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Estimating forage quantity and quality using aerial hyperspectral imagery for northern mixed-grass prairie

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Abstract

Sustainable rangeland stewardship calls for synoptic estimates of rangeland biomass quantity (kg dry matter ha^{-1}) and quality [carbon:nitrogen (C:N) ratio]. These data are needed to support estimates of rangeland crude protein in forage, either by percent (CP_c) or by mass (CP_m). Biomass derived from remote sensing data is often compromised by the presence of both photosynthetically active (PV) and non-photosynthetically active (NPV) vegetation. Here, we explicitly quantify PV and NPV biomass using HyMap hyperspectral imagery. Biomass quality, defined as plant C:N ratio, was also estimated using a previously published algorithm. These independent algorithms for forage quantity and quality (both PV and NPV) were evaluated in two northern mixed-grass prairie ecoregions, one in the Northwestern Glaciated Plains (NGGP) and one in the Northwestern Great Plains (NGP). Total biomass (kg ha^{-1}) and C:N ratios were mapped with 18% and 8% relative error, respectively. Outputs from both models were combined to quantify crude protein (kg ha^{-1}) on a pasture scale. Results suggest synoptic maps of rangeland vegetation mass (both PV and NPV) and quality may be derived from hyperspectral aerial imagery with greater than 80% accuracy.

Keywords: HyMap; Rangeland; Biomass; Carbon; Nitrogen ratio; Crude protein

1. Introduction

The 124 million ha of northern U.S. mixed-grass prairie rangelands (Vogelmann et al., 2001) are typically managed as 20 to 200-ha pastures, calling for synoptic decision support tools at high to moderate spatial resolutions. Rangeland managers need reliable, current data delineating vegetation quantity and quality across multiple landscapes to support management strategies (Moran et al., 1997). Remote sensing-based products could assist with rangeland carrying capacity assessment (Hunt et al., 2003), for range condition varies widely with climate and land use. While synoptic data indicative of range condition are needed, remote assessment products rarely provide information in physically meaningful units, e.g. kg ha^{-1}. Remote sensing-based model formulation is often based on data from one image or one area of interest, so extrapolation one area could be spatially limited. Here, we take steps to address these issues by developing and validating spectral models for rangeland biomass (live only and total) and C:N ratio to calculate crude protein by mass (CP_m) on a pasture scale using two images acquired on the same day over neighboring ecoregions (Fig. 1).

Spectral estimates of rangeland biomass (kg ha^{-1}) at high to moderate spatial resolutions are needed to delineate variability for pastures within the larger northern mixed-grass prairie region. Spectral signatures are influenced by variable landscape factors such as plant community distribution (Boelman et al., 2005), soil color (Gao et al., 2000), hydrology (Todd & Hoffer, 1998), and topography (Kawamura et al., 2005). Consequently, spectral algorithms should be developed at scales that encompass these factors without compromising spatial resolution within and among pastures. Many studies correlate spectra with relative differences in biomass (Everitt et al., 1989; Frank & Aase, 1994; Rundquist, 2002; Tucker et al., 1983), yet few delineate the amount of plant material on a mass per unit area basis (kg ha^{-1}). A spectral model for estimating biomass based on data for more than one mixed-grass prairie ecoregion would

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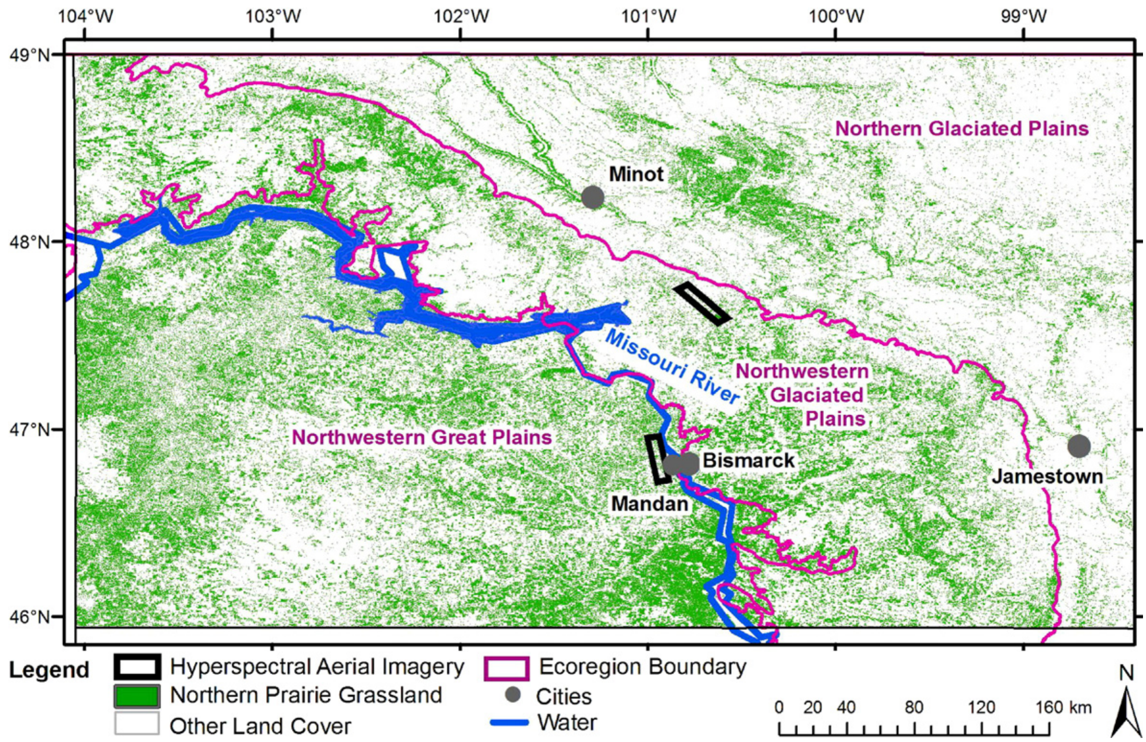

