A METHOD TO ACCESS ABSOLUTE FIPAR OF VEGETATION IN SPATIALLY COMPLEX ECOSYSTEMS

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1. INTRODUCTION

Arid and semi-arid lands compose a large fraction of the earth's terrestrial vegetation, and thereby contribute significantly to global atmospheric-biospheric interactions. The thorny shrubs and small trees in these semi-arid shrub lands have counterparts throughout much of the world's tropical and subtropical zones (Brown 1982) and have captured substantial areas of the world's former grasslands (Johnston 1963, Brown 1982, Schofield and Bucher 1986, Archer 1990). The objective of our field and remotely sensed measurements in the semi-arid shrublands of Texas is to monitor interannual variability and directional change in landscape structure, ecosystem processes and atmosphere-biosphere exchanges. To understand the role ecosystems play in controlling the composition of the atmosphere, it is necessary to quantify processes such as photosynthesis and primary production, decomposition and soil carbon storage, and trace gas exchanges. Photosynthesis is the link whereby surface-atmosphere exchanges such as the radiation balance and exchange of heat, moisture, and gas can be inferred. It also describes the efficiency of carbon dioxide exchange and is directly related to the primary production of vegetation. Our efforts in this paper focus on the indirect quantification of photosynthesis, and thereby carbon flux and net primary production, via remote sensing and direct measurements of intercepted photosynthetically active radiation (IPAR).

While it is well known that NDVI is strongly correlated to certain biophysical parameters, in the past such correlations have typically been used at the scale of remotely sensed imagery to illustrate *relative* variance of the fraction of photosynthetically active radiation intercepted (fIPAR) by the canopy. We use spectral mixture analysis in combination with ground data to predict *absolute* values of fIPAR at the image level. We reproduce previously established relationships between fIPAR, leaf area index (LAI), and traditional spectral vegetation indices (SVIs), and utilize a spectral mixing algorithm to quantify the relative contribution of sub-pixel green vegetation components to full pixel fIPAR and LAI values. Spectral mixture analysis (SMA) can be used to remove non-green contributions from pixel-scale reflectance and thus permit the calculation of fIPAR based on the fractions of only green photosynthesizing vegetation in a highly mixed landscape. Correction of fIPAR measurements for the fraction of green biomass has been shown to improve relationships with ground-based NDVI measurements (Gamon et al. 1993). Moreover, SMA separates functionally different woody and herbaceous vegetation forms. We compare the abilities of traditional SVIs and our SMA model in predicting both *relative* and *absolute* ground values of fIPAR at both a transect and a landscape scale.

2. METHODS

2.1 Study Site

The Texas Agricultural Experiment Station La Copita Research Area is located in Jim Wells County, 15 km south west of Alice, Texas (27°40'N; 98°12'W) in the eastern portion of the Central Rio Grande Plain. The vegetation is described as subtropical thorn woodland (McMahan et al. 1984), or semi-arid savanna parkland (Archer et al. 1990), and is characterized by intermittent low-lying closed-canopy wooded drainages surrounded by a matrix of herbaceous uplands. The greater proportion of La Copita is characterized by large honey mesquite trees (*Prosopis glandulosa*) subtended by a variety of woody shrubs. Scattered thoughout the herbaceous zones are clusters of woody shrubs surrounding individual mesquite trees (mottes) as well as more extensive groves consisting of a contiguous wooded canopy of multiple mesquite trees and shrub understories. Occasional playa (lakebed) sites, lowlands dominated by open grassland with varying degrees of woody overstory, are scattered across the ranch.

Anthropogenic disturbances are largely related to brush control and include the application of herbicides in strips at various dates ranging back to 1983, clearing of brush by chaining in 1979, selective burning, and rotational grazing by cattle. The soils within the uplands generally consist of a fine sandy loam whereas the drainages consist of a non-directional clay loam (Scifres and Koerth 1987). The climate is subtropical with hot summers and mild winters. Mean annual rainfall (680 mm) is bimodaly distributed, with maxima in May/June and September (Scifres and Koerth, 1987).

