Joint Fire Science Program

Fire Science Brief

RESEARCH SUPPORTING SOUND DECISIONS

Los Padres National Forest early season (low fire risk vegetation types) showing Blue Oak Woodland.
Credit: Jenny Rechel.

From the Ground Up, *Way* Up: Measuring Live Fuel Moisture with Satellite Imagery to Fine-Tune Fire Modeling in Western Ecosystems

Summary

Remote sensing from space may well become one of the world's most effective, accurate, and efficient ways to assess fire risk and thus manage large landscapes. The technology is evolving quickly, and researchers are busy keeping up. Some major western U.S. landscapes are just now being assessed for integrating remote sensing data with "on the ground" data that helps fine tune remote sensing models, and helps researchers assess which models work best. Drs. Jenny Rechel and Dar Roberts have worked together to gather Live Fuel Moisture (LFM) data from seven major western landscapes with similar mixed vegetation types. They compared their LFM data to multiple spectral indices and remote sensing models to assess which are the most accurate. They found that MODIS is overall the best remote sensing imagery to use when it comes to looking at LFM. They validated the LFM data with the satellite imagery, which confirmed their results. They found unexpected variation in the LFM measurements both across season and within sites. That the remote sensing data confirmed this variation, is more evidence for the power of using remote sensing imagery to assess LFM as a component of fire risk.

Key Findings

- This research focused on vegetation types that are sometimes ignored because fire research has historically focused on forested ecosystems with economically valuable timber resources and not on shrublands and mixed shrub/forested lands.
- Normalized Difference Vegetation Index (NDVI) is sensitive to vegetation cover; while Normalized Difference Water Index (NDWI) is sensitive to vegetation condition (e.g., amount of moisture in the foliage and stems).
- There are sometimes unexpected differences in Live Fuel Moisture (LFM) values between early (low risk) and late (high risk) fire season.
- This work successfully used multiple satellite sensors and vegetation indices with scientifically credible results.
- This study combined remote sensing technologies and Geographic Information Systems (GIS) to derive map products to display seasonal LFM values.

Introduction

For managers and planners more accurate data from space imaging would invite more effective fire severity modeling, as well as the consequent additional tools and options for risk assessment. Remote sensing may well become one of the most valuable and accurate tools ever used for fire management, risk assessment, and planning.

But because the technology continues to evolve, some landscapes and vegetation types— including some major western U.S. ecosystems—remain less well understood in terms of remote sensing technology and imagery products. One significant approach in the evolution of these tools is to compare remotely sensed data with "on the ground" data to more effectively evaluate its accuracy, and in turn, make the remotely sensed data all the more powerful.

Dr. Jennifer Rechel is a Geographer with the USDA Forest Service at the Pacific Southwest Research Station in Riverside, California. Dr. Dar Roberts is an Associate Professor of geography at the University of California, in Santa Barbara. The two teamed up to evaluate various remote sensors and learn more about how to use remote sensing to assess fire risk in major western landscapes. They wanted to know what kinds would serve managers and planners the best.

They also wanted to learn more about how well remotely sensed data could estimate and interpret LFM in different vegetation types, especially those western ecosystems that had not yet been studied in depth. LFM is one of the best predictors of fire risk available. They focused on field level LFM values from the vegetation canopy and small fine fuels that are important indicators of fire risk.

If remotely sensed data can accurately depict LFM, then fire severity modeling using that data would have multiple benefits. For instance, mapping the distribution of LFM over large landscapes would be easier and more accurate, as would the ability to monitor seasonal changes in LFM. Given the strong link between LFM and fire risk in many types of vegetation, this ability would be invaluable. With a Joint Fire Science Program (JFSP)-funded proposal, Rechel and Roberts set out to do just that.

A remote understanding of living fuels

Rechel explains, "Satellite imaging uses electronic imagery—not photographs—to quantify what's happening on the ground. Dar (Roberts) and I wanted to compare information gleaned from different spectral indices (different remote sensing approaches) and determine which worked best for measuring fire risk."

