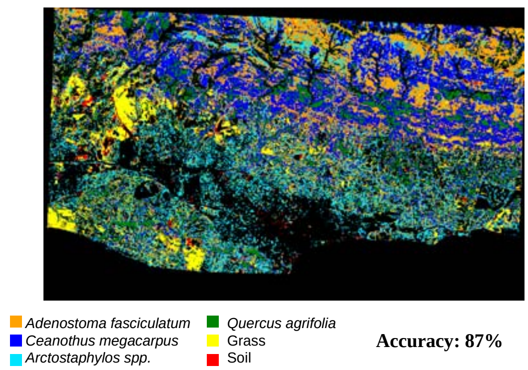
Final Report

Quantitative Comparison of Spectral Indices and Transformations of Multi-resolution Remotely Sensed Data using Ground Measurements: Implications for Fire Severity Modeling

(Project 01-1-4-23)

Vegetation Mapping using MESMA
Santa Barbara Front Range



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Summary

The number and severity of wildfires in the western United States since the late 1990s has focused research efforts and subsequent management actions on assessing fire hazards using remote sensing imagery and processing techniques. A major factor that determines fire hazard is live fuel moisture (LFM) content. The changes in live fuel moisture are dynamic, and fuel conditions modify fire behavior and fire danger ratings in shrublands and forested ecosystems. We investigated the empirical relationship between field-measured LFM and remotely-sensed greenness and moisture measures from the Airborne Visible/Infrared Imaging spectrometer (AVIRIS) and the Moderate Resolution Imaging Spectrometer (MODIS). Key goals were to assess the nature of these relationships as they varied between sensors, across sites, and across years.

Live Fuel Moisture (LFM) is a strong determinant governing ignition success and fire intensity, particularly in shrublands where a majority of the biomass available for combustion is living. This information can be useful both for prescribed fire planning and for predicting fire intensity and crown fire initiation of wildfires. LFM, or fuel moisture content (FMC), changes through the year, primarily due to available soil moisture, and soil and air temperature (Countryman and Dean 1979). The following levels of fire risk in chaparral based on FMC: low fire risk when FMC>120%, moderate 120%>FMC>80%, high 80%>FMC>60%, extreme 60%>FMC. Agee et al. (2002) suggest that moisture levels of 100-120% are required for crown fire initiation for Pacific Northwest conifers.

Remote sensing has the potential of significantly improving our capability of mapping the distribution of LFM and monitoring seasonal changes. In a joint proposal to the Joint Fire Science program, Drs. Rechel and Roberts proposed to address many of the current limitations in mapping LFM. Specific objectives were:

<u>Primary Objectives</u>

1. **Evaluate the accuracy of spectral indices and spectral transformations to determine their usefulness in developing 'greenness maps' for fire severity mapping for a variety of major ecosystems in the western United States**. Characterization of the spectral and spatial distribution of biophysical properties of a range of ecosystems in the western United States and seven locations identified by Dr. Rechel as representing a range of important western ecosystems. Archived AVIRIS data were ordered and used, where available, to provide high quality spectral and textural characterization of these sites. A primary focus of this analysis was on AVIRIS data acquired over the Santa Monica Mountains (SMM). A secondary focus has been on high quality AVIRIS data acquired over Yosemite National Park. While none of Dr. Rechel's sites were in this range, the SMM data set provided high quality temporal sampling of LFM through the Los Angeles County Fire Department (LACFD). Completed.

2. **Investigate the use of multiple spatial resolutions from satellite and aircraft imagery in conjunction with the spectral indices and transformations to determine the appropriate resolution for the major ecosystems**. Multiscale/multitemporal analysis using broad band sensors. AVIRIS data are insufficient for large area mapping and thus do not address the needs of an operational program. To address these needs, we implemented a multiscale program, in which information derived from AVIRIS was used

to aid the interpretation of ETM+ and MODIS. ETM+ and MODIS analysis focused on a subset of broad band indices, applied to the SMM time series and all of Dr. Rechel's LFM sampling sites. Completed.

3. **Compare each index and transformation with the remote sensed images using ground based vegetation and fuels sampling at the appropriate scales.** Completed.

4. **Develop web-based graphical user interfaces to be accessed via the Internet by multiple users for fire management decisions as well as for multiple resource use planning efforts for post-fire rehabilitation efforts.** In Progress.

Methods

Study Sites

Seven study areas were selected in the western United States. The areas were chosen based on the importance of the dominant vegetation types to fire severity and the absence of data on fuels. All study sites were located on public lands administered by the Federal government. The study sites were: 1) Sierra National Forest, California; 2) Lassen National Forest, California; 3) Los Padres National Forest, California; 4) Coconino and Kaibab National Forests, Arizona; 5) Gila National Forest, New Mexico; 6) Rio Grande National Forest, Colorado; and 7) Birds of Prey Conservation Area, Idaho.

Major vegetation communities sampled were aspen (*Populus tremuloides*), mixed fir (*Pseudotsuga menziesii*, *Abies lasiocarpa*), mixed pine (*Pinus jeffreyi, Pinus ponderosa*, *Pinus coulteri*), mixed oak woodlands (*Quercus agrifolia, Quercus chrysolepis, Quercus douglasii*), mixed chaparral (*Adenostoma fasculatum, Ceanothus sp., Arctostaphylos* sp.), mixed Great Basin sage (*Artemisia tridentata*, *Eriogonum* sp., *Atriplex* sp.), and pinyon-juniper (*Juniperus* sp., *Pinus edulis*).

Field Data Collection

Above ground standing live biomass was collected in 15-33 plots for each of the dominant vegetation types. Tree plots were $400m^2$ and shrub plots were $100m^{2.}$ At each plot up to 6 samples were clipped from individual trees and shrubs and stored in moisture proof polypropylene bottles. We used a fuel gauge to collect samples that consisted of less than 10-hour fuel size classes. Each fuel bottle was weighed with the live (wet) fuel and then oven dried for at least 96 hours at 95º F/35º C. Percent fuel moisture was calculated as the difference between the wet and dry fuel weights, divided by dry weight.

All plots were located on a map and with a Global Positioning System (GPS). Samples were collected at each site in the early (low risk) fire season and again at the same plots in the late (high risk) fire season.

Fuel Moisture Values

Mean percent change in fuel moisture per dominant vegetation type between early and late season for forest and shrub study sites in the Western United States.

Study Site	% Change	Study Site	% Change
Birds of Prey Con. Area, Idaho		**Los Padre NF, California**	
Rabbit brush	-14.25	Ceanothus	-38.82
Sage brush	-6.44	Douglas-fir	-15.10
Salt brush	-15.41	Oaks	-7.49
Gila NF, New Mexico		Firs	-32.45
Aspen	-6.35	Pines	-16.24
Douglas-fir	14.50	**Rio Grande NF, Colorado**	
Firs	5.09	Aspen	-11.39
Juniper/pinyon pine	24.85	Douglas-fir	9.36
Oaks	-23.86	Firs	36.31
Pines	16.42	Juniper/pinyon pine	24.85
Lassen NF, California		Pines	1.17
Firs	10.41	Spruces	4.02
Pines	12.10	**Kaibab/Coconino NFs, Arizona**	
Sierra NF, California		Aspen	-7.76
Firs	-2.79	Firs	-21.07
Incense-cedar	-10.41	Juniper/pinyon pine	12.87
Oaks	-11.47	Oaks	68.73
Pines	-13.54	Pines	-14.88

Improved Estimates of LFM using imaging spectrometry and broad band sensors

Data Sets and Methods

This effort focused on AVIRIS and MODIS time series data acquired over Los Angeles County (Figure 1; Table 1). Los Angeles County was selected because it includes an extensive network of LFM sites that have been routinely sampled by the LACFD approximately every two weeks since 1981. LFM is sampled by LACFD following protocols described by Countryman and Dean [1979], in which leaves and small stems (3.2 mm or less) from old and new foliage are collected from each site. Following this protocol, all reproductive plant parts and dead plant material are removed from samples and only branches that include live foliage and stems are sampled. Where two shrub species are codominant at a site, separate samples are collected for each species. Samples are weighed, dried at a temperature of 104º C for 15 hours, than reweighed to determine LFM.

