P1.5 CORRELATION BETWEEN REMOTELY SENSED FIRE TEMPERATURE AND FUEL CONSUMPTION IN CALIFORNIA CHAPARRAL – A CASE STUDY

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1. INTRODUCTION

The use of remote sensing to estimate the consumption of biomass by wildland fire is an area that has received much attention over the past 15-20 years as various sensors have been deployed on satellites and in aircraft and concern about the impact of large-scale biomass burning in the tropics and boreal forests on the atmosphere and global change. Satellites such as the Advanced Very High Resolution Radiometer (AVHRR) and the Moderate Resolution Imaging Spectroradiometer (MODIS) provide imagery that has been correlated with biomass consumption by fires (Justice et al 2002).

In October 2006, a wildfire burned 16137 hectares near Banning, CA. The dominant fuel types within the fire perimeter were desert scrub, chamise chaparral, and interior sage scrub. High-resolution thermal imagery of active fire behavior was collected by the aircraft-based FireMapper® on 6 percent of the total burned area. This paper reports results of comparing the aerial estimates of fire temperature with ground fuel-based estimates.

2. METHODS

2.1 Remote measurement of fire temperature

The FireMapper is an airborne thermal imager that utilizes a single uncooled microbolometer array and a series of filters to measure radiant emissions in the 8.5 – 12.5 µ wavelength and in two narrow bands centered at 9 and 12 µ (Riggan et al 2003). FireMapper thermal imagery was collected during the Esperanza Fire a total of eight times over the three day period of active burning. The aircraft elevation was such that each image pixel covered an area approximately five m by five m.

Post-processing of the raw image files involved classifying the measured radiance into 19 classes which correspond to estimated ground surface temperatures of 50 to > 750°C (Fig. 1). Classes 1-4 (50 to 100°C) were excluded from this analysis because of the possibility that they did not burn. Thus 15 classes representing temperatures from 100 to > 750°C were categorized into three classes: low = 5-9, moderate = 10-14, and high = 15-19. The total estimated areas of these categories are found in Table 1.

Class	Temperature (°C)	Area (ha)
Low	101-300	876.0
Moderate	301-550	90.6
High	551 - >750	1.9

Table 1. Estimated area classified into fire temperature classes from FireMapper imagery.

2.2 Ground-based sampling

Fuel consumption and fire intensity class were assessed using circular plots 16.2 m^2 (radius = 2.26 m) in size. Sample locations were determined randomly within each fire intensity class. The sampling objective was to sample 90 plots of known intensity equally distributed within each fire intensity class. An additional 60 plots were located in areas where no active or residual burning was observed by FireMapper. At each plot, an onsite assessment of the intensity class was made using the following criteria: high intensity = virtually all above ground biomass consumed, moderate intensity = fine fuels and small branches consumed, low intensity = majority of fine fuel still on plants.

For all shrubs that originated within the plot, the basal diameter of each stem 10 cm above the ground was measured. An attempt to identify the plant species as chamise (*Adenostoma fasciculatum*), ceanothus (*Ceanothus spp.*), scrub oak (*Quercus berberidifolia*) or manzanita (*Arctostaphylos spp.*) was made. Each plant was visually divided vertically into two height classes (≤1 m and >1 m). Countryman and Philpot (1970) reported that chamise branches greater than 1.28 cm diameter are typically not consumed by wildfire. For each height class, a go-nogo gauge was used to classify the burned tip branch diameter into 4 classes: 0 - 0.32, 0.33 -0.64, 0.65 - 1.27, and 1.28 - 2.54 cm. Up to six tip diameters

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were measured for each height strata around the plant.

2.3 Statistical analysis

In order to assess the agreement between the fire temperature classes determined from the imagery and the fire intensity classes from the ground sampling, an error classification matrix was created (Congalton and Green 1999). This is the 1st time that such an analysis has been performed using FireMapper imagery. Several types of agreement (or accuracy) of the data were examined using contingency table analysis. The plot data were summarized to determine if the average burned tip diameters differed between fire intensity classes for both the aerial and ground sampling effort. Using the basal diameters, the fuel mass was estimated using unpublished equations developed from fuel sampling that took place within the fire perimeter a few years prior to the fire. The amount of fuel consumed was determined using the tip diameter to estimate the proportion of fuel mass consumed. Estimated fuel consumption was then correlated with the fire imagery.