"Scientists are still in the midst of learning so much about the speed of electrons returning to the remote sensors," says Rechel. "There are scores of different kinds of digital numbers to interpret—we are learning about how to quantify different soil types, trees, shrubs, and various vegetation types, especially in the drought prone western states. We can even determine different stages of growth using this technology."

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But, she emphasizes, "There is hardly any information on using remote sensing to understand fire risk in southwest species—specifically shrub and shrub-forest mixed ecosystems of the southwest. We also wanted more information on the major ecosystems across the western United States."

While there is a clear and well-documented relationship between LFM and fire risk in large homogenous coniferous forest areas—and various fire severity models that rely on that relationship—there was far less information available that united remote sensing data with the LFM in the remaining major western ecosystems. The absence of data on fuels was a driving factor in Rechel and Roberts work.

But LFM measurements in nature are always in flux. Moisture content of vegetation can be driven by soils, vegetation type, weather, climate, and season. Meanwhile, the relationship between LFM and fire risk is paramount. As Rechel and Roberts write in their JFSP final report on this research, "Live Fuel Moisture is a strong determinant governing ignition success and fire intensity, particularly in shrublands where a majority of the biomass available for combustion is living." Furthermore, the researchers strongly suspected that early season LFM would equate with lower fire risk while, later season LFM would generally mean higher fire risk.

Rechel and Roberts' objectives were to integrate the remote sensing with LFM in major western ecosystems that so far, had not been assessed in this way. Thus, one of their primary objectives was to get out in the field, measure seasonal changes in LFM across seven major western ecosystems, and then use those data to fine-tune the remotely sensed data. Their goal is to make it much easier and more powerful to use remote imaging to quantify fire risk across very large and important fire-prone landscapes.

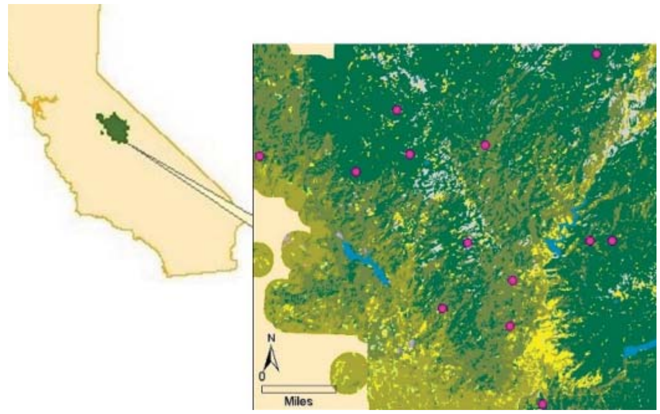
From earth to sky

The researchers chose seven major study areas in the western U.S. "based on the importance of the dominant vegetation types to fire severity" as well as "the absence of data on fuels." They picked the following sites, all located on public lands:

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
7. Birds of Prey Conservation Area, Idaho

% Change in fuel moisture from early season to late season samples	Minimum # Sampled	% Change
Boise		
Rabbit brush	11	-14.25
Sage brush	68	-6.84
Salt bush	7	15.41
Gila		
Aspen	4	-6.35
Douglas fir	7	14.50
Firs	3	5.09
Junipers	11	24.85
Oaks	9	-23.06
Pines	32	18.42
Kaib/Coco		
Aspen	16	-7.76
Firs	2	-21.07
Junipers	10	12.87
Oaks	15	68.73
Pines	42	-14.88
Lassen		
Firs	21	10.41
Pines	38	12.10
Los Padres		
Ceaothus	8	-34.82
Douglas fir	2	-15.10
Firs	2	-7.49
Oaks	29	-32.45
Pines	8	-16.24
Rio Grande		
Aspen	60	-11.39
Douglas fir	22	9.36
Firs	24	36.31
Junipers	2	-31.14
Pines	22	1.17
Spruce	2	4.02
Sierra		
Firs	34	-2.79
Incense cedar	17	-10.14
Oaks	8	-11.47
Pines	21	-13.54

Fuel Moisture Plots. (Above) Map depicting the seven study areas. (Left) Percentage of change in fuel moisture from early to late season samples. Credit: Jenny Rechel.



Sierra National Forest in California, Fuel Moisture Plots. Map depicts details and data from one of the seven study areas: the Sierra National Forest. Field plots surrounded Yosemite National Park. Credit: Jenny Rechel.

