Hyperspectral remote sensing of sagebrush canopy nitrogen

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Abstract - Plant canopy nitrogen (N) is associated with ecosystem processes such as photosynthetic and aboveground net primary production, particularly in forested ecosystems. Sagebrush N is directly relatable to wildlife nutritional status and contributes to assessments of habitat quality, productivity, plant / soil water dynamics and controls on canopy photosynthesis. Hyperspectral remote sensing studies have successfully estimated biochemicals under closed canopy conditions; however, more studies are needed to assess potential in sparsely vegetated shrub environments. Spectroscopic measurements of individual sagebrush shrub canopies collected in the field are relatable to foliar N concentrations analyzed in the laboratory. Encouraging results at the shrub scale warranted extension of the study to an airborne platform, whereby sagebrush canopy N concentrations are estimated across a landscape. Challenges include leaf water content, soil reflectance, and leaf angles, all of which can dampen or mask absorption features of interest.

Keywords: Spectroscopy, hyperspectral, nitrogen, sagebrush, semiarid

1. INTRODUCTION

Spectroscopy laboratory experiments and empirical studies link foliar nitrogen (N) concentrations to narrow absorption regions in the visible and near-infrared portions of the spectrum (e.g., Matson et al. 1994, Martin and Aber 1997). Recent hyperspectral remote sensing studies have successfully mapped canopy N at landscape and regional scales for forested ecosystems using derivative transformation (e.g. , Ollinger and Smith 2005) and continuum removal (e.g., Mutanga et al. 2004, Huber et al. 2008) methods. Both approaches are designed to enhance the signal of narrow absorption band features. The extent to which similar methods can be applied to sparsely vegetated systems has been largely unexplored.

Leaf water is a major challenge to extending near-infrared spectroscopy (NIRS) techniques from the dry leaf scale to live shrub (field) and canopy (pixel or remote sensing) scales because strong water absorption bands tend to mask subtle absorption features associated with constituents such as nitrogen. Partial canopy coverage, or bare ground exposure, is another challenge, particularly when estimating canopy N concentrations across a landscape. Although continuum removal methodologies (Kokaly and Clark, 1999) are expected to have relatively low sensitivity to partial canopy coverage, changes in leaf chemistry are not thought to translate to landscape level detection unless cover exceeds 70% (Asner et al. 2000).

The objective of this study is to determine if signals from individual shrub canopies are sufficient for estimating foliar N concentrations. In so doing, we also evaluate the use of continuum removal to estimate sagebrush foliar N concentrations and examine changes in signal response when scaling from dry leaf to live shrub. Findings are encouraging and preliminary results from an airborne platform are presented. Remote estimation of sagebrush foliar N would allow for direct estimates of nutritional status and contribute to assessments of habitat quality, productivity, plant / soil water dynamics and controls on canopy photosynthesis.

2.1 Field Sampling

A total of 36 spatially-isolated sagebrush (*Artemisia tridentata* subsp. *Wyomingensis* and subsp. *tridentata*) were sampled for leaf- and shrub-level nitrogen content using both a field spectrometer and combustion analysis. To validate airborne data, a roaming survey was conducted to sample a total of 35 plots (49 m^2) for percent cover (sagebrush, shrubs other than sagebrush, grass / herbaceous, bare ground, and dead wood), average sagebrush height and foliar N content. Plots were located where bare ground and sagebrush were the dominant features. Understory vegetation, grasses, and other shrubs were minimized to control for the influence of non-target vegetation. Foliar N content was estimated by randomly selecting four sagebrush from each plot, then collecting green-leaf samples from each of the selected shrubs. Green-leaf samples were then analyzed for N content, again using combustion analysis.