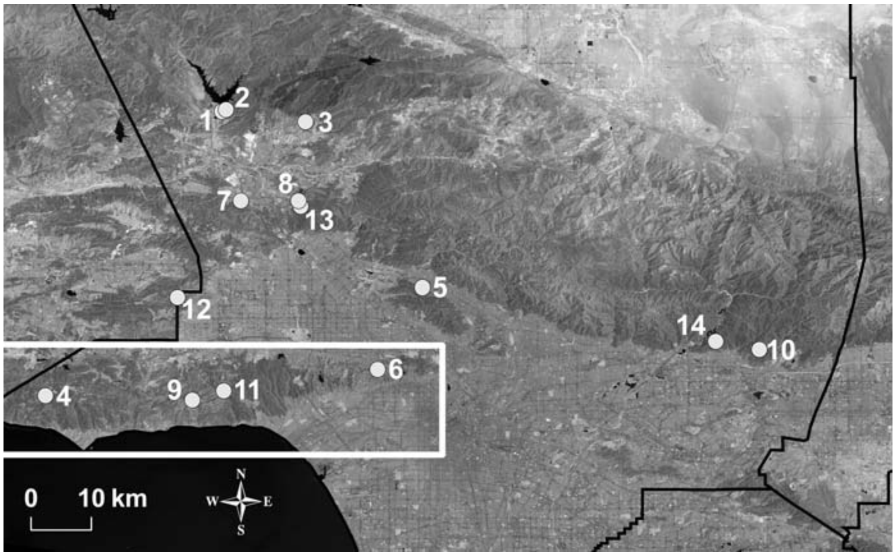

Figure 1) MODIS image showing the location of the 14 LACFD LFM sites. Numbers correspond to the Site #s in Table 1.

Table 1) Geographic location and number of LFM measurements between 2000 and 2004 for 14 LACFD LFM sample sites (LACFD, 2000-2004). Site number corresponds to the number of the site shown on Figure 1. Sample number refers to the number used in the analysis. Where two species were sampled at the same site there are two sample numbers for a single site number. Drought deciduous vegetation is highlighted in grey.

Sample#	Site	Sample Name	Lat	Long	2000	2001	2002	2003	2004	Total
1	1	Bitter Cyn sagebrush	34° 30' N	118° 36' W	16	21	21	21	21	100
2		Bitter Cyn purple sage			16	21	21	21	21	100
3	2	Bitter Cyn 2 chamise	34° 31' N	118° 36' W	16	21	21	21	21	100
4	3	Bouquet Cyn black Sage	34° 29' N	118° 29' W	16	17	0	0	0	33
5		Bouquet Cyn chamise			16	17	0	0	0	33
6	4	Clark Mtwy chamise	34° 05' N	118° 52' W	16	21	21	21	21	100
7		Clark Mtwy big pod Ceanothus			16	21	21	21	21	100
8	5	La Tuna Cyn chamise	34° 15' N	118° 18' W	15	20	21	21	21	98
9	6	Laurel Cyn chamise	34° 08' N	118° 22' W	16	20	21	21	21	99
10	7	Pico Cyn chamise	34° 22' N	118° 35' W	16	21	21	18	0	76
11	8	Placerita Cyn chamise	34° 22' N	118° 29' W	16	21	21	21	11	90
12	9	Schueren Rd. chamise	34° 05' N	118° 39' W	16	21	19	21	21	98
13	10	Sycamore Cyn chamise	34° 09' N	117° 48' W	15	20	16	0	0	51
14		Sycamore Cyn hoaryleaf Ceanothus			15	20	16	0	0	51
15	11	Trippet Ranch black sage	34° 06' N	118° 36' W	16	21	21	21	21	100
16		Trippet Ranch chamise			16	21	21	21	21	100
17	12	Woolsey Cyn chamise	34° 14' N	118° 40' W	16	21	21	21	21	100
18	13	Peach Mtwy chamise	34° 22' N	118° 32' W	0	0	0	3	21	24
19	14	Glendora Ridge chamise	34° 10' N	117° 52' W	0	0	2	21	20	43
20		Glendora Ridge hoaryleaf Ceanothus			0	0	2	21	20	43
		Total Samples			269	345	307	315	303	1539

AVIRIS analysis focused on an extensive 9 year time series of AVIRIS images acquired between 1994 and 2001 (Table 2). These data cover a range of moisture conditions, as characterized by the Cumulative Water Balance Index (CWBI: Dennison et al., 2003). AVIRIS reflectance data were processed to generate a series of spectral indices that have been shown to be correlated with LFM, including several measures of greenness, more direct measures of moisture and spectral mixture models (Figure 2: Table 3). Greenness measures studied included several that have been identified as good predictors of LFM in grasslands or shrublands, including the Normalized Difference Vegetation Index [NDVI: Rouse et al., 1973; Paltridge and Barber 1988; Hardy and Burgan, 1999] and Visible Atmospherically Resistant Index [VARI: Gitelson et al., 2002; Stow et al., 2005; Table 3]. We included two more indices that are promising, including the Enhanced Vegetation Index (EVI) [Huete et al., 2002], a modified form of the NDVI designed to be less sensitive to changes in soil brightness and atmospheric scattering and the Visible Green Index (VIg), which is a simplified form of VARI (Table 3). The most relevant aspect of these indices to LFM is their sensitivity to changes in leaf area, expressed as an increase in NIR or green reflectance and decrease in red reflectance due to multiple scattering (especially in the NIR) and increased red light absorption by chlorophyll. These indices would be expected to respond to a change in LFM within a stand primarily through a change in the leaf area [Riggan et al., 1988; McMichael et al., 2004], green leaf cover [Gitelson et al., 2002] or the ratio of photosynthesizing to non-photosynthesizing tissue [Roberts et al., 2003], not a change in individual leaf moisture. AVIRIS chamise spectra illustrate how these indices might be expected to respond to changes in LFM, causing a decrease in all four indices as the contrast between NIR and red and green and red reflectance declines (Figure 2).

Table 2) Date, time of acquisition, solar zenith, solar azimuth and Cumulative Water Balance Index (CWBI) for 13 AVIRIS images acquired between 1994 and 2001. The CWBI was calculated using methods described by Dennison et al. [2003].

AVIRIS date	Time (UTC)	Solar Zenith (°)	Solar Azimuth (°)	CWBI (cm)
11 April 1994	19.276	27.7	24	-3
19 October 1994	20.012	44.3	-5.5	-76.2
9 May 1995	21.228	24	-50.7	+23.6
20 October 1995	20.734	46.7	-19.8	-41.5
26 October 1995	19.984	46.7	-5	-43.2
17 October 1996	19.467	44	5.9	-35.6
23 October 1996	19.291	46.4	8.8	-37.2
7 April 1997	19.763	27.4	8.8	+15.2
3 October 1997	20.088	38.3	-6.4	-64.7
18 May 1998	19.197	17.5	37	+100.0
4 October 1999	19.317	39.1	11.5	-49.2
6 June 2000	19.633	12.3	22.8	-20.2
27 June 2001	18.365	24.5	70.6	-12.8

Moisture measures included several indices that are sensitive to leaf or canopy moisture including the Water Index [WI: Penuelas et al., 1997], Normalized Difference Water Index [NDWI: Gao, 1996] and Normalized Difference Infrared Index (NDII Hardisky et al., 1983; Hunt and Rock, 1989]. The WI and NDWI are formulated as the ratio of NIR reflectance outside of a liquid water band, to reflectance within the 970 (WI) or 1200 (NDWI) nm band. Both indices would be expected to increase with an increase in leaf moisture, but are also sensitive to changes in leaf area and fractional cover [Dawson et al., 1999]. AVIRIS chamise spectra show a clear decrease in the depth of the 970 and 1200 nm liquid water bands with decreasing LFM (Figure 2). When combined with an increase in reflectance slope from 750 to 1200 nm, most likely due to an increase in the presence of non-photosynthetic vegetation (NPV), the WI decreases and NDWI becomes negative (Table 3). The NDII is based on a change in SWIR reflectance along the short wavelength wings of the 2900 nm liquid water band. At leaf scales, a decrease in leaf water results in no or a modest increase in NIR reflectance, and a significant increase in SWIR reflectance [Dawson et al., 1999]. When calculated as a normalized ratio between 857 nm and 1640 or 2130 nm, this results in a decrease in the NDII with decreasing LFM. AVIRIS chamise spectra show this decrease (Figure 2a). However, in this example a decrease in NDII6 is largely driven by a drop in the NIR, not a change at 1640 nm, while a decrease in NDII7 is driven by both the NIR decrease and an increase in reflectance at 2130 nm. While some of these changes may be in response to leaf-level changes in moisture, an increase the ratio of NPV to GV would also produce these changes, resulting in a correlation that is driven more by a change in fuel condition than

