2002

Fuel loading prediction models developed from aerial photographs of the Sangre de Cristo and Jemez mountains of New Mexico, USA

Kelly Scott

Brian P. Oswald
Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, boswald@sfasu.edu

Kenneth W. Farrish
Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, kfarrish@sfasu.edu

Daniel Unger
Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, unger@sfasu.edu

Recommended Citation

Scott, Kelly; Oswald, Brian P.; Farrish, Kenneth W.; and Unger, Daniel, "Fuel loading prediction models developed from aerial photographs of the Sangre de Cristo and Jemez mountains of New Mexico, USA" (2002). *Faculty Publications.* Paper 410.
http://scholarworks.sfasu.edu/forestry/410

International Journal of Wildland Fire, 2002, **11**, 85–90

Fuel loading prediction models developed from aerial photographs of the Sangre de Cristo and Jemez mountains of New Mexico, USA

Kelly Scott, Brian Oswald, Kenneth Farrish and Daniel Unger

Arthur Temple College of Forestry Stephen F. Austin State University, PO Box 6109, Nacogdoches, Texas 75962, USA. Telephone: +1 936 468 2275; fax: +1 936 468 2489; email: boswald@sfasu.edu; kfarrish@sfasu.edu; unger@sfasu.edu

Abstract. Fuel load prediction equations that made use of aerial photographs were developed for Mixed Conifer, Ponderosa Pine (*Pinus ponderosa* Dougl. ex Laws.) and Pinyon–Juniper (*Pinus edulis* Engelm.)–(*Juniperus monosperma* Engelm.) cover types from one-time measurements made in the Santa Fe watershed (SFWS) located in the Sangre de Cristo Mountains of northern New Mexico, and at Los Alamos National Laboratory (LANL) located in the Jemez Mountains of northern New Mexico. The results of the watershed data set were favorable and exhibited a high degree of relative accuracy. The results from the LANL data set did not share the same degree of accuracy, but rather exhibited a high degree of error. Use of these or similar prediction equations may be limited to certain regions and community types that exhibit similar regional characteristics such as terrain, soil, and weather conditions. Applied use of the prediction equations required less time than traditional fuel sampling performed on-site, but suffered from a loss of accuracy. It is strongly suggested that additional study of this method be undertaken to generate more accurate and reliable equations. Hopefully, more accurate equations may augment existing fuel sampling techniques and be put to practical use for fire planning purposes.

Additional keywords: Fuel loads; aerial photography; Ponderosa Pine; New Mexico; fire hazard; conifers; Pinyon–Juniper.

Introduction

Forest fires were a regular phenomenon in what is now the western United States before the arrival of the Europeans. Active fire suppression of the last 100 years has promoted an unnatural amount of forest fuels (Dodge 1972). Accumulation of fuels is now showing a profound effect on forest conditions. Low-intensity fires that would periodically reduce fuel loads have been replaced by infrequent high-intensity fires that are stand-replacing events on a catastrophic level. Such a fire occurred in Yellowstone National Park in 1987 (Wright 1988).

Research aimed at developing techniques for the estimation of fuel loading in forest conditions has been performed for forest cover types common to the Jemez mountains in north-central New Mexico. Previous work (Kittredge 1944; Cable 1958; Ffolliot *et al.* 1968, 1977) has shown that strong correlations exist between certain stand characteristics and forest fuel loads of woody material. Of the stand characteristics examined, stand basal area (BA) was the most consistent stand characteristic for estimating fuel loads. Crown diameter or percentage crown cover are stand characteristics commonly measured using aerial photography. Remote sensing (i.e. satellite imagery and aerial photography) has been used for such purposes as predicting the fuel model (Oswald *et al.* 2000) and fire danger rating by evaluating the cover vegetation of an area (Jain *et al.* 1996). Aerial photograph-based fuel predictions may provide rapid assessment of fuels for large areas quickly, or maybe useful for areas that are difficult to access.

There is very little information on the use of aerial photography for the purpose of fuel load predictions (K.C. Ryan, personal communication 1998). However, the use of aerial photography for the purpose of determining fuel models was reported by Oswald *et al.* (2000). From air photos, stand and overstory characteristics such as stand composition, basal area, and crown cover were estimated. A photo guide of south-eastern fuel types (Reeves 1988) was used to compare and match stand appearances to a particular fuel model. Plots were measured on the ground and corresponding points matched to black and white, panchromatic 1 : 80 000 scale photos. Results of the field checking produced an accuracy of 84.6%. Improper classification was partly due to loss of detail from the photo