2.2 Field Measurements

Our study at the La Copita Research Area involved two distinct stages. First, a high resolution ground sampling of fIPAR was made along transects in 2 of our 8 landscapes (L1 and L6) for the purpose of intensive ground truthing in the evaluation of the relationships between fIPAR and the SVI/SMA-derived values (Kennedy and Wessman *in review*). Second, measurements of selected landscape units were made across the entire ranch to define the natural range in variation of fIPAR and LAI for SMA extrapolation. The landscape units were selected to characterize different vegetation structural forms as described above. Within each of 8 landscapes distributed throughout La Copita, the following sites were established: 1 grove site, 1 drainage site, 3 mottes without *Prosopis* overstory, 3 mottes with *Prosopis* overstory, and 3 herbaceous sites. An additional 6 sites were established in recently burned herbaceous zones. Within the 6 playas sampled, 3 woody sites and 3 herbaceous sites were established.

PAR was measured using a line quantum sensor held in each of the 4 cardinal directions while the incident radiation was simultaneously being measured with a point quantum sensor mounted on a rangepole. The two sensors were calibrated to each other by logging 6 entries of incident PAR simultaneously several times during the course of a day, and then adjusting the line quantum data during the data processing phase. We calculated fIPAR according to $fIPAR = (PAR_i - PAR_t) / PAR_i$ where PAR_i is the incident PAR and PAR_t is the PAR transmitted through the canopy.

A LICOR Plant Canopy Analyzer was used to collect leaf area index (LAI) data for all the landscape sites within the same week as the AVIRIS overflight. LAI was not measured along the transects. Measurements were made at ground level to include both over- and understudy for total LAI. These data are included in this paper, although fIPAR was of primary interest.

Transect measurements

Approximately 1200 fIPAR measurements were made to best quantify fIPAR variation along transects spanning the upland regions of Landscapes 1 and 6 (Kennedy and Wessman *in review*). Landscape 1 was sampled with two N-S transects 7 meters apart and approximately 320 m in length. Landscape 6 was sampled with two E-W transects 7 meters apart and approximately 270 m in length. PAR measurements were made at 4-meter intervals along each transect. All the fIPAR measurements that fell into one AVIRIS pixel (post-georegistration) were averaged to create a single fIPAR value to be compared directly with the single image value for that pixel.

Landscape measurements

Total fIPAR measurements (below understory) were made for each of the 181 sites from all 8 landscapes. Four to six replicates of measured fIPAR were averaged to yield a single fIPAR value per site. Since the PAR measurements were made during two separate time periods (July 7-10 and August 9-10) and were to be compared with AVIRIS imagery acquired on August 8, the data were organized into both the mean of the two months as well as the separate month of August. In the following analysis, the average of the July-August fIPAR data was used.

2.3 Image processing

AVIRIS imagery was acquired on 8 August 1993. Atmospheric effects within the image were removed with a solar and atmospheric model (ATREM, Gao et al. 1993). Noise within the image was reduced by applying a maximum noise fraction (MNF) transformation (Green et al. 1988). Georegistration was focused on the pixels running the length of the transects. Aerial photography was incorporated into the registration procedure for highly accurate registration and location of ground fIPAR measurements (Kennedy and Wessman *in review*). The RMS error of prediction for procedure was less than 0.8 meters.

ENVI (Environment for Visualizing Images, Research Systems Inc.) was used to calculate values of NDVI and SAVI. NDVI was calculated according to NDVI = (NIR - R) / (NIR + R) where NIR refers to the reflectance at 0.83 μm and R refers to the reflectance at 0.68 μm. SAVI was calculated according to SAVI = ((NIR - R) / (NIR + R + L)) (1 + L) where L (the soil-adjustment factor) = 0.5.

A spectral mixture model (Bateson and Curtiss 1996) was used to produce 5 endmembers characteristic of the La Copita ranch. Each pixel was assumed to consist of combinations of a short-stature "grass" endmember, a taller stature "shrub" endmember, soil, shade, and litter. It was assumed that the grass endmember described the herbaceous component and that the "shrub" endmember described the taller stature woody vegetation dominating the drainages and groves.
We used the landscape-unit fIPAR/LAI data from Landscapes 1 through 8 to determine median values for the herbaceous zone (0.389/1.135) and the grove/drainage class (0.928/3.415). Assuming fIPAR values of the litter, shade and soil endmembers to be zero, SMA-weighted values of fIPAR and LAI were then calculated according to:

weighted fIPAR = (grass fraction * herb median fIPAR) + (shrub fraction * grove/drainage median fIPAR)

weighted LAI = (grass fraction * herb median LAI) + (shrub fraction * grove/drainage median LAI).