Index	Formula	Reference
NDVI	(ρ857-ρ645)/(ρ857+ρ645)	Rouse et al. [1973]
EVI	2.5*(ρ857-ρ645)/(ρ857+6*ρ645-7.5*ρ469+1)	Huete et al. [2002]
VI_g	(ρ555-ρ645)/(ρ555+ρ645)	Gitelson et al. [2002]
VARI	(ρ555-ρ645)/(ρ555+ρ645-ρ469)	Gitelson et al. [2002]
NDII6	(ρ857-ρ1640)/(ρ857+ρ1640)	Hunt and Rock [1989]
NDII7	(ρ857-ρ2130)/(ρ857+ρ2130)	Hunt and Rock [1989]
WI	ρ900/ρ970	Penuelas et al. [1997]
NDWI	(ρ857-ρ1240)/(ρ857+ρ1240)	Gao [1996]

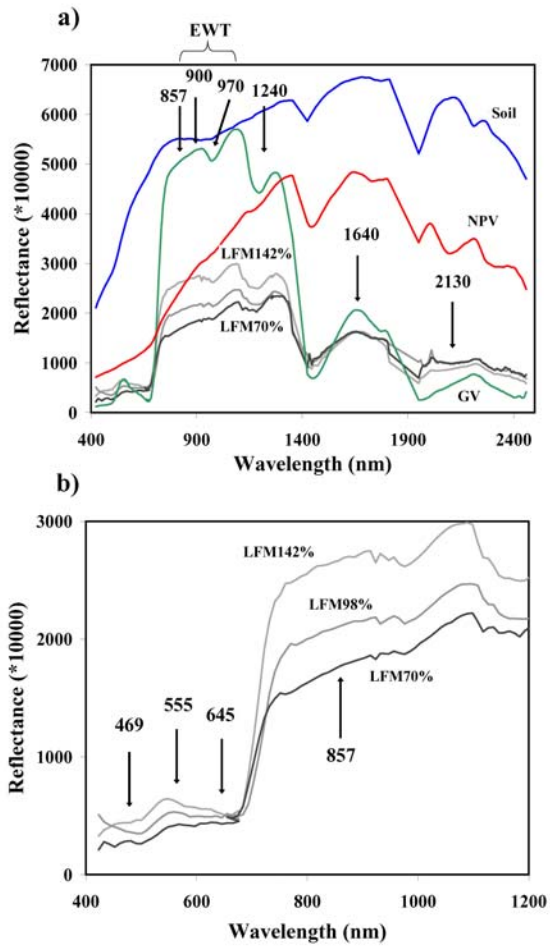

Figure 2) AVIRIS spectra of chamise with three LFM amounts. Wavelength regions used to calculate the various indices are labeled.

Table 3) Spectral indices calculated for MODIS and AVIRIS including their shortened acronym, mathematical formulation and citation.

MODIS analysis focused on MODIS reflectance data acquired between 2000 and 2005. These data were composited using a new technique developed during the course of this project (Roberts et al., in press). This technique screens out clouds, extreme off-nadir views and removes outliers that significantly weaken regression relationships. A key component of the new compositing technique is that it preserves spectral shape and brightness, and thus produces a high quality composite for all spectral indices and mixture models.

Results

Both AVIRIS measures of greenness and moisture were highly correlated with LFM (Figure 3). However, when plotting an AVIRIS measure (x) against LFM (y) for individual and pooled sites, the relationship was linear only over a portion of the range in the value of the measure. All of the greenness and moisture measures showed a similar trend, although the amount of change below 60% LFM varied considerably between each index. For example, the largest threshold was observed in the NDVI, with more moderate thresholds for VARI, VIg and EVI and the smallest threshold for GV (Fig 3, b to e). In the moisture measures, WI showed the largest range (Fig 3h) followed by NDII6 and NDWI (Fig 3 f & g). EWT had the smallest range below the threshold and thus came closest to a linear model over the entire range of EWT (Fig 3i).

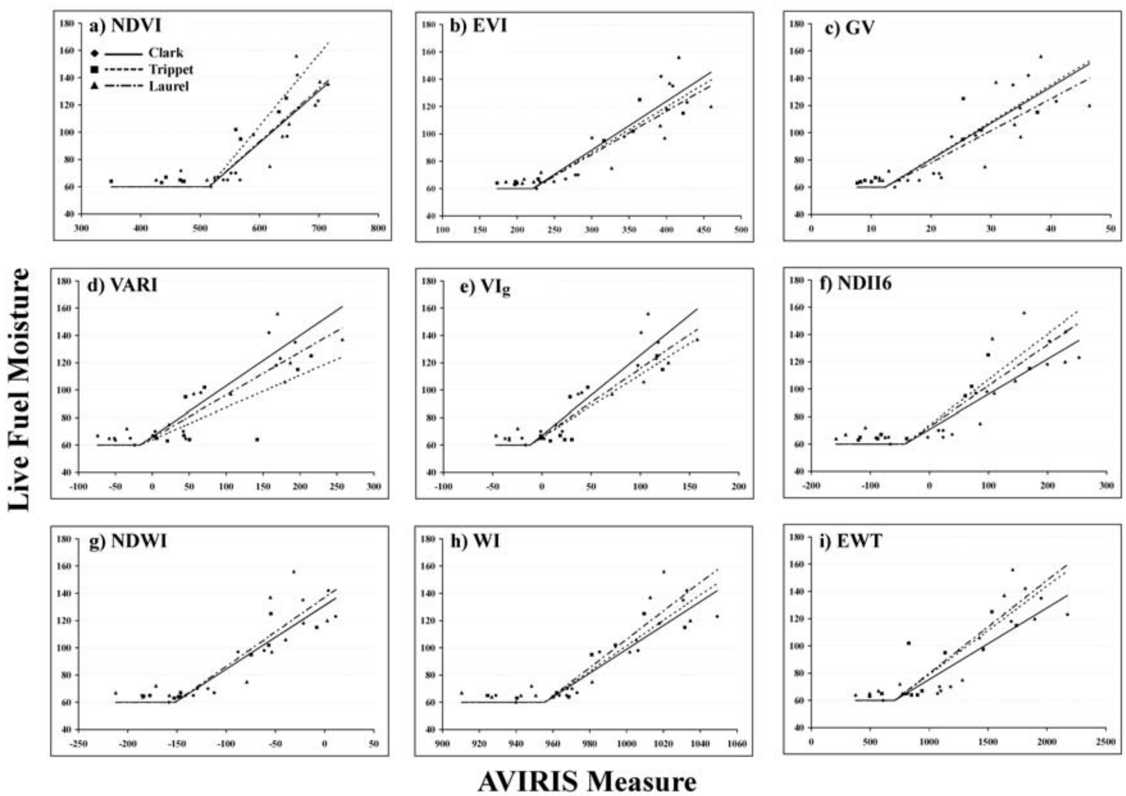

Figure 3) Relationship between AVIRIS measures and LFM.

A simple, thresholded linear model was developed to predict LFM from each AVIRIS measure (Table 4). Based on statistical analysis, all greenness and moisture measures were highly correlated with LFM, ranging from a high r^2 of 0.856 for VIg to a low of 0.723 for NDII7. Of the greenness measures, VIg showed the highest correlation, while WI was the moisture measure that had the highest correlation. Another measure of the utility of an index is its generality across sites. Comparison of pooled to individual site regressions demonstrated that most of the regression relationships were not significantly different between the pooled and individual site models, suggesting that a single threshold and single slope would be adequate for estimating LFM. The one exception was VARI, which did require site specific equations as expressed by a high F value of 3.506 and P value of 0.044. NDVI and VIg were also somewhat more site dependent, with F values of 1.906 and 1.806, respectively. Of the moisture measures, EWT was the most site dependent with an F value of 1.882. The index that appeared least site sensitive was NDWI, which produced a reasonably high r^2 of 0.813 and the lowest F-value.

Table 4) Thresholded linear models for 5 greenness and 5 moisture measures derived from AVIRIS and chamise LFM. Threshold reports the fitted value where LFM has decreased to 60% for each measure. Site specific slopes are reported in columns 2 to 4. Adjusted r^2 is reported for the model that includes site specific slopes, while pooled slope and r^2 is reported for a single model applied to all three sites. F is the F-value between the pooled model and site specific regressions and P reports the probability that this F value is statistically significant. P values below 0.05 would be highly significant, P values below 0.20 slightly significant.