The major vegetation communities they sampled were aspen, mixed fir, mixed pine, mixed oak woodlands, mixed chaparral, mixed Great Basin sage, and pinion-juniper. For every dominant vegetation type, the researchers identified 15 to 33 plots from which they collected above ground live biomass—once early in the season and once late in the season. They hypothesized that fire risk would move from lower to higher over the course of the season, in large part because of shifts in fuel moisture content.

Meanwhile, the researchers set out to improve estimates of LFM using imaging spectrometry and broad band satellite sensors. In summary, the researchers took different remotely sensed data sets and compared them to each other while also integrating the field data recovered from the on-the-ground LFM measurements. For some of the remotely sensed data comparisons the researchers also used extensive LFM data previously recorded. So they had not only their own field LFM measurements, but also another supportive body of LFM data.

Specifically, Rechel and Roberts used the following remotely sensed data sets: MODIS and AVIRIS time series data acquired over various western locations. Both sets had extensive time series data that spanned numerous years. Both sets of data were processed to generate a "series of spectral indices" shown to correlate with LFM, "including several measures of greenness, more direct measures of moisture, and spectral mixture models," according to the JFSP final report.

Thus the researchers used the remotely sensed imaging data to generate various spectral indices that would help them asses which are the best for measuring LFM—and hence which are best for most accurately predicting and map using a GIS fire risk over large western landscapes.

The spectral indices they used include the following (see the final JFSP report for a full explanation and sources):

- Cumulative Water Balance Index (CWBI)
- Normalized Difference Vegetation Index (NDVI)
- Visible Atmospheric Resistant Index (VARI)
- Enhanced Vegetation Index (EVI)
- Visible Green Index (VGI)

By comparing these different spectral indices and their ability to accurately describe what is happening on the ground, the researchers can gauge which indices are most accurate and why. The power here is in the valuable potential to ever more accurately assess the fire risk across vast areas of land.

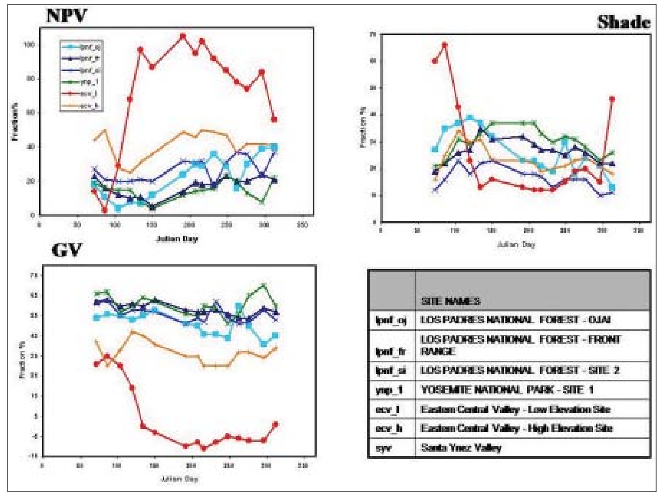
Understanding fire risk

Says Rechel, "What's most interesting is that our hypothesis that fire risk would be consistently low early in the season and consistently higher later in the season, based primarily on LFM values, across most of the sites just didn't pan out. And that was because there was so much variability across the sites in the direction and amount that LFM changed."

The mean percent changes in fuel moisture in each dominant vegetation site across a season were very different. "They were all very, very different," says Rechel. "For instance, in the Rio Grande National Forest there were six different major tree species, and they were all very different. For instance, LFM of aspen declined by 11 percent over the season, while the firs and juniper/pinion pine increased by 36 percent and 25 percent, respectively. Meanwhile the other species also went up, but by quite a bit less."

In the Los Padres, as expected all the LFM percent changes went down for all species, and in other sites the variation was more mixed with some species increasing in LFM content and some going down. "There were just lots of differences in and among species," says Rechel. "And all those differences were confirmed by our satellite imagery." So with those data, the team created models that much more accurately estimate LFM (and hence fire risk) using remote sensing.