Pixel-scale fIPAR, calculated from geo-registered and aggregated field measurements, were then regressed against (1) the NDVI and SAVI values and (2) SMA-weighted median values for those same pixels.

3. RESULTS AND DISCUSSION

Figure 1 shows the distribution of the ground measurements of fIPAR and LAI split by vegetation type. As expected, the greatest fraction of light is intercepted by the woody landscape components such as the drainages, groves, mottes, and woody playa sites. The least amount of light is intercepted in the herbaceous zone, with slightly more interception in the burned herbaceous zone where grasses are regenerating rapidly due to disturbance, and yet more interception in the herbaceous playa which is characterized by a tall thick grass cover. This trend is mimicked in the LAI data with the exception of a greater data spread in the playa sites.

Five endmembers were derived from the SMA (Figure 2). The grass endmember was characterized by a higher NIR plateau than the woody vegetation. Litter was distinguished from soil largely based on lignin-cellulose features near 1.7 and 2.3 μm.

All regressions of the transect fIPAR data with the remote sensing data were significant (Table 1). In fact, the correlation coefficients were all very similar. However, the intercept and slope values were significantly different. Of all the relationships, only that of the SMA produced a slope not significantly different from 1.0; with a y-intercept of -0.02 , the SMA:fIPAR regression line was essentially the 1:1 line. This suggests that the SMA model approximates the true field values well and that field data must be incorporated into any model if the absolute field values are to be adequately predicted.

Table 1. Regression coefficients of field data and remotely sensed values.

	y-intercept	slope	R2	p
NDVI	-0.54	2.29	0.77	<0.0001
SAVI	-0.82	5.08	0.74	<0.0001
SMA-weighted landcape units	-0.02	1.02	0.74	<0.0001

Given the goal of predicting absolute values of ground fIPAR rather than merely describing relative variance across the landscape, the predictor equations developed using the ground transect data set were used to predict fIPAR values for the entire La Copita Ranch:

(a) Field fIPAR = -0.54 + 2.29 * NDVI
(b) Field fIPAR = -0.02 + 1.02 * SMA-weighted scaled fIPAR

The ranges of the fIPAR values derived from (a) and (b) models for the ranch were compared to the ranges established using the SMA model on the transects (Figure 3). Note that the relative distribution of mean fIPAR values derived from the NDVI model for the different landscape units appears somewhat similar to the SMA, but the range of absolute values differ substantially within and across groups.

4. CONCLUSIONS

It has been shown that field measures of fIPAR discriminate well between different vegetation functional groups at the La Copita Research Area in South Texas. Woody, herbaceous and mixed sites intercept significantly different amounts of PAR. This suggests that variation in photosynthetic rates will be significant in highly mixed landscapes and a lack of sensitivity to the green vegetation in mixed conditions may impair large-scale fIPAR estimates.

Comparison of our SMA model with traditional remote sensing indices such as NDVI showed that both measures perform equally well in predicting relative variance in field fIPAR data at the transect scale. In other words, there is no significant difference between the results of simple linear regression between field fIPAR values and NDVI values/SMA model values. We have shown that, while NDVI is strongly correlated to field fIPAR values, in its unscaled form it cannot shed light on the absolute values of field fIPAR. Moreover, NDVI values across the entire heterogeneous region show a wider variation than those derived from the SMA model. Given the close approximation of the SMA model to the actual fIPAR values and the fact that the scaling of the SMA was accomplished using the measured range in fIPAR values for several landscapes, it is possible that the NDVI values are influenced by the varying (sub-pixel) structure of the landscape across the ranch.