3. RESULTS AND DISCUSSION

3.1 Ground-truthing results

A total of 145 sample plots were established within the fire perimeter to sample fuel consumption. 90 plots fell within the areas where the FireMapper recorded fire energy. The overall agreement between the remotely-sensed fire intensity and the ground-based estimates was poor (24% = (3+12+7)/90, Table 2). Following Gongalton and Green's terminology (1999), user-accuracy is calculated by dividing the number of plots in which the remotely sensed and ground-based values agree by the total number of plots assigned to the class by the ground survey. Thus, from table 2, user-accuracy for the low class is 3/12 or 25%. Producer accuracy is defined as the number of plots in which the remotely sensed and ground-based values agree by the total number of plots assigned to the class by the remote sensing. The producer accuracy for the low class is 3/25 or 12%. Of the three classes, the moderate classification had the highest accuracies.

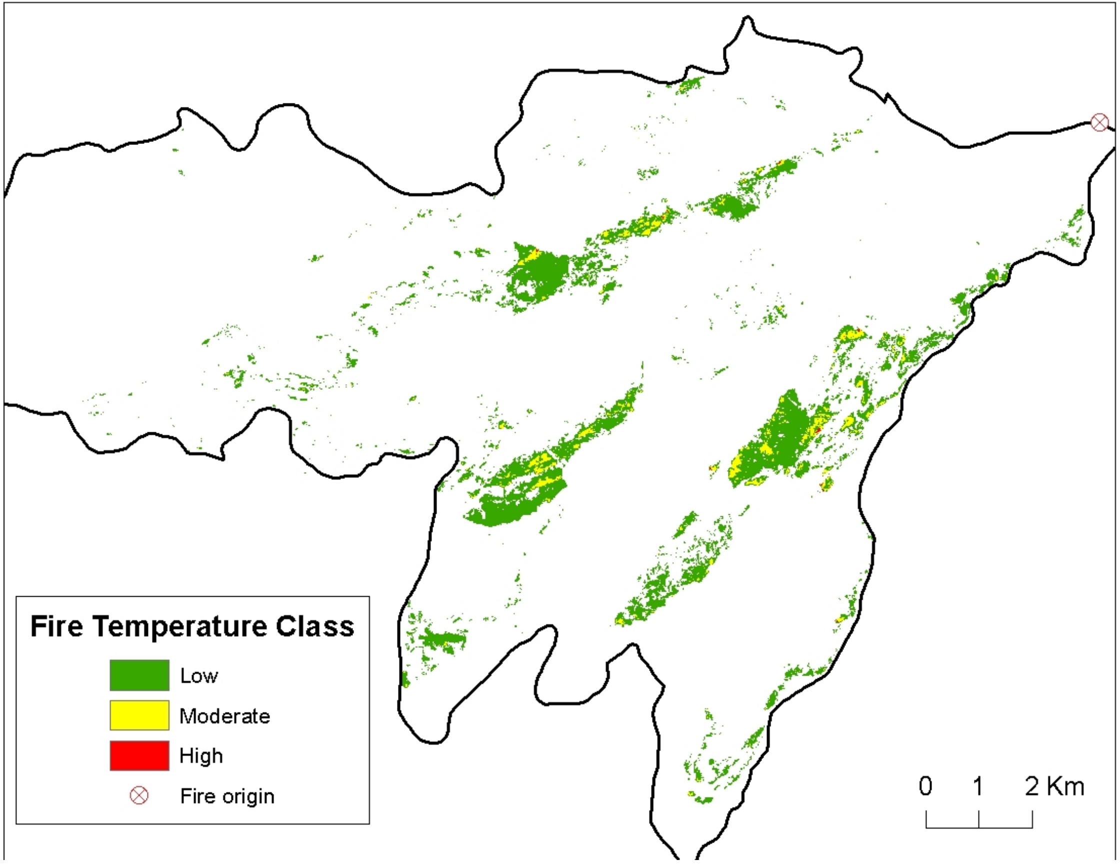

Figure 1. Fire temperature classes measured by FireMapper thermal imaging radiometer over a three day period for the Esperanza Fire, 26-29 Oct 2006.