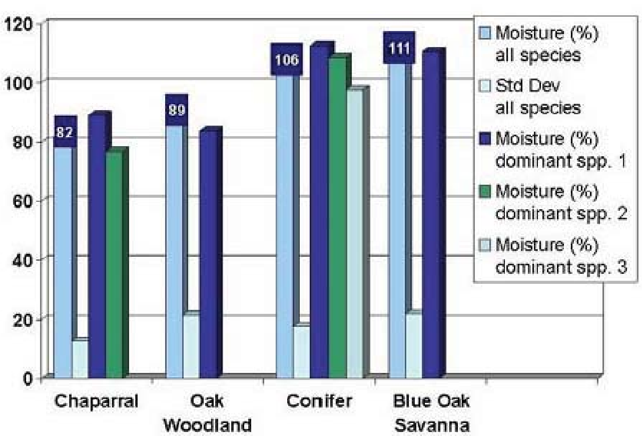
Perhaps this variation, confirmed by the combination of remote sensing and field data, is the most powerful result of the team's work. To be able to assess remotely—using easy to acquire data and software—the status of LFM over large areas so precisely, could significantly influence the way managers and planners approach the management of large landscapes.

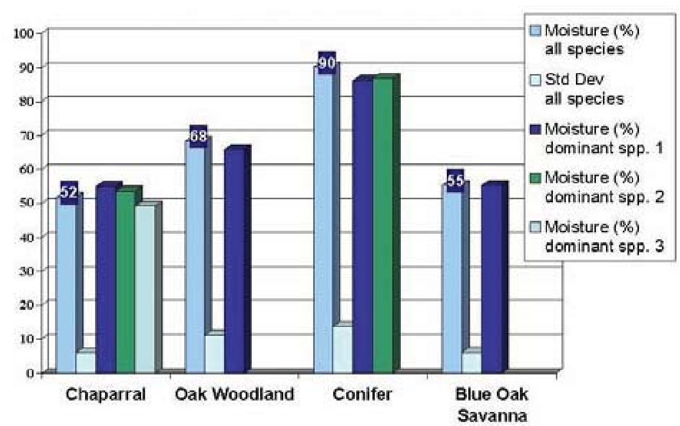


MODIS Time Series. Multiple linear regression of MODIS data against LFM dataset on the Los Padres National Forest, Yosemite National Park, the Central Valley of California, and the Santa Ynez Valley (near Santa Barbara). They show changes by site and vegetation index; where the %LFM declines over time. Credit: Dar Roberts.

"There are a lot of sensors on a satellite," says Rechel. "Essentially, we determined which sensors are the best for getting accurate numbers for managers." The team worked with PhD student Seth Peterson who focused on the imaging processing models. After their work, the group determined that the MODIS sensor "was the best."

MODIS products, in this case, refer to the different spectral indices mentioned above that account for various spectral measures and interpretations. Essentially the R2 of their regression data shows the relationship between LFM and the spectral indices. The MODIS sensor has more spectral bands available than the Landsat sensor, which is typically used for NDVI methods. More available bands on MODIS means that each band covers smaller wavelength units and can therefore record more specific vegetation characteristics. For example, says Rechel, Landsat and NDVI are able to detect major vegetation types, whereas





Average fuel moisture for (left) early-season spring and (right) late-season fall at Los Padres National Forest.
Credit: Jenny Rechel.

MODIS can detect individual species and is good at detecting spectral values for mixed vegetation types.

Interestingly, the researchers found according to their proceedings paper (see Further Information), that "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; the late season when vegetation has dried out. The researchers explain that the different sites and seasonal changes in fire risk are likely related to weather patterns for each site.

Meanwhile, the individual indices had different strengths depending on season. Most important, they found that Visible Atmospheric Resistant Index was the best overall vegetation index for both seasons when only considering vegetation 'greenness' and not using a combination of greenness and LFM values.

Beyond boundaries

"Forests don't stop at administrative boundaries," concludes Rechel. "There are different fire risk models being used among different National Parks and Forests but the vegetation doesn't recognize political jurisdictions. We are trying to work towards a standard LFM map across federal and eventually state agency boundaries."