The SMA model allows for sub-pixel identification of relative fractions of photosynthesizing endmembers, which can then be weighted and scaled using spot field measurements obtained thoughout the study area. In fact, identification and measurement of landscape units may be the best sampling strategy in heterogeneous environments. In combination with spectral mixture analysis, which gives the abundance of those units at sub-pixel scales, appropriate scaling of the actual values of functional properties can be made without confounding influences from litter and soil.

5. ACKNOWLEDGMENTS

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6. REFERENCES

Archer, S. 1990. Development and stability of grass/woody mosaics in a subtropical savanna parkland, Texas, U.S.A. *Journal of Biogeography* 17: 453-462.

Bateson, C.A. and B. Curtiss. 1996. A method for manual endmember selection and spectral unmixing. *Remote Sensing of Environment.* 55:229-243.

Brown, D. E. (ed.). 1982. Biotic communities of the American southwest-United States and Mexico. *Desert Plants* 4: 101-106.

Gamon, J. A., C. B. Field, D. A. Roberts, S. L. Ustin and R. Valentini, 1993. Functional patterns in an annual grassland during an AVIRIS overflight. *Remote Sensing of Environment,* 44: 239-253.

Gao, B.-C., K.B. Heidebrecht and A.F.H. Goetz. 1993. Derivation of scaled surface reflectance from AVIRIS data. *Remote Sensing of Environment* 44(2):165-178.

Green, A.A., M. Berman, P. Switzer, and M.D. Craig. 1988. A transformation for ordering multispectral data in terms of image quality with implications for noise removal. *IEEE Transactions on Geoscience and Remote Sensing* 26(1):65-74.

Johnston, M. C., 1963. Past and present grasslands of southern Texas and northeastern Mexico. *Ecology* 44:456-466.

Kennedy, R.E. and C.A. Wessman. Vegetation indices and fIPAR in a structurally complex landscape. *Landscape Ecology* In review

McMahan, C. A., R. G. Frye, and K. L. Brown. 1984. The vegetation types of Texas. Texas Parks and Wildlife Dept., Austin, Tx.

Schofield, C. J. and E. H. Bucher. 1986. Industrial contributions to desertification in South America. *TREE* 1: 78-80.

Scifres, C. J. and B. H. Koerth, 1987. Climate, soils and vegetation of the La Copita Research Area. MP-1626, July 1987. The Texas Agricultural Experiment Station, The Texas A&M University System, College Station, Texas.