Fig. 1. North Dakota northern prairie grasslands mapped by Strong et al. (2005) and United States ecoregions mapped by Omernik (1987).

likely reduce site specificity by including a large breadth of geospatial variability.

Canopies comprised of photosynthetically active (PV) and non-photosynthetically active (NPV) vegetation are ubiquitous in northern mixed-grass rangelands, thereby affecting vegetation quality and spectral response. NPV interferes with plant biomass–spectra relationship when using handheld instruments (Frank & Aase, 1994; Rundquist, 2002) and when scaling up from handheld to aerial and satellite-borne sensors (Loris & Gianelle, 2006; Serrano et al., 2002). Despite issues associated with NPV, both PV and NPV contribute to biogeochemical cycling, which is an essential component to ecosystem functional assessment. Consequently, inclusion of both pools in remote sensing product development is necessary.

Remote rangeland assessment tools for vegetation quality on a mass basis are lacking. Vegetation quality is commonly expressed in terms of percent crude protein [CP_c (mg g^{-1})], or nitrogen [N_c (mg g^{-1})], which is a factor in animal management. Crude protein (CP_c) or N_c has been correlated with spectra using handheld sensors for grasses (Mutanga et al., 2004; Starks et al., 2006) and airborne sensors for forests (Matson et al., 1994; Wessman et al., 1988). However, leaf moisture masks leaf N_c spectral signature in fresh vegetation (Kokaly & Clark, 1999), which presents a problem with quantification of forage quality under variable drought stress. This has been addressed using hyperspectral data manipulation, such as continuum removal (CR) (Curran et al., 1992; Kokaly & Clark, 1999), and by experimentally separating effects of leaf moisture from leaf quality using C:N ratio (Phillips et al., 2006). Methods to remotely estimate range condition are available (Hunt et al., 2003), although methods to remotely and independently assess forage quality and quantity are lacking for northern mixed-grass prairie.

This manuscript describes how we i) developed and validated spectral algorithms for estimating rangeland biomass using HyMap imagery acquired over two Northern Plains ecoregions, ii) applied and validated a previously published algorithm for forage quality (C:N ratio) on the HyMap airborne sensor, and iii) combined biomass and C: N ratio estimates to map the mass of crude protein (CP_m) on a pasture scale.

2. Methods

2.1. Image acquisition areas-of-interest (AOI)

Aerial hyperspectral images were acquired for two areas-of-interest (AOIs), 13,250 ha each, located on opposite sides of the Missouri River near the center of North Dakota (Fig. 1). The northeast AOI in Fig. 1 is located in the Northwestern Glaciated Plains (NGGP) ecoregion (Omernik, 1987), where kettle holes, kames, and moraines are common among gently rolling continental glacial till plains. Natural prairie vegetation is characterized by western wheatgrass [*Pascopyrum smithii* (Rydb.) A. Löve], needle-and-thread [*Hesperostipa comata* (Trin. and Rupr.) Barkworth], green needlegrass [*Nassella viridula* (Trin.) Barkworth], and blue grama associations [*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths] (USDA, 2006). The southwest AOI in Fig. 1 is located in the Northwestern Great Plains (NGP) ecoregion (Omernik, 1987), with gently rolling continental glacial till plains and rolling hills. Natural prairie vegetation is characterized by grama–needlegrass–wheatgrass associations. Similar to the NGGP