomass in grassland with low canopy cover. Field spectral and biomass measurements were conducted during 2009 and 2010 growing seasons in desert steppe of Inner Mongolia. Band depth (BD), band depth ratio (BDR), normalised band depth index (NBDI), band depth normalised to area (BNA), maximum band depth (BD_{max}), and area of absorption region (BD_{area}) extracted from red absorption region (650–740 nm) were utilised as band depth indices. Results indicated that: (1) BD at individual bands between 655 and 716 nm showed good accuracy for aboveground green biomass estimation; (2) BD at 698 nm yielded the best accuracy ($R^2 = 0.7$, RMSECV $= 29.6$ g m^{-2} for calibration; RMSE $= 32.4$ g m^{-2}, rRMSE $= 26.9\%$ for validation); (3) BDR, NBDI, and BNA at all bands were not reliable estimators of aboveground green biomass ($R^2 < 0.3$, RMSECV > 45 g m^{-2} for calibration; RMSE > 46 g m^{-2}, rRMSE $> 39\%$ for validation); (4) although the performance of BD_{max} ($R^2 = 0.65$, RMSECV $= 32.1$ g m^{-2} for calibration; RMSE $= 34.5$ g m^{-2}, rRMSE $= 28.7\%$ for validation) and BD_{area} ($R^2 = 0.69$, RMSECV $= 30.2$ g m^{-2} for calibration; RMSE $= 33.1$ g m^{-2}, rRMSE $= 27.6\%$ for validation) was slight lower than that of BD_{698nm}, the performance was far better than that of BDR, NBDI, and BNA. Our results suggest that BD_{698nm} has good potential to estimate aboveground green biomass in grassland with low canopy cover. The performance of BD_{698nm} needs to be further tested using space-borne hyperspectral images.

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http://dx.doi.org/10.1016/j.biosystemseng.2014.08.014
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Nomenclature

Variables

R	reflectance
R_c	reflectance of continuum line
R'	continuum-removed reflectance

Abbreviations

ASD	analytical spectral device
BD	band depth
BD_{area}	area of absorption region
BD_i	band depth at wavelength i
BD_{max}	maximum band depth
BDR	band depth ratio
BNA	band depth normalised to area
FOV	field of view
GPS	global positioning system
NBDI	normalised band depth index
NIR	near-infrared
P	p-value, probability
r	correlation coefficient
R^2	coefficient of determination
REP	red-edge position
RMSE	root mean square error
RMSECV	root mean square error of leave-one-out cross validation
rRMSE	relative root mean square error

Subscripts

i	wavelength

1. Introduction

Timely and accurate estimation of aboveground green biomass in grasslands has been an important focus because of its importance to ecosystem processes and carbon cycles. The estimation also provides useful information for the sustainable management of grassland ecosystem and grazing activities. Traditional methods of aboveground green biomass estimation based on destructive sampling are expensive, time-consuming, and feasible only for small-scale biomass surveys. Remote sensing offers a cost-effective solution for timely and accurate estimation of aboveground green biomass in grasslands from local to regional scale (Eisfelder, Kuenzer, & Dech, 2012). In recent years, remote sensing techniques have been widely used to estimate aboveground green biomass in grasslands (Anderson, Hanson, & Hass, 1993; Boschetti, Bocchi, & Brivio, 2007; Jin et al., 2014; Mirik, Norland, Crabtree, & Biondini, 2005; Moreau, Bosseno, Gu, & Baret, 2003; Schino et al., 2003; Todd, Hoffer, & Milchunas, 1998; Wylie, Meyer, Tieszen, & Mannel, 2002). More recently, the development of hyperspectral sensors, which provide detailed spectral information at higher spectral resolution, has offered unprecedented opportunities to estimate grassland aboveground green biomass using new techniques, such as narrow-band vegetation indices, red-edge position (REP), and band depth analysis.

Extensive studies, including our previous study in desert steppe of Inner Mongolia (Ren, Zhou, & Zhang, 2011), have been conducted to explore the potential of narrow-band vegetation indices and REPs to estimate grassland aboveground green biomass at higher and/or lower canopy cover. These studies have demonstrated that narrow-band vegetation indices can not only overcome saturation problem at higher canopy cover (Chen, Gu, Shen, Tang, & Matsushita, 2009; Elvidge & Chen, 1995; Mutanga & Skidmore, 2004a), but also provide significant improvements over broad-band vegetation indices at lower canopy cover (Elvidge & Chen, 1995; Li, 2008; Li et al., 2010). These studies also have showed that REPs are reliable predictors of aboveground green biomass in grasslands with higher canopy cover (Cho & Skidmore, 2009; Cho, Skidmore, Corsi, van Wieren, & Sobhan, 2007). Nevertheless, REPs lose their utility in arid and semiarid areas because of indistinct red-edge features at lower canopy cover (Billings & Morris, 1951; Ehleringer, 1981; Gates, Keegan, Schleter, & Weidner, 1965; Ray & Murray, 1996; Ren et al., 2011).

The logic behind band depth analysis is the isolation and normalisation of the absorption features using continuum removal (Clark & Roush, 1984). With the increase of aboveground green biomass, the reflectance in red bands decreases and reflectance in near-infrared (NIR) bands increases. As a result, there is deepening and widening of red absorption region as biomass increases (Clevers & Jongschaap, 2001; Todd et al., 1998). Therefore, an investigation of band depth analysis on the red absorption pit may be effective for aboveground green biomass estimation. The well-known band depth indices are the band depth (BD), band depth ratio (BDR), normalised band depth index (NBDI), and band depth normalised to area (BNA).

In recent years, these band depth indices of red absorption pit in combination with stepwise multiple linear regression or partial least square regression have been widely used to estimate biophysical and biochemical variables in grasslands (Curran, Dungan, & Peterson, 2001; Kokaly & Clark, 1999; Mutanga, Skidmore, Kumar, & Ferwerda, 2005; Mutanga, Skidmore, & Prins, 2004; Schlerf et al., 2010), including biomass (Chen et al., 2009; Mutanga & Skidmore, 2004b; Ullah et al., 2012). These studies reported that band depth indices in combination with these regressions could be accurate predictors of biophysical and biochemical parameters in grasslands. This can be attributed to multivariate band depth information available at numerous bands (Darvishzadeh, Skidmore, Schlerf, Atzberger, & Cho, 2008). Nevertheless, stepwise multiple linear regression suffers from the problem of collinearity and model parsimony (Curran, 1989; Curran et al., 2001; De Jong, Pebesma, & Lacaze, 2003), and partial least square regression suffers from the problem of overfitting (Darvishzadeh et al., 2008; Hansen & Schjoerring, 2003; Li, Li, Gao, Bai, & Wang, 2011). Also, these previous studies, regarding grassland biomass estimation, were restricted

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