10.1071/WF01044 1049-8001/02/010085

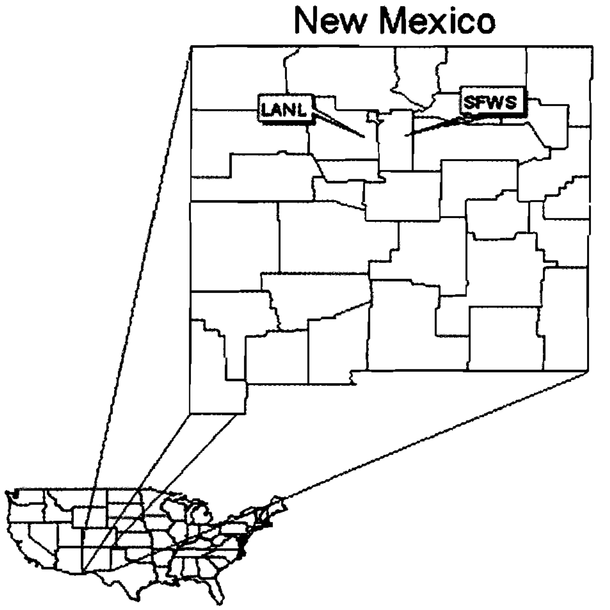

Fig. 1. General location of research sites at Los Alamos National Laboratory (LANL) and the Santa Fe Watershed (SFWS), New Mexico, USA.

scale. Use of air photos for fuel model prediction appears to be an effective technique worthy of further research.

Objectives

1. Determine if a relationship exists between forest fuels measured on the ground and overstory conditions (stand composition, basal area, and crown cover) of Pinyon–Juniper, Ponderosa Pine, and Mixed Conifer cover types commonly found within the Jemez and Sangre de Cristo Mountains of north-central New Mexico,
2. Develop fuel load prediction equations based on results of field sampling of fuel loads and overstory conditions measured from on-site and overstory conditions measured from aerial photographs, and
3. Assess the accuracy of the resulting prediction equations when tested against the actual fuel data collected.

Methods

Two research areas (Fig. 1) were utilized in this study. For the Santa Fe Watershed Area (SFWS), 60 sample sites were utilized and for the Los Alamos National Laboratory (LANL) research area, 56 sample sites were used. Site locations were established to represent the Pinyon–Juniper woodlands, Ponderosa Pine forests and Mixed Conifer forests within these two areas.

Each sample site was evaluated for homogeneity with respect to vegetation structure, soils and topography within a 105 ft × 105 ft (32 m × 32 m) square, and the area surrounding the square. The UTM coordinates of the center of each site were recorded with a global positioning system (GPS) unit. The slope and aspect of each site was recorded using a Suunto clinometer and compass, respectively.

From the center of each sample site, 16 radiating lines 50 ft (15.2 m) long were established. A compass was used to determine true north (magnetic declination 11° East) for the initial line location. The 15 subsequent lines were placed at 22.5° intervals in a clockwise direction radiating outward from the center point. To avoid excessive sampling at the center location, the odd numbered lines were started at 10 ft (3 m) and even numbered lines at 30 ft (10 m) from the center point.

Down woody fuels, litter and vegetation samples

Fuel (downed woody material, litter, vegetation) sampling followed the procedure described by Brown *et al.* (1982). To facilitate subsequent analysis, downed woody fuels were subdivided into 1 h (< 0.25 in; <0.6 cm), 10 h (0.25–1 in; 0.6–2.5 cm), 100 h (1–3 in; 2.6–7.6 cm) and 1000 h fuels (>3 in; > 7.6 cm).

Tree measurements

Tree species were sampled in 0.25 acre (0.1 ha) square plots which were situated over the plot centers. Within each plot, all trees were recorded by species, total height and diameter. The diameters of trees less than 1 in (2.54 cm) in diameter at 4.5 ft (1.4 m) in height were measured at ground level; all others were measured at dbh. Total heights were measured to the nearest ft (m) and diameters to the nearest inch (cm). Canopy densities of each plot were measured using a crown densiometer at the center of each 0.25 acre (0.1 ha) plot. Four readings (facing the four cardinal directions) were made and an average canopy density was determined and recorded.

Laboratory measurements

The litter and vegetation samples were dried to constant weight for a minimum of 24 h at 65°C. The estimated litter and vegetation samples were converted to weight measures from the dry weight data. Fuel loads and number of trees were transformed to a per-acre (ha) basis. These data were summarized for each of the three communities of interest (Pinyon–Juniper, Ponderosa Pine, and Mixed Conifer).

Normal color aerial photographs (1 : 15 840 scale) of the Santa Fe Watershed study area were obtained from the U.S. Forest Service. Study site and plot locations were identified on the air photos and crown density was measured using visual density guides. Crown density from the air photos was compared to crown density in the field measured with a crown densiometer for accuracy. Both crown density estimation techniques placed the crown densities into six density classes (0–15%, 16–25%, 26–50%, 51–75%, 76–85%, 86–100%) for analysis. Providing a sufficiently accurate match between on-site crown density and remote crown density was found, correlations between woody fuels on the ground and crown density were examined with the intent of generating mathematical models for predicting fuel load. Aerial photographs of the LANL study plots were not utilized due to difficulty in obtaining the photos.