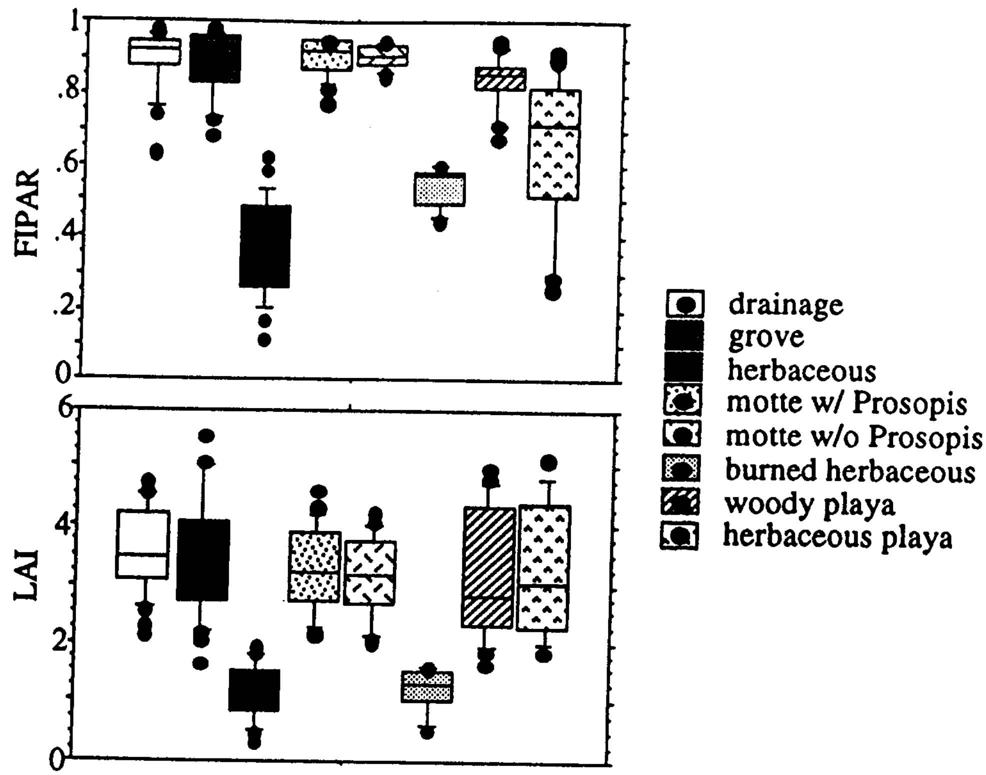

Figure 1. Distribution of ground-measured FIPAR and LAI showing the 10th, 25th, 50th, 75th, and 90th percentiles.