2.2 HyMap Data

An airborne HyMap sensor (operated byHyVista, Inc., Sydney, Australia) collected two overlapping flightlines (≈ 11 km^2 total) of hyperspectral imagery approximately 2496 m above ground level with a nominal pixel resolution of 2.1 m. The sensor collects calibrated radiance data in 126 near-contiguous spectral bands (0.45–2.48 μm) that range in width from 15 μm in the visible and near-infrared to 20 μm in the shortwave infrared (Cocks et al., 1998). The radiance values were converted by the vendor to apparent reflectance using the HyCorr (Hyperspectral Correction) absolute atmospheric correction modeling package, which is based on the Atmospheric Removal Program (ATREM). Combined HyMap georegistration error was approximately 2.8 m. The following regions were removed from the data due to obvious influences by noise and water absorption: 1390–1419, 1796–1948, and 2472–2487 nm.

2.3 Spectral Data Processing

Leaf-, shrub-, and canopy-level reflectance data were transformed using standard derivative analysis, continuum removal, and band depth analysis of continuum removed absorption feature spectra. These transformation techniques were applied directly to the field spectrometer data, to a smoothed version of the spectrometer data, and to the HyMap data. Partial least squares (PLS) regression was used to relate transformed wavebands to shrub- and canopy-level N concentration estimates.

3. RESULTS

3.1 Individual Sagebrush Shrub Estimates

Differences in the spectra of dry, ground leaf material and live shrub canopy were mostly attributable to leaf water. Our spectral datasets highlight increased reflectance from leaf drying and a drastic change in the shape of the red-edge shoulder. Sagebrush dry leaf spectra produced PLS models that could predict N concentrations within the dataset more accurately than PLS models generated from live shrub spectra. Spectrally averaging reflectance data to coarser bandwidths did not improve results for the dry leaf dataset but did improve results for the live shrub dataset. Overall, the continuum removed regressions tended to select wavelengths in the visible and near-infrared associated with plant pigments and the chlorophyll red-edge. The first derivative reflectance (FDR) regressions included wavelengths selections in the mid-infrared region associated with leaf water (1185, 1200, 1232, 1263, and 1272 nm).

3.2 Sagebrush Canopy Estimates

Overall, preliminary PLS regression model results are encouraging, with most of the selected wavelengths in the continuum removed datasets occurring in the visible portion of the spectrum and most of the selected wavelengths in the FDR datasets occurring in the infrared portion of the spectrum. The wavelengths in the visible are likely associated with chlorophyll. The shorter mid infrared wavelengths (1076 nm and 1229 nm) are not related to known N absorption features but could be associated with leaf water. Some of the longer wavelengths selected in the mid infrared (e.g. 1662, 1663, and 1675 nm) are associated with known N absorption features, while others (i.e., 1737 and 1749 nm) are likely related to cellulose.

4. DISCUSSION AND CONCLUSIONS

At the shrub-level, inclusion of wavelengths associated with leaf water in the FDR transformations appeared to improve regression results compared to continuum removed calculations, which did not include wavelengths associated with leaf water absorption. Since leaf water plays an obvious role at estimating N at the shrub scale, August may be an optimal time for acquiring additional sagebrush reflectance spectra because leaf water is lowest in late summer. At the canopy-level, subsetting the dataset to plots with bare ground cover less than 40% illustrated that open canopies can substantially reduce PLS model performance. Preliminary HyMap results also suggest that field spectrometer data might be a powerful tool for increasing the predictive ability in each hyperspectral pixel.

The results of this study warrant further exploration into remotely estimating sagebrush canopy N concentrations. The implementation of spectral transformation techniques should be further refined and additional datasets should be collected in different study areas to improve and further evaluate the predictive ability of regression models. The results presented herein represent an important step toward addressing the confounding influence of bare ground. Consequently, future research should focus on image processing techniques to reduce the influence of bare ground, such as leveraging equations derived at the field / individual shrub scale. Further consideration should also be given to the role of leaf water and plot level canopy N calculation methods by expanding the breadth of field data analysis. For example, green leaf specimens could be analyzed for leaf water content and LAI measurements could be collected at the shrub and plot levels. Finally, it should be noted that future efforts will eventually need to address N contributions from grasses and other shrub species.

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