		Site Specific Slopes				Pooled			
Variable	**Threshold**	**Clark**	**Laurel**	**Trippet**	r^2_{adj}	**Slope**	r^2	**F**	**P**
NDVI	514.972	0.379	0.525	0.39	0.822	0.4	0.809	1.906	0.168
EVI	220.945	0.356	0.333	0.316	0.826	0.334	0.832	0.469	0.63
GVF	12.322	2.654	2.714	2.341	0.732	2.524	0.741	0.422	0.66
VARI	-16.445	0.37	0.235	0.313	0.786	0.309	**0.748**	**3.506**	**0.044**
VI_g	-11.919	0.586	0.458	0.498	**0.856**	0.518	0.847	1.809	0.183
NDII6	-41.498	0.257	0.332	0.3	0.786	0.282	0.781	1.269	0.297
NDII7	154.021	0.206	0.296	0.219	0.723	0.22	0.714	1.373	0.271
NDWI	-151.856	0.469	0.464	0.507	0.813	0.481	0.822	0.227	0.798
WI	955.568	0.874	0.933	1.04	**0.846**	0.939	0.844	1.099	0.348
EWT	709.461	0.053	0.065	0.068	0.782	0.059	0.768	1.882	0.172

Analysis of spectral fractions (Figure 4) demonstrated a positive correlation between GV and LFM and negative correlation for NPV and shade. The Soil fraction showed a poor relationship to LFM (Figure 4d). The Shade fraction was inversely correlated, with low Shade values corresponding to the highest LFM. However, this relationship is also somewhat spurious, in that LFM is also expected to be highest when soil water balance is most positive, which in these data sets occurred in April, May or June, when the solar zenith was lowest and thus Shade fraction lowest (Table 2). Similar to other moisture measures, NPV, GV and Shade showed a threshold of LFM below which the fractions continued to change with no net change in LFM.

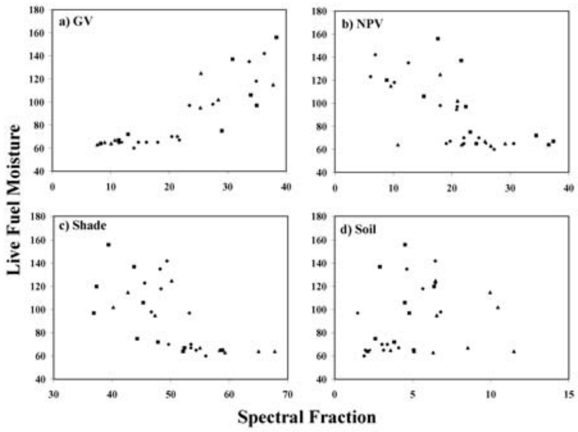

Figure 4) Plot of LFM vs Spectral Fractions

MODIS analysis focused on a subset of these spectral indices applied to the 2000 to 2004 LFM data sets. Scatterplots between MODIS and LFM for Bitter Canyon purple sage and Clark Motorway chamise, demonstrate three basic classes of behavior, near linear relationships (Bitter Canyon NDWI; Figure 5h), convex (Bitter Canyon NDVI; Figure 5a) and concave (Clark Motorway NDII6; Figure 5f). Convex relationships were restricted to deciduous sites, while evergreen sites were concave or linear. As was found for AVIRIS, both measures of greenness and moisture were highly positively correlated to LFM. NPV was also highly correlated, but showed a negative relationship (Figure 5i). Two types of models were fit for each variable, a linear and a 2nd order polynomial. Convexity or concavity of the polynomial was determined by the sign of the term multiplied by the square of x. r^2 and adjusted r^2 values were calculated for each site across all years, for all sites pooled and sites placed into deciduous and evergreen chaparral categories (Table 5). In the table, deciduous chaparral is marked in light grey. Where a polynomial provided the highest correlation r^2 are shown in bold.

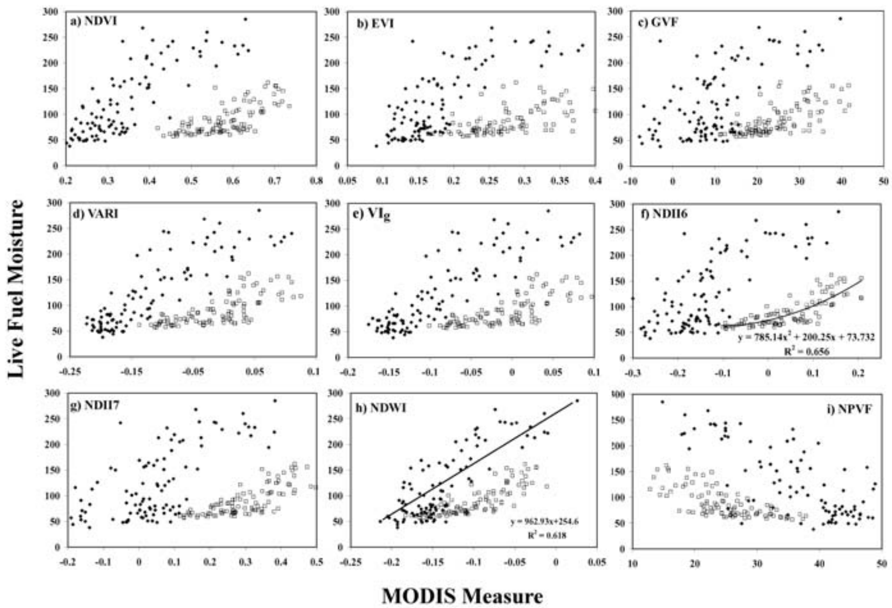

Figure 5) Scatterplots between MODIS measures and LFM.

Table 5) r^2 values for four greenness and three moisture measures and spectral fractions derived from MODIS. Samples highlighted in grey are from a drought deciduous species. Where a linear model was the best model, r^2 is shown in regular fonts and where a 2nd order polynomial was superior the r^2 is shown in bold. Regressions pooled across all sites and years are listed as all, while those subdivided into evergreen and drought deciduous functional types are labeled accordingly. Best correlation is reported within a class of chlorophyll-based , moisture or fractional measures and represents the number of times that index produced the highest r^2. Polynomial reports the number of times a polynomial was selected as the best model. Average r^2 is the average across all sites.