Statistical analysis

Statistical Analysis was performed on the data using the PROC ANOVA procedures in SAS Version 6 (SAS Institute, Inc. 1990). An alpha value of $P=0.1$ was used to determine if significance existed. Parameters included surface fuels, overstory characteristics (basal area, percentage crown cover) and percentage crown cover measured from aerial photographs. Pearson's Correlation was performed on all significant parameters. Prediction equations were developed using the PROC REG procedures in SAS Version 6. The prediction equations were derived from overstory characteristics and total fuel loads by community type.

Results

Basal area

When basal area was used as the independent variable for statistical analysis of the woody fuels, the Mixed Conifer

Table 1. ANOVA P-values when basal area was used as the independent variable for Ponderosa pine, Mixed Conifer, and Pinyon–Juniper cover types

Significance was set at the $P = 0.1$ level. All significant relationships had Pearson's Correlation Coefficients ≥ 0.80. SFWS = Santa Fe Watershed site; LANL = Los Alamos National Laboratory site

Dependent	Ponderosa Pine			Mixed Conifer			Pinyon–Juniper		
variable	SFWS	SFWS/LANL	LANL	SFWS	SFWS/LANL	LANL	SFWS	SFWS/LANL	LANL
Crown cover	0.7880	0.0240	0.0324	0.0001	0.0001	0.1584	0.6667	0.1657	0.5165
Total fuels	0.5648	0.6163	0.8684	0.0005	0.0001	0.1233	—[A]	0.0024	0.0001
1 h fuels	0.2643	0.4717	0.0171	0.0791	0.1519	0.6268	0.6667	0.8590	0.7170
10 h fuels	0.2530	0.2464	0.3604	0.0705	0.1400	0.6742	0.0001	0.8089	0.3286
100 h fuels	0.6357	0.6992	0.2013	0.2654	0.2611	0.4468	—[A]	0.6677	0.2643
1000 h fuels	0.6977	0.1515	0.0422	0.0439	0.0299	0.0046	—[A]	0.6308	0.7170
1000 h rotten	0.4241	0.5660	0.8684	0.0011	0.0001	0.0709	—[A]	0.0823	0.0075
Litter	0.5887	0.8288	0.6932	0.0013	0.0014	0.1805	0.6667	0.4263	0.2720
Vegetation	0.9655	0.0774	0.3087	0.0085	0.0029	0.6364	—[A]	0.7780	0.2630

[A] Insufficient data to perform analysis.

Table 2. ANOVA P-values when percentage crown cover measured from the ground was used as the independent variable for Ponderosa Pine, Mixed Conifer, and Pinyon–Juniper cover types

Significance was set at the $P = 0.1$ level. All significant relationships had Pearson's Correlation Coefficients ≥ 0.80. SFWS = Santa Fe Watershed site; LANL = Los Alamos National Laboratory site

Dependent	Ponderosa Pine			Mixed Conifer			Pinyon–Juniper		
variable	SFWS	SFWS/LANL	LANL	SFWS	SFWS/LANL	LANL	SFWS	SFWS/LANL	LANL
Crown cover	0.1532	0.0138	0.0293	0.0301	0.0277	0.1526	0.6667	0.3206	0.1616
Total fuels	0.9780	0.5708	0.0999	0.0568	0.1077	0.6088	—[A]	0.2040	0.1616
1 h fuels	0.4770	0.4671	0.0888	0.8167	0.7892	0.9521	0.0001	0.4781	0.0674
10 h fuels	0.6579	0.1155	0.0690	0.0442	0.0903	0.6726	0.6667	0.1793	0.0895
100 h fuels	0.8847	0.4958	0.3778	0.4245	0.6000	0.9839	—[A]	0.7844	0.6459
1000 h sound	0.2470	0.7286	0.8688	0.8754	0.9643	0.5523	—[A]	0.4591	0.6248
1000 h rotten	0.8495	0.5296	0.0999	0.0253	0.1097	0.3862	—[A]	0.5959	0.5860
Litter	0.0677	0.1008	0.3008	0.2088	0.0390	0.0583	0.6667	0.0594	0.0537
Vegetation	0.4743	0.0550	0.4360	0.0207	0.0108	0.5387	—[A]	0.0266	0.0592

[A] = Insufficient data to perform analysis.

cover type had the most variables that exhibited significant correlations (Table 1).