There was a great deal of error associated with classifying plots as moderate or high intensity. There are several potential sources of classification error. The georeferencing of the image to the ground may cause an error in location. The timing of the FireMapper image relative to the actual fire behavior that occurred in a pixel may not have captured the maximum level of fire behavior. If the image was collected after the pixel had burned, but was still radiating with temperatures higher than ambient, the image may have been classified in the low temperature class while the plot may have burned with a higher intensity as determined by the amount of fuel consumed. A time integration of the FireMapper data would potentially address this source of error. The third source of error is error caused by inaccurate location of the sample plot due to GPS errors. We used a military grade Rockwell PLGR GPS unit* to locate the sample plots. Occasionally this GPS unit would not stabilize and the field crew had to estimate the approximate location of the plot. Foot travel through the rugged terrain of the burned landscape undoubtedly added error to plot location.

Ground Intensity	FireMapper Temperature			
	Low	Moderate	High	Total
Low	3 25 (U) 12 (P)	2	7	12
Moderate	10	12 29 (U) 38 (P)	19	41
High	12	18	7 19 (U) 21 (P)	37
Total	25	32	33	90

Table 2. Classification "error" matrix for remotely-sensed temperature and ground-based of fire intensity for the Esperanza Fire near Banning, CA. Within each cell, the values are the count, the "user's accuracy" (%), and the "producer's accuracy" (%).

3.2 Residual fuel characteristics

The species composition was fairly consistent within the fire intensity classes (Table 3). While basal area of chamise, manzanita, ceanothus, and scrub oak was fairly similar (6-13 m^2/ha), chamise had the greatest number of stems/ha of all species for all intensity levels. As fire intensity increased and as fuel consumption increased, it became more difficult to identify the species of the residual stems. This accounts for the increase in basal area and stem density attributed to the unknown category.

Over 16000 branch tip diameters were measured on the 131 plots to determine the diameter size of the consumed live and dead fuels (Table 3). It was not possible to determine if the branch was alive or dead at the time of the fire. Branch diameters < 0.32 cm represented the majority (51%) of the branches measured. The number of stems by branch tip diameter class differed between the ground-based fire intensity classes (Fig. 2). The greatest number of stems was measured in the moderate intensity class with nearly half of the count falling in this category. As fire intensity increased the number of stems in the 2.54 cm class increased as would be expected.

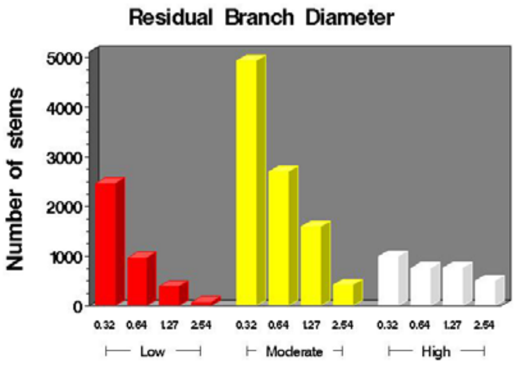

Figure 2. Diameter distribution of residual branch tips for three fire intensity classes based on data from 145 plots located within the Esperanza Fire perimeter.

The relative distribution of tip diameter differed between the intensity classes (Fig. 3). For the low and moderate intensity classes, the relative frequency decreased as diameter increased. For the high intensity class, the relative frequency of residual branch tip diameter was nearly constant among the four diameter classes. The relative frequency of the 2.54 cm class in the high intensity class was much larger than in the moderate and low intensity classes. These distributions of residual tip diameter are not unexpected and support the ground classification of fire intensity in this study.

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*Commercial names are provided for informational purposes only and do not constitute endorsement by the U.S. Department of Agriculture.