SITE	NDVI	EVI	VARI	VI_g	NDII6	NDII7	NDWI	GV	NPV	Soil	Shade
Bitter Cyn sagebrush	0.655	0.598	0.777	0.777	0.498	**0.46**	0.647	**0.401**	**0.538**	0.072	0.066
Bitter Cyn purple sage	**0.676**	**0.647**	**0.768**	**0.76**	0.547	**0.486**	**0.707**	**0.442**	**0.596**	0.053	0.052
Bitter Cyn 2 chamise	**0.553**	0.661	0.541	0.537	**0.626**	**0.562**	0.628	**0.558**	**0.555**	0.009	0.012
Bouquet Cyn black Sage	0.674	**0.724**	**0.898**	**0.897**	0.845	0.796	0.857	0.698	**0.801**	0.182	0.025
Bouquet Cyn chamise	0.463	0.713	0.524	0.524	**0.721**	**0.655**	**0.671**	0.723	0.504	**0.291**	0.013
Clark Mtwy chamise	**0.527**	0.411	**0.529**	**0.535**	**0.656**	**0.594**	**0.689**	0.445	**0.512**	0.011	**0.032**
Clark Mtwy big pod Ceanothus	**0.623**	0.364	**0.694**	**0.699**	**0.688**	**0.611**	**0.674**	0.379	**0.6**	0	**0.004**
La Tuna Cyn chamise	**0.445**	**0.425**	0.661	0.655	**0.492**	**0.41**	0.459	0.369	0.464	0.001	**0.079**
Laurel Cyn chamise	**0.214**	0.423	**0.412**	**0.408**	**0.444**	0.336	0.372	**0.486**	0.131	0.001	**0.209**
Pico Cyn chamise	**0.69**	0.661	0.792	0.791	**0.663**	**0.651**	**0.659**	**0.592**	**0.508**	**0.031**	**0.157**
Placerita Cyn chamise	**0.431**	**0.581**	**0.574**	**0.574**	**0.544**	**0.475**	**0.56**	**0.553**	**0.407**	**0.04**	**0.187**
Schueren Rd. chamise	0.147	0.114	**0.272**	**0.271**	0.227	0.158	0.345	0.1	0.282	**0.033**	0.001
Sycamore Cyn chamise	0.628	0.657	0.74	0.733	0.651	0.604	0.623	0.63	0.425	0.05	**0.147**
Sycamore Cyn hoaryleaf Ceanothus	0.558	0.581	0.779	**0.776**	0.621	**0.551**	0.65	**0.558**	0.508	0.013	**0.091**
Trippet Ranch black sage	0.334	**0.136**	0.624	**0.621**	0.378	**0.351**	0.395	**0.129**	**0.477**	**0.017**	0.023
Trippet Ranch chamise	0.379	**0.267**	0.616	**0.609**	0.446	**0.409**	0.448	**0.256**	0.423	**0.04**	0.002
Woolsey Cyn chamise	0.49	0.646	0.632	**0.632**	0.558	**0.514**	0.622	0.547	0.387	0.013	0.086
Peach Mtwy chamise	0.498	0.639	0.758	0.751	**0.729**	0.649	0.644	0.568	**0.565**	0.04	0.01
Glendora Ridge chamise	**0.824**	0.837	0.87	0.871	0.834	**0.823**	**0.81**	0.828	0.674	0.123	**0.535**
Glendora Ridge hoaryleaf Ceanothus	**0.845**	0.847	0.897	0.902	**0.844**	**0.814**	**0.819**	0.829	0.648	0.14	**0.56**
All	**0.147**	**0.153**	**0.308**	**0.308**	**0.155**	**0.145**	**0.207**	**0.127**	0.112	0	0.01
Deciduous	**0.271**	**0.265**	**0.533**	**0.534**	0.275	0.225	**0.483**	0.198	**0.439**	0.033	0.026
Evergreen	**0.352**	**0.363**	**0.526**	**0.521**	**0.377**	**0.341**	**0.367**	**0.311**	**0.22**	0	**0.047**
Best Correlations	0	5	10	5	9	0	11	11	9	0	0
Polynomial	10	6	7	11	10	15	8	9	10	6	10
Average	0.533	0.547	0.668	0.666	0.6006	0.5455	0.614	0.505	0.5	0.058	0.115

MODIS correlations were lower than those found with AVIRIS. This is not surprising given the larger footprint of MODIS, slight differences in wavelengths (broad band vs narrow band) and the larger number of samples for most sites. Of the greenness measures, VARI had the highest r^2, producing the best correlation in 10 of 20 sites, the highest average r^2 of 0.668 and an r^2 as high as 0.898 at one site. High correlations were also found for VIg, which produced an average r^2 of 0.666. The lowest correlations were found for the GV fraction, with an average r^2 of only 0.505, followed by NDVI (0.533) and EVI (0.547). When pooled across sites and years, correlations decreased significantly with the highest overall correlation found for VARI and VIg, at 0.308 r^2 .When pooled by functional type, r^2 increased, rising to a high of 0.526 and 0.533 for VARI in evergreen and deciduous chaparral, respectively. VARI also tended towards a linear model, with only 7 of 20 chosen with a 2nd order polynomial. The least linear was VIg in which a 2nd order polynomial was selected in 11 of 20 cases.

NDII6 and NDWI proved to have the highest r^2 of the moisture measures, although correlations were lower than VARI and VIg. NDWI had the highest r^2 for 11 of 20 sites, producing an average r^2 across all sites of 0.614. This index was inferior to VARI in most instances, but superior for four chamise sites. NDII6 was a close second, accounting for the highest correlation in the remaining 9 sites with an average of 0.60. A concave model produced the highest r^2 in half of the sites for NDII6, and 8 of 20 for NDWI. NDII7 produced the lowest r^2, with an average of 0.546 with 15 of 20 sites requiring a 2nd order polynomial. When pooled across sites and years, correlations decreased significantly with the highest overall correlation found for NDWI at 0.207 with only a 0.145 found for NDII6. When pooled by functional type, correlations improved significantly, with an r^2 for NDWI of 0.483 and 0.367 for deciduous and evergreen chaparral sites, respectively. None of the fraction images matched correlations for VARI, VIg or NDWI.

Pooling data across years incorporates considerable interannual variation. Examples are provided for Bitter canyon purple sage and Clark Mountain Motorway chamise for greenness and moisture measures and spectral fractions (Figure 6). LFM is also included on all plots for reference. Time series of LFM demonstrates the expected pattern of early spring greenup followed up dry down in the late spring. However, the amplitude, and phase of seasonal changes in LFM varied considerably between years. For example, the largest amplitude was observed in 2003 in which very low LFM at the end of 2002 was followed by the highest measured LFM during the five year period. The lowest amplitude was observed in 2002, in which LFM at Clark Motorway peaked below 120% and barely exceeded 150% at Bitter Canyon, approximately half the peak observed in 2003. The shape of annual changes in LFM also varied significantly, ranging from a sharp peak, such as 2004 and 2001 in Bitter Canyon, to the broad peak observed in 2003.

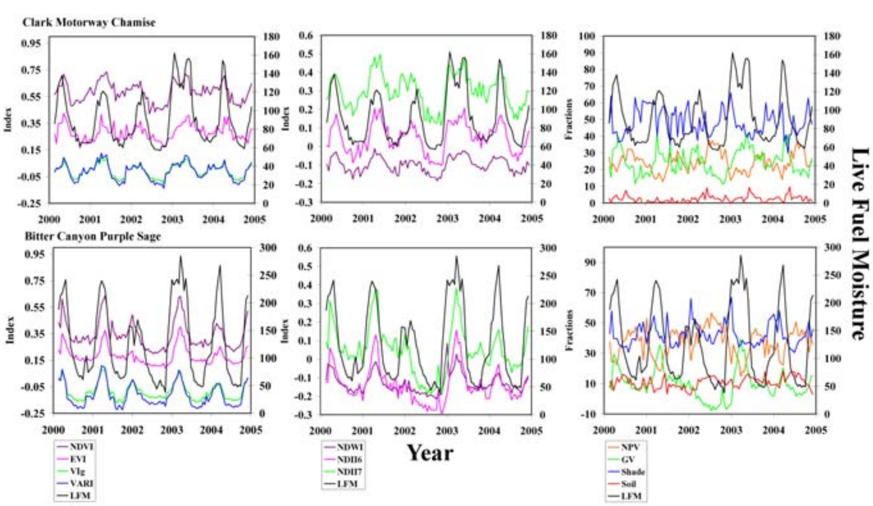

Figure 6) Time series plots of chlorophyll-based (left) moisture (center) and spectral fractions (right) for Clark Motorway chamise (upper row) and Bitter Canyon purple sage

(lower row). Units for each measure are shown on the left y axis of each plot while units for LFM are shown on the right.

Discussion and Summary

Within chaparral ecosystems fire danger is considered to reach critical levels at a LFM of 60% or less [Countryman and Dean, 1979]. The time of year when this occurs varies depending on plant functional type, site quality and seasonal precipitation [Countryman and Dean, 1979]. For example, in sites sampled by LACFD between 2000 and 2004, LFM for chamise varied from 198% to 51%, while deciduous vegetation varied from 350% to 20%. In some years, such as 2003, LFM never reached critical levels for some evergreen sites. Site quality impacts LFM, with more productive sites typically having a higher LFM [Countryman and Dean, 1979] and higher leaf area [Schlesinger and Gill, 1980].

Within a sample, four main factors control LFM: leaf-level LFM, the age distribution of foliage, stem LFM and the balance between stems and leaves. Each of these varies seasonally. For example, in chamise leaf LFM is typically highest early in the year then declines after the rains have stopped (Figure 7). Older foliage has lower LFM than younger foliage [Countryman and Dean, 1979] and stem LFM is lower than foliage moisture. As the season progresses, LAI can change by more than a factor of two, reaching a minimum late in the dry season [Riggan et al., 1988] thus changing the balance between foliage and stems in the sample. LAI can also vary substantially between years, thus modifying the ratio between stems and leaves depending on available moisture [McMichael et al., 2004].