Rio Grande National Forest in Colorado showing high elevation late season (high fire risk) fuel types including mixed aspen and fir. Credit: Jenny Rechel.

The researchers already have copious data to share. "At this time some of these data are available to and intended for use by fuels specialists and interested biologists," says Rechel. "Some of it is still in the process of being analyzed for further modeling efforts. You will be able to get the data without any of the fancy technology, using a standard GPS (Global Positioning System), and standard spreadsheet software package to find what you are looking for. All of the LFM data is being submitted to the National Fuels Moisture Database (online at: http://72.32.186.224/nfmd/public/about.php)."

An important insight to consider is that the researchers evaluated not only the various sensors themselves, but also different habitats, plant-types (e.g., evergreen vs. deciduous), season, and different values of LFM within sites (e.g., leaf-level LFM, age distribution of foliage, stem LFM). The resulting models vary in their predictive abilities and depend on the model, and the data themselves.

This study has generated valuable data that are already refining the powerful approach of using remote sensing technology to assess LFM as a part of fire risk. Anyone interested in using this technology to better understand, and unify risk assessment across borders, has a treasure trove of new information available.

Rechel adds, "It was a wonderful thing to see all the teamwork—people coming together from across agencies and institutions."

As researchers, managers, and planners move forward, this information—and the analysis and use of it—will be what many will come to rely on for perhaps the most widespread and effective way to assess, and then address, LFM and the resulting fire risk across large western landscapes.

Management Implications

- It is possible to estimate changes in LFM over an entire season using remote sensing.
- MODIS satellite imagery data is the best sensing data the researchers found in their work. It is reliable, inexpensive or free, and easy to get from federal agencies.
- The satellite data have been validated by on-the-ground LFM measurements, making them far more credible in terms of assessing their accuracy of measuring fire risk across large landscapes.
- GIS-derived maps based on LFM data can be quickly generated to show seasonal changes in LFM.
- The LFM field plots are permanent and can be located based on the GPS and used for future research work on temporal changes; especially related to climate change.
- This research has led to increased use of available satellite data.
- Use of MODIS and AVIRIS, in addition to VARI has led to more credible fire danger rating and fire/weather systems.

Further Information: Publications and Web Resources

Rechel, J.L. and D.A. Roberts. May 2006. Final Report submitted to the Joint Fire Sciences Program. Quantitative Comparison of Spectral Indices and Transformations of Multi-resolution Remotely Sensed Data using Ground Measurements: Implications for Fire Severity Modeling.

Rechel, J.L., S.H. Peterson, D.A. Roberts, and J.W. Van Wagtendonk. 2005. Predicting seasonal fuel moisture in the western United States using end member fractions at multiple spatial and spectral resolutions. Pgs 245–248 in De la Riva, J. Perez-Cabello, F., and Chuviceco E. Eds. Proceedings of the 5th International Workshop on Remote Sensing and GIS Applications to Forest Fire Management: Fire Effects Assessment. Zaragoza, Spain. June 2005.

Scientist Profiles

Jennifer Rechel is a Geographer with Pacific Southwest Research Station, Forest Fire Laboratory in Riverside, California. Her research interests include fire effects on wildlife habitats and populations, wildlife responses to post-fire erosion treatments, and quantifying landscapes and habitats using GIS and remote sensing. Since 2001, she has been evaluating use of remote sensing technologies for fire and fuels management and combining this information to produce GIS-derived products.

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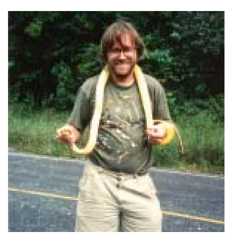

Dar Roberts is a Professor in Geography at the University of California, Santa Barbara. His research interests include sensor fusion, change identification using multitemporal remote sensing, imaging spectrometry, spectroscopy and wildfire hazard assessment. He is the UCSB Principal Investigator of the Southern California Wildfire Hazard Center and leads the group in developing wildfire fuels maps and mapping fuel moisture using remote sensing.

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The information in this Brief is written from JFSP Project Number 01-1-4-23, which is available at www.firescience.gov.

An Interagency Research, Development, and Applications Partnership

JFSP *Fire Science Brief*
is published monthly.
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