Intensity	Species	Basal Area (m2/ha)		Stems per ha	
		Mean	Std. Error	Mean	Std. Error
Low	Chamise	9.87	3.14	17328	5451
	Manzanita	4.56	2.46	3113	1821
	Scrub oak	9.15	4.92	4306	2254
	Rhus integrifolia	0.09	0.09	104	108
	Unknown	1.69	0.72	3113	1624
	Yerba santa	0.03	0.04	934	975
Moderate	Chamise	8.36	1.65	14926	3239
	Ceanothus	0.04	0.03	167	142
	Manzanita	6.75	2.08	3644	1136
	Scrub oak	6.10	2.07	2870	856
	Unknown	3.80	1.34	5816	3418
	Yerba santa	0.09	0.09	304	307
High	Chamise	7.53	2.55	9641	3357
	Manzanita	6.04	2.09	3483	1589
	Scrub oak	13.84	5.57	2726	1004
	Unknown	8.19	2.57	2894	862
	Yerba santa	0.04	0.04	151	154

Table 3. Estimated basal area and stem density by species for three fire intensity classes, Esperanza Fire near Banning, CA.

	Residual branch tip diameter (cm)			
	< 0.32	< 0.64	<1.27	<2.54
Number	8380	4423	2745	990
Percent	51	27	16	6

Table 4. Total count of residual branch tip diameters measured on 145 sample plots on the Esperanza Fire near Banning, CA.

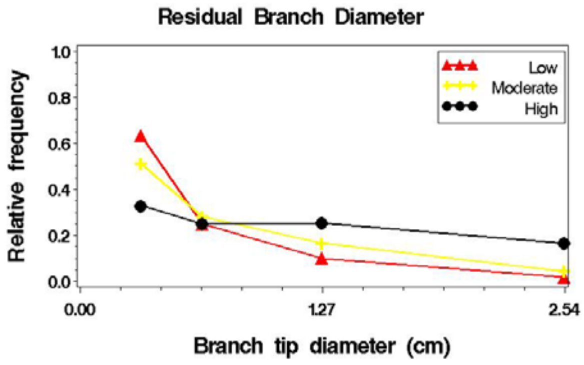

Figure 3. Relative frequency of residual branch tip diameter for three fire intensity classes, Esperanza Fire.

The Esperanza Fire burned a portion of the North Mountain Experimental Area (NMEA). Fuel characteristics, particularly of chamise, have been measured here over the past few decades (Countryman and Philpot 1970, Paysen and Cohen 1988, Ottmar et al 2000). The fuel loading distribution by size class from each of these studies for NMEA are contained in Table 5. Paysen and Cohen sampled chamise from several locations in southern California. These percentages are for chamise chaparral only. In the case of the Countryman and Paysen studies, these percentages are based on individual shrubs. The Ottmar et al percentages were determined from a plot.

For the purposes of this study, we assumed following fuel loading distribution: < 0.32 (includes foliage) = 23%, 0.32 - 0.64 cm = 20%, 0.64 – 2.54 cm = 42%, > 2.54 cm = 15%. Two unpublished equations were used to estimate total fuel loading for chamise and all other species using basal diameter. Based on the average burned tip diameter, we calculated fuel consumption using these percentages. Fuel consumption was then determined from the branch tip diameters and correlated with fire intensity class. Correlation between fuel consumption and fire intensity class was low ($\rho = 0.22$)

Source	Year	Fuel size class (cm)				
		Foliage	<0.64	1.28	2.54	7.62
Countryman	1970	13.2	26.0	21.6	29.5	9.7
Paysen	1988	14.7	41.4	22.0	14.5	5.9
Ottmar (CH06)	1996	15.6	31.1	*	47.5	5.7
Ottmar (CH09)	1996	7.2	23.7		34.5	34.5

*Ottmar et al fuel size class was 0.64 – 2.54 cm. Only chamise component reported.

Table 5. Distribution (%) by fuel size class for 3 studies that sampled chamise chaparral at North Mountain Experimental Area near Riverside, CA.

4. SUMMARY

Initial attempts to correlate fire temperature measured using an airplane-mounted thermal imaging radiometer with ground-based estimates of fuel consumption and fire intensity were not very successful. The fire temperature data provided a single point in time as opposed to an integrated energy release measure. Correlation between aerially measured temperatures and ground fire intensity values was poor; possible sources of error were identified. Correlation between fire intensity class and estimated fuel consumption was also poor. Future work will involve development of improved estimates of fuel consumption and energy release as well as numerical integration of the FireMapper imagery in order to better test correlation between remotely-measured fire characteristics with similar measures based on ground sampling.

5. LITERATURE CITED

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