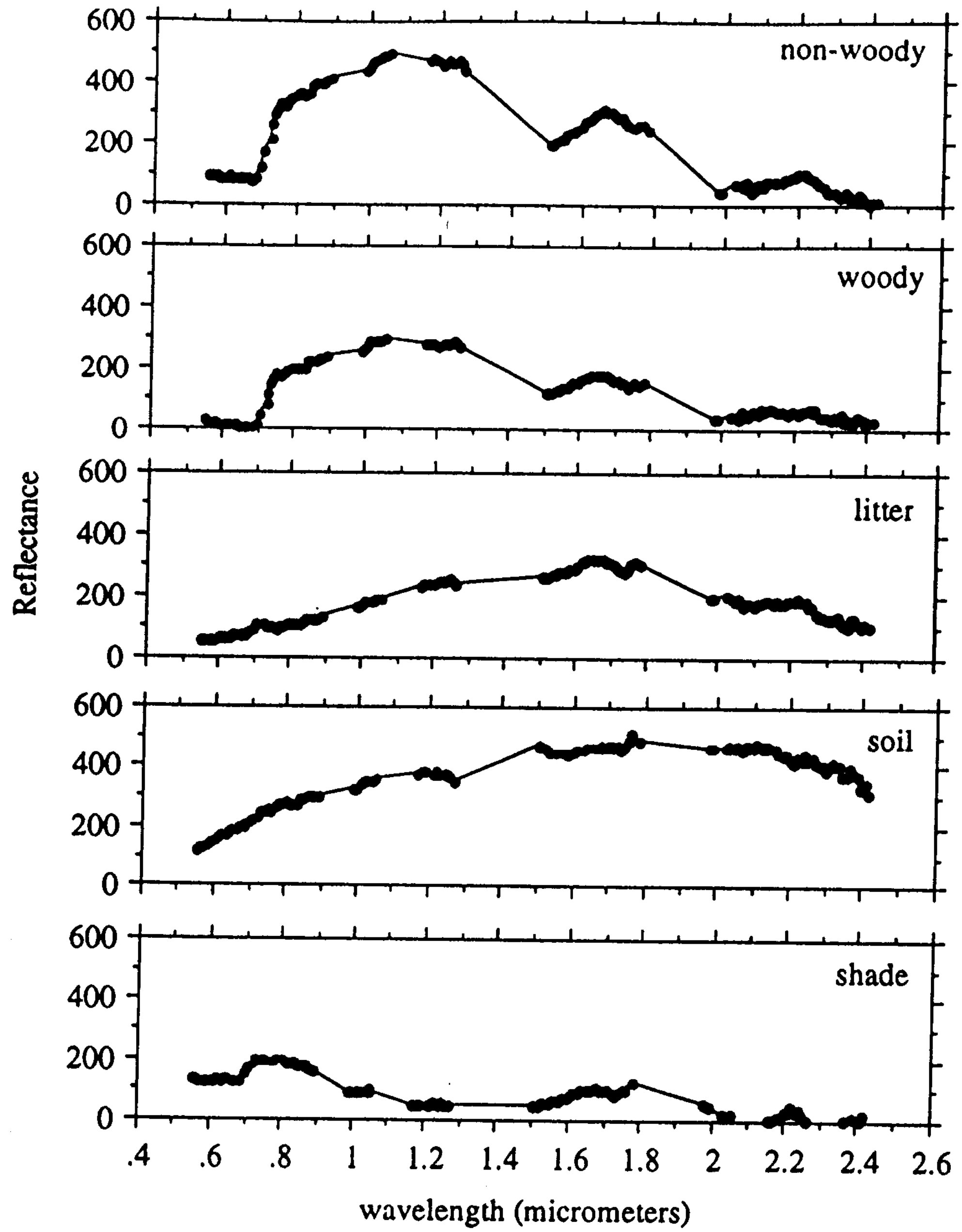

Figure 2. Five endmembers resulting from spectral unmixing. The breaks in the data are indicative of bad bands in the AVIRIS imagery.

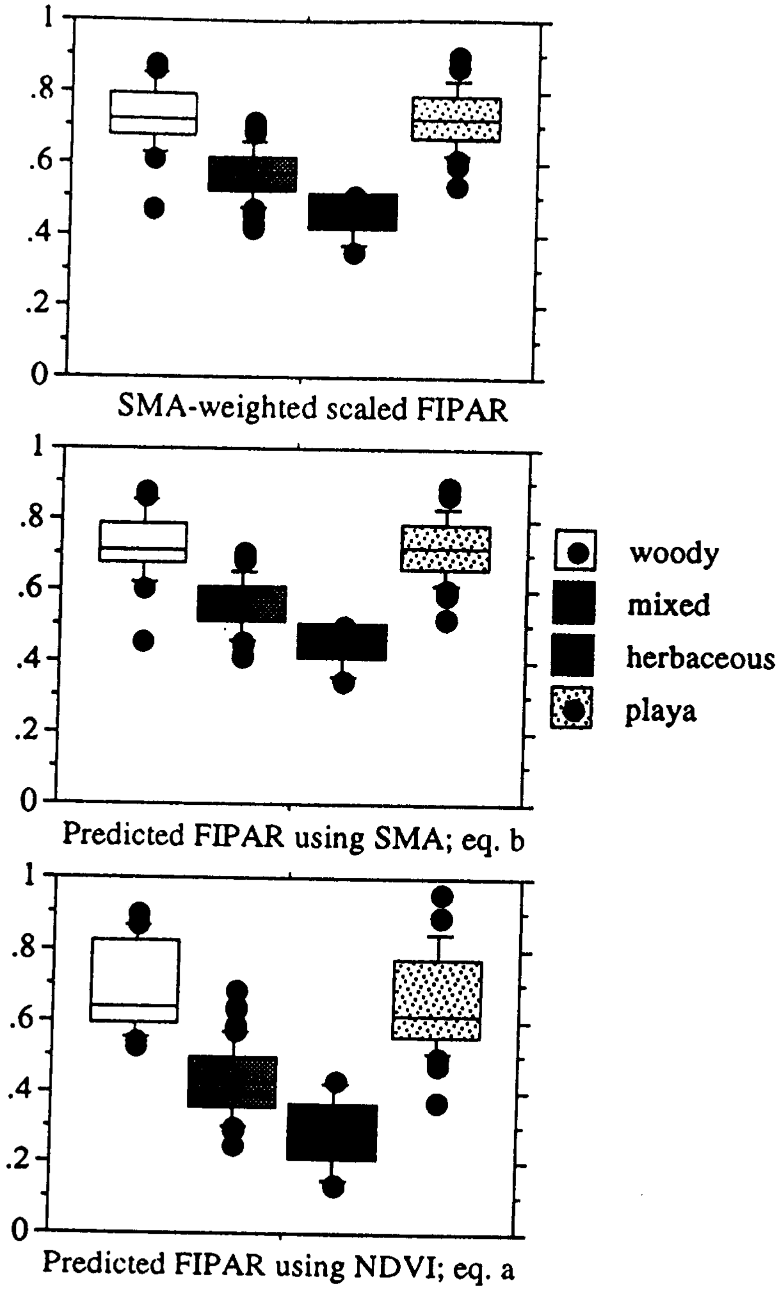

Figure 3. Distribution of fIPAR values for: (a) the SMA-weighted scaled fIPAR for 4 transects in 2 landscapes, and for the entire La Copita ranch derived from the (b) SMA and (c)NDVI models.