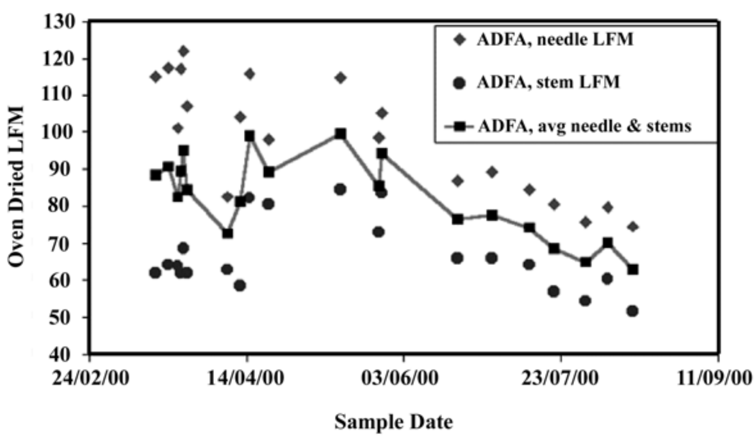

Figure 7) Seasonal changes in LFM for stems and leaves for chamise.

Sampling methodology, site quality and plant functional types are highly relevant for understanding the relationship between LFM and the remotely sensed measures evaluated in this paper. Using AVIRIS, all of the measures evaluated required a thresholded linear model, in which each measure showed a linear relationship to LFM above 60% LFM, and no relationship below this. This result is most likely a product of the field sampling protocol, in which only live foliage and stems are included in the sample, and dead material is excluded. If one considers individual samples, this field sampling protocol would capture changes in leaf and stem moisture and changes due to leaf aging and an increase in the ratio of stems to leaves. However, it would fail to capture branch scale increases in the amount of dead leaves and stems and would not sample plants dominated by dead plant materials. Furthermore, it would be unable to capture the effects of an increase in plant litter or exposed soil with a seasonal decline in LAI. As a result, while LFM in an evergreen shrub would be expected to reach some minimum level, below which no branches would be sampled, stand scale increases in litter, dead materials and exposed soil would still impact reflectance, and thus impact indices and mixture models. This hypothesis is reinforced by mixture models, which show that NPV increases and GV decreases, while LFM remains fixed at 60%. This may explain the concave nature of MODIS, LFM relationships for evergreen shrubs, which are similar in form to the thresholded relationship observed in AVIRIS, but fit a polynomial better because of a greater amount of scatter.

Drought deciduous shrubs showed a very different relationship, with either a linear or convex model showing the best fit. These results are most likely due to differences in leaf properties and the balance between stems and leaves between evergreen and drought deciduous plants. For example, in California sagebrush and purple sage the ratio of stems to branches changes dramatically as the dry season progresses and plants shed their leaves, but retain most fine branches [Gray and Schlesinger, 1981]. Furthermore, those leaves that are retained become highly desiccated and often curl. As a result, minimum LFM in drought deciduous stands is often much lower than evergreen stands, reaching minima of 38% in LACFD Bitter Canyon sagebrush, and 20% in Trippet ranch black sage. Combined with high early season LFM due to a lower leaf specific weight [Gray, 1982], this produces a linear or even convex relationship (where remote sensing measures are no longer sensitive to the highest LFM).

Two greenness measures, VIg and VARI, proved to be the best predictors of LFM, producing higher correlations than NDVI or EVI for MODIS, and higher correlations than NDVI for AVIRIS VIg. Similar results were reported by Stow et al. [2005] for VARI calculated for MODIS from San Diego County. While leaf-scale visible reflectance is not sensitive to changes in moisture status [e.g., Bowyer and Danson, 2004], visible reflectance at canopy scales is sensitive to changes in vegetation cover and LAI [Gitelson et al., 2002; Davis and Roberts, 1999]. Furthermore, when comparing NDVI to VARI and VIg for wheat, Gitelson et al. [2002] noted a near-linear relationship between VARI, VIg and vegetation cover, yet a non-linear relationship for NDVI above 50% cover. While evergreen and deciduous shrubs differ chemically and structurally from wheat, a more linear relationship between vegetation cover and VARI and VIg may provide a better prediction of cover in dense stands than NDVI, and thus higher correlation with LFM.

Moisture measures should correlate with LFM either through a direct measurement of reflectance changes within a liquid water band, or as a response to a change in the amount of NPV relative to live foliage. With AVIRIS, highest correlations for moisture measures were observed for the two indices that involve a ratio between a non-water and water absorbing band, WI and NDWI (Table 3). Highest correlation was observed for WI, which produced an R^2 that was only slightly lower than VIg and a relationship that did not differ significantly across sites. Similarly high R^2 values were produced form NDWI and EWT. Findings regarding WI are similar to those described by Danson and Bowyer [2004], who found that WI was more sensitive to LFM than NDWI, while high MODIS correlations for NDWI match earlier findings by Dennison et al [2005].

MODIS NDWI and NDII6 were both highly correlated to LFM with NDWI producing the highest correlation to LFM, which exceeded VARI at four chamise sites and had higher overall correlation for 2001 when averaged across all sites. NDII7 had the lowest correlations for AVIRIS and MODIS. Similar results are reported by Chuvieco et al. [2002] in which Landsat NDII5 (Equivalent to MODIS NDII6) outperformed NDII7 for most shrubland sites. While the SWIR is generally considered to be more sensitive to canopy moisture than dry plant material [Ceccato et al., 2001], we suspect that some of the correlation between LFM and NDII is a product of an increase in dead branches and litter at lower LFM, which would tend to decrease NDII as NPV increased. This hypothesis is supported by high correlations between NDII6, NDII7 and NPV, which produced R^2 values of 0.77 and 0.70, respectively when pooled across all years and sites. This is significantly higher than any correlation with LFM for pooled data.

Several factors had a substantial impact on correlations between LFM and remotely sensed measures (Table 5). The largest factor was the number of observations, with the three highest correlations found in sites with less than 50 observations (Table 1). Higher correlations in both of these cases can be attributed, in part, to exclusion of 2002, which lowered correlations in most cases. However, a shorter observation period would also minimize the impact of interannual variability, in general. Plant functional type also appears to be a major factor modifying LFM relationships, leading to a significant improvement in all correlations when pooled by functional type. This finding is consistent with site specific relationships, in which convex relationships for LFM were restricted to drought deciduous vegetation, where as concave relationships were only found in evergreen shrubs. Although both functional types produced linear models as well, merging these two patterns would be expected to seriously weaken the global relationship. These findings are also consistent with findings by Bowyer and Danson [2004], who found strong site specific relationships between LFM and NDWI, but a weak global relationship and Sims and Gamon [2003] who show a strong functional type dependence for the relationship between EWT and water content. Lowest correlations were restricted to three sites, Laurel Canyon, Schueren road and Trippet Ranch. For the first two sites, poor correlations can be attributed to urbanization or disturbance – in both cases large amounts of exposed soil, roads and other urban surfaces are present within the MODIS footprint, leading to an overall high soil fraction of 6 to 9% and soil fractions that ranged as high as 22% in the time series depending on the size of the GIFOV. The last site, Trippet ranch, includes two codominant functional types and thus shows a poor relationship for both types.

Regional relationships between LFM and broad-band measures

<u>Data and Methods</u>

Two different LFM datasets were used in this research. The first included the spring/fall pairs of LFM measures collected by Dr. Rechel at 7 sites throughout the western US. The second set of LFM consisted of the same LFM data described in part I.

Remotely sensed data from the MODIS sensor were utilized, specifically the 500 m reflectance product, and both vegetation indices (VIs) and endmember (EM) fractions were regressed against the field-based LFM data. Daily data were used with the spring/fall LFM data as the actual dates of sampling were known. Only near-nadir daily data were used as effective pixel size of off nadir data ranges from 1.1 – 2.4 km; approximately 9 days of daily data are acquired near-nadir in the 16 day repeat cycle for mid-latitude regions. Data from the 2 closest near-nadir dates to the sampling date for each plot were averaged to form the remotely sensed predictor variables. 16-day MODIS composite data were used with the time-series LFM data.

<u>Results</u>

Spring/Fall LFM data

Relationships between fuel moisture and a number of VIs as well as EM fractions were examined. Table 6 contains R^2 for the relationships. Figure 8 contains example plots of fuel moisture versus NDVI for Coconino-Kaibab NF and GV and NPV for Lassen NF. A number of interesting patterns are present. The strength of the relationship between fuel moisture and image products appears to be a function of fire risk. For each study site, the season having the stronger relationship between fuel moisture and image products was the season having higher fire risk. In the spring, study sites in California are still quite wet due to winter rainfall associated with the Mediterranean climate. The Colorado site is at high elevation so elevated soil moisture associated with snow melt reduces fire danger. Only the Arizona and New Mexico study sites experience high fire danger during the spring. During August and September, monsoonal rainfall has lowered fire danger in the southwest, but the other sites have dried out.

Table 6. R^2 between FMC and MODIS image products

Spring

	NDVI	NDWI	NDII6	NDII7	NDGRI	VARI	GV	GVN	NPV	NPVN	SOIL	SOILN
C-K NF	0.628	0.253	0.458	0.526	0.504	0.511	0.569	0.537	0.518	0.529		
GNF	0.757	0.594	0.649	0.712	0.672	0.683	0.576	0.601	0.613	0.573		
LPNF	0.173	0.098	0.128	0.207	0.002	0.002	0.457	0.344	0.147	0.386		
LNF	0.454	0.038	0.062	0.04	0.06	0.056	0.249	0.361	0.469	0.36		
SNF	0.084	0.004	0.018	0.064	0.039	0.039	0.094	0.076	0.02	0.062		
ID	0.308	0.112	0.407	0.471	0.346	0.365	0.263	0.37	0	0	0.19	0.07
RGNF	0.15	0.183	0.189	0.149	0.116	0.115	0.389	0.216	0.037	0.227		

Fall

	NDVI	NDWI	NDII6	NDII7	NDGRI	VARI	GV	GVN	NPV	NPVN	SOIL	SOILN
C-K NF	0.619	0.173	0.563	0.659	0.633	0.643	0.759	0.76	0.798	0.803		
GNF	0.035	0.048	0.015	0.019	0.052	0.052	0.001	0.007	0.05	0.02		
LPNF	0.625	0.583	0.639	0.619	0.409	0.417	0.575	0.697	0.657	0.718		
LNF	0.409	0.393	0.398	0.389	0.511	0.503	0.369	0.539	0.544	0.532		
SNF	0.535	0.582	0.562	0.493	0.405	0.416	0.548	0.395	0.3	0.423		
ID	0.606	0.261	0.141	0.081	0.572	0.568	0.08	0.03	0.589	0.57	0.392	0.56
RGNF	0.53	0.318	0.577	0.583	0.427	0.423	0.263	0.39	0.329	0.445		

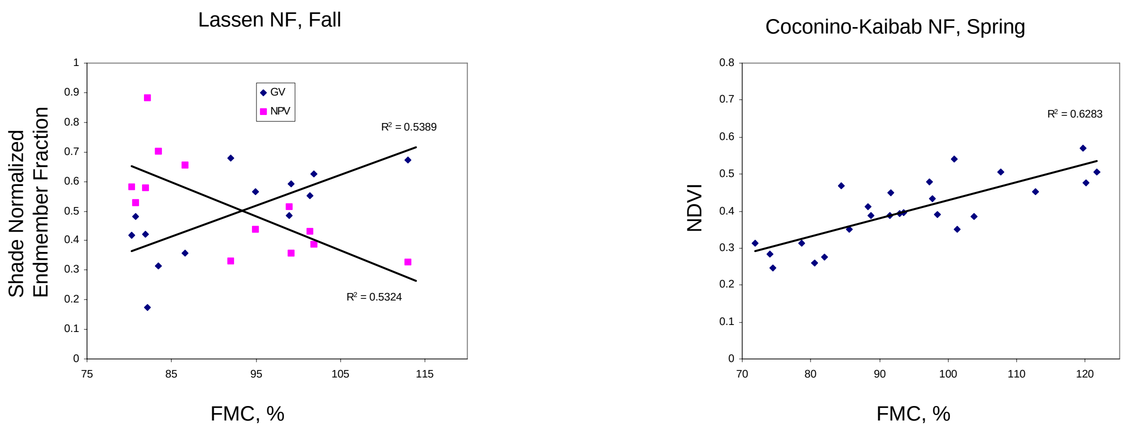

Figure 8. Selected plots of FMC and MODIS image products

NDVI showed the highest correlations of all vegetation indices for both seasons. NDII7 showed the second highest correlation for spring; there was no clear pattern for the fall. NDWI has been shown to track temporal changes in fuel moisture better than NDVI (Dennison et al. 2005), but it did not prove useful in this spatial fuel moisture study.

For the EM fractions, GV and NPV proved to be about equally useful, and R^2 were similar to those for the vegetation indices. EM fractions have an advantage, however, in that they decompose the remote sensing signal into a live and dead vegetation component, and thus are more readily interpretable than vegetation indices.

For fall, an interesting finding was that shade normalized fractions performed better than “raw” ones. Shade normalizing is a process designed to reduce noise associated with differences in topographic shading. The spring data was acquired within a month of the summer solstice, the fall data 3 months from summer solstice. Thus, spring remotely sensed data was more illuminated, minimizing topographic shading.

The Idaho site is unique in this study because vegetation cover is much lower. It was the only site on which a 4 EM model (GV, NPV, and soil) was required to model pixel reflectance. The NPV fraction showed the strongest relationship with fuel moisture, with soil having less of a relationship and GV having no relationship.

Time-series FMC data

Multiple linear regression was used to regress MODIS data against the LACFD LFM dataset. The desired final products of this research question are cross-validated regressions which work for all sites of the same plant functional type; prior research suggests the form of the relationships (e.g., linear, quadratic concave and convex) is different for chaparral and coastal sage scrub (Roberts et al. in press). Thus, given a map of plant functional types, spatio-temporal maps of LFM could be produced, greatly extending the informational content of the field data. To control for intersite and interannual differences in vegetation condition and response, summary statistic variables (e.g., minimum, maximum, mean, median, range), analogous to the phenological metrics of Friedl et al. (1999), were used in the multiple linear regression models. This advances FMC research as current studies are focused on site-specific relationships.

There are 20 data sets from the 14 LACFD plots, due to data acquired for multiple species at certain sites. Potential predictors include the time series of 7 vegetation indices (NDVI, NDWI, NDII6, NDII7, VI_{green}, VARI, EVI) and 6 SMA related variables (GV, GVn, NPV, NPVn, GV/NPV ratio, and shade) from a MODIS 16 day composite; site elevation; and summary statistics (minimum, maximum, mean, median, and range) of the vegetation indices and EM fractions, both overall and for each year (2000-2004).

Only the drydown period for each year is currently being considered as LFM from the full year has 1) non-linear tendencies and 2) becomes noisier. However, as fire danger is low during the wet part of the year and the progression of the dry down – the timing of the onset of “extreme” conditions is more important than the absolute minima, the “dry down only” assumption is considered reasonable.

The precise number and arrangement of MODIS pixels extracted for each fuel moisture site/data set varied. The 49 pixels in a 7x7 window of pixels, centered on the coordinates of each site were extracted and individual pixels were correlated with the LFM for the vegetation species for that site. Those pixels having the highest individual correlations with VARI were retained (generally R^2 of 0.7 and greater). VARI was used because it had the highest correlations when a uniform 3x3 window was applied. This approach was utilized because by selecting specific pixels a defacto vegetation map is incorporated into the analysis, misregistration effects are controlled for, and actual size of the sampled area for each study site is unknown.

For individual sites, 1, 2 (an additive or multiplicative variable was added), and 3 (an additive and a multiplicative variable was added) variable models were considered. Additional variables could be an additional time series variable or a yearly summary statistic variable. In the interest of parsimony, higher order models were selected only if the improvement in adjusted R^2 was .04 or greater per added variable. An all possible regressions approach to multiple regression was utilized.

Individual data set adjusted R^2 ranged from 0.68 to 0.96, with an average of 0.84 when a single variable was utilized.8 data sets showed considerable improvement when 1 or 2 variables were added. In most of these cases, a yearly summary statistic was added, indicating that there were interannual differences in vegetation response to soil moisture deficit. Of these 8 cases, the summary statistic tended to be derived from a greenness measure (NDVI, VI_{green}, VARI, EVI, GV). The “best” adjusted R^2 (single variable for 12 datasets, multivariate for 8 data sets) ranged from 0.79 to 0.96, with an average of 0.88. NDVI was never the best time series variable, though summary statistics involving NDVI were utilized. The best time series variables were VI_{green} and VARI, which are calculated very similarly.

Cross-validation was performed for sites of chaparral functional types (data from 1 plot was withheld, a regression model was developed from the remaining chaparral plots, and the equation was tested on the withheld plot). Average individual adjusted R^2 for just chaparral plots was 0.883. Average cross-validated adjusted R^2 was 0.794, indicating a slight reduction in predictive ability (Table 7). However, the value is still quite good, suggesting that mapping LFM is possible.

		cross validation					
	individual	2 vars	3 vars	4 vars	diff 2-i	diff 3-i	diff 4-i
bc_s	0.843						
bc_ps	0.896						
bc_adfa	0.903	0.851	0.748	0.657	-0.053	-0.155	-0.246
bq_same	0.916						
bq_adfa	0.876	0.694	0.837	0.852	-0.183	-0.039	-0.024
cl_adfa	0.867	0.838	0.789	0.779	-0.029	-0.078	-0.087
cl_ce	0.859	0.795	0.818	0.822	-0.064	-0.041	-0.037
lat_adfa	0.838	0.747	0.779	0.803	-0.091	-0.058	-0.035
lau_adfa	0.793	0.232	0.645	0.673	-0.561	-0.148	-0.120
pi_adfa	0.901	0.613	0.825	0.822	-0.288	-0.076	-0.079
pl_adfa	0.879	0.793	0.850	0.841	-0.085	-0.029	-0.037
sch_adfa	0.853	0.657	0.792	0.788	-0.196	-0.060	-0.065
syc_adfa	0.929	0.168	0.755	0.760	-0.761	-0.174	-0.169
syc_ce	0.898	0.346	0.827	0.833	-0.552	-0.071	-0.065
tri_same	0.797						
tri_adfa	0.860	0.707	0.743	0.764	-0.152	-0.117	-0.096
wool_adfa	0.862	0.753	0.802	0.755	-0.109	-0.060	-0.107
peach_adfa	0.964	0.886	0.778	0.813	-0.078	-0.186	-0.152
glen_adfa	0.918	0.803	0.745	0.846	-0.115	-0.172	-0.072
glen_ce	0.926	0.870	0.870	0.895	-0.057	-0.057	-0.032

Table 7. Individual site and chaparral cross-validated R^2 for the 20 LAC FMC datasets

Deliverables

Item	Completion/Status	Estimated Completion Date
Web Site	partial	December 2006
Photographic documentation	Completed	
GIS maps/brochures	partial	December 2006
Article with San Luis Valley GIS Authority	no	January 2007
Vegetation Data to Cooperators	partial	October 2006
Field Trips	no	Depends on Home Unit funding
Combine data in WFAS	In progress	December 2006
Publications/Presentations	Completed	Ongoing
PhD Dissertation (UC Santa Barbara)	In progress	June 2008
Multi-agency fuels Maps/LFM maps	partial	Ongoing

Publications and Presentations

Professional Presentations

Dr. Roberts has been invited to a large number of professional meetings and has presented Joint Fire Science results at all of them. Professional presentations include:

2003

Roberts, D. A., 30 minute invited talk at the "Workshop on Wildland Fire Modeling and Prediction in the Southeast United States", Tallahassee Florida, March 12-14, 2003.

Roberts, D.A. 25 minute invited talk entitled "Evaluation of the Potential of Hyperion for Fire Danger Assessment", presented at the 2003 ASPRS meeting , Anchorage Alaska, May 8-10, 2003.

Roberts, D.A., 50 minute professional talk entitled "Applications of Hyperspectral Remote Sensing for Wildfire Fuels Mapping, presented at the USFS fire lab, Missoula, Montana, May 22, 2003. Also discussed collaborative research with Pat Andrews and Dr. Mark Finney.

Roberts, D.A., Green, R.O., 2 day short course on imaging spectrometry, at the XI Annual SBSR Brazilian Remote Sensing Symposium, Belo Horizonte, Brazil, April 5-6, 2003.

Roberts, D.A., One hour short course entitled "Advanced Vegetation Analysis Using Hyperspectral Remote Sensing", Pasadena, CA, Feb 25, 2003.

Roberts, D.Aone hour key note address at the 4th International Workshop on Remote Sensing and GIS Applications to Forest Fire Management, Ghent Belgium, June 5-7, 2003.

Roberts, D.A., One hour invited talk entitled "Applications of Remote Sensing to Wildland Fires", presented at the USGS Sioux Falls, SD, September 22, 2003

2004

Dennison, P.E., Talk entitled "Mapping Fuels and Fires in Southern California Chaparral Using Hyperspectral Remote Sensing" presented at the Tenth Biennial USDA Forest Service Remote Sensing Applications Conference, Salt Lake City, UT, April 7, 2004,.

Dennison, P.E, 20 minute professional talk entitled "Examining seasonal changes in canopy moisture using AVIRIS time series data", presented at the 2004 AVIRIS Earth Science and Applications Workshop, Pasadena, CA, April 1, 2004,.

Roberts, D.A., 4 hour short course entitled "Applications of Imaging Spectrometry", Nagoya, Japan, January 12, 2004

Roberts, D.A., One hour invited talk entitled "Advanced Vegetation Analysis using Imaging Spectrometry", Tokyo, Japan January 14, 2004.

Roberts, D.A., One hour invited talk entitled "Advanced Vegetation Analysis using Imaging Spectrometry", Nagoya, Japan January 16, 2004.

Roberts, D.A., 20 minute professional talk entitled "Fine spatial, spectral and temporal characterization of the land surface through the integrated analysis of imaging spectrometry and coarser resolution broad band data", April 1, 2004.

Roberts, D.A. One hour invited presentation entitled "Integrated Assessment of Wildfire Danger" as part of Parents and Family Weekend at UC Santa Barbara, November 6, 2004.

2005

Dennison, P.E. 20 minute professional talk entitled "Simultaneous retrieval of wildfire temperature and fuel type using AVIRIS" 2005 AVIRIS Earth Science and Applications Workshop, Pasadena, CA, May 27, 2005,.

Dennison, P.E., 20 minute professional talk entitled "Deriving High-Resolution Fire Parameters from Hyperspectral Remote Sensing Data for Wildfire Modeling" presented at the Association of American Geographers Annual Meeting, Denver, CO., April 7, 2005

Roberts, D.A., 20 minute professional talk entitled "Fine spatial, spectral and temporal characterization of the land surface through the integrated analysis of imaging spectrometry and coarser resolution broad band data", presented at the 2005 Annual Meeting of the AAG, Denver, CO April 8, 2005.

Roberts, D.A., 8 hour invited short course entitled "Advanced Analysis of Imaging Spectrometry Data", taught at the XII Annual SBSR Brazilian Remote Sensing Symposium, Goiania, Brazil, April 17, 2005.

Roberts D.A. 50 minute invited professional talk entitled "Advanced Applications of Imaging Spetrometry", presented at the XII Annual SBSR Brazilian Remote Sensing Symposium, Goiania, Brazil, April 18, 2005.

Roberts, D.A., invited poster entitled "Fine spatial, spectral and temporal characterization of the land surface through the integrated analysis of imaging spectrometry and coarser resolution broad band data" presented at the 5th International Workshop on Remote Sensing and GIS Applications to Forest Fire Management, Zaragosa Spain, 16-18, June, 2005.

Roberts, D.A., Panel member one hour round table discussion entitled "Interactions Between Mediterranean Europe and other Mediterranean Regions", North American representative at the 5th International Workshop on Remote Sensing and GIS Applications to Forest Management: Fire Effects Assessment, 16, June 2005.

Travel expenses for Tallahassee, Belo Horizonte, Nagoya and Goiania were provided by the inviting agency, while expenses for Anchorage, Missoula and Ghent were covered on a separate NASA grant for wildfire research. Expenses for Zaragosa were covered by the JFS program.

2006

Rechel, J. L. Poster presentation entitled "Making fuels data usable with maps" at the First Fire Behavior and Fuels Conference, International Association of Wildland Fire; Portland, OR. March 2006.

Rechel, J. L. Invited Speaker presentation entitled " Evaluation and mapping of live fuel moisture in relation to seasonal fire danger in the Sierra National Forest"; First Yosemite Area Fire Symposium, Yosemite National Park, May 2006.

Rechel, J.L. Presentation entitled: "Seasonal differences in live fuel moisture in conifer, pinyon-juniper, oak, aspen, and shrub communities in the southwestern United States. 3rd International Congress on Fire Ecology and Management. Nov. 2006, San Diego.

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