Crown cover and total fuels for the Santa Fe Watershed (SFWS) and combined watershed and Los Alamos National Laboratory (SFWS/LANL) data sets exhibited significance ($P \leq 0.1$). Other variables such as 1000 h fuels, litter and vegetation were also significant in the same two areas. This pattern is not reflected in the Los Alamos National Laboratory (LANL) data.

For the Ponderosa Pine cover type only the crown cover, 1 h and 1000 h sound fuels from the LANL data exhibited significance. For the Pinyon–Juniper cover type the 10 h fuels from the SFWS and 1000 h rotten and total fuels from the combined and LANL data exhibited significance.

For all three cover types, high (> 0.80 correlation coefficient) positive correlations were found for all significant parameters.

Crown cover from ground estimation

When percentage crown cover was used as the independent variable for statistical analysis, the Mixed Conifer cover type again had the most variables that exhibited significance (Table 2). Yet, no single variable exhibited significance across the data sets. Crown cover, 10 h fuels, litter and vegetation showed significance within the combined data, while crown cover, total fuels, 10 h fuels, 1000 h rotten fuels, and vegetation were significant within the SFWS data. Litter was the only variable significant in the LANL data.

The Ponderosa Pine cover type had no variables that exhibited significance across all three data sets and only one variable, litter, had significance in the SFWS data (Table 2). Most of the variables that exhibited significance for this cover type were not found to be significant in the LANL data.

Table 3. ANOVA *P*-values when percentage crown cover measured from aerial photographs was used as the independent variable for the Ponderosa Pine, Mixed Conifer, and Pinyon–Juniper cover types

Data are from Santa Fe Watershed site only. Significance was set at the $P = 0.1$ level. All significant relationships had Pearson's Correlation Coefficients ≥ 0.80

Dependent variable	Ponderosa Pine	Mixed Conifer	Pinyon–Juniper
Basal area	0.8691	0.1729	0.6667
Crown cover	0.6106	0.6106	0.6667
Total fuels	0.8806	0.5406	—[A]
1 h fuels	0.9915	0.8611	0.6667
10 h fuels	0.3574	0.0213	0.6667
100 h fuels	0.4098	0.0984	—[A]
1000 h sound	0.6065	0.2731	—[A]
1000 h rotten	0.9002	0.6589	—[A]
Litter	0.8689	0.6744	0.0001
Vegetation	0.1811	0.1811	—[A]

[A] = Insufficient data to perform analysis.

Table 4. Prediction equations by cover type for the Santa Fe Watershed site

Y = total fuel loads in tons/acre; PH = Crown cover (%) estimated from aerial photographs; GR = Crown cover (%) estimated from ground, BA = basal area (ft^2/A). Significance was set at the $P = 0.1$ level

Prediction equation	*P*-values	r^2	Equation
Mixed Conifer cover type			
$Y = 29.28 + (PH)*(0.192076)$	0.0135	0.67	(1)
$Y = -7.87 + (GR)*(0.822022)$	0.2369	0.36	(2)
$Y = 2.45 + (BA)*(0.192076)$	0.3779	0.41	(3)
Ponderosa Pine cover type			
$Y = 8.58 + (PH)*(-0.130975)$	0.0185	0.71	(4)
$Y = 22.75 + (GR)*(-0.130970)$	0.0101	0.69	(5)
$Y = 14.88 + (BA)*(0.023149)$	0.0014	0.57	(6)
Pinyon–Juniper cover type			
$Y = 7.46 + (PH)*(-0.055429)$	0.5614	0.44	(7)
$Y = 5.63 + (GR)*(-0.008667)$	0.0176	0.56	(8)
$Y = 3.56 + (BA)*(0.047932)$	0.9572	0.35	(9)

The Pinyon–Juniper cover type had three variables that exhibited significance in two of the data sets (Table 2). The 1 h fuels were the only variable with significance for the SFWS and LANL data sets, while litter and vegetation exhibited significance in the combined and LANL data sets.

For all cover types, high (> 0.80 correlation coefficient) positive correlations were found for all significant parameters.

Crown cover from aerial photographs

Only the SFWS data set was used in the analysis procedure when statistical analysis was performed with percentage crown cover measured from aerial photographs (Table 3). Air photos were not available for the LANL research area. Results of statistical analysis for that area determined that few variables exhibited significance. For all cover types, high (>0.80 correlation coefficient) positive correlations were found for all significant parameters.

The Ponderosa Pine cover type had no significant variables. The Mixed Conifer cover type had two variables, 10 and 100 h fuels, which were significant. No variables were significant across all cover types. Specifically, analysis indicated that there were no significance between total fuels and percentage crown cover measured from aerial photos, which was the aim of this research project.

Prediction equations

Forest fuel prediction equation models (Table 4) were developed for percentage crown cover derived from air photos, on-site percentage crown cover and on-site stand basal area from each research plot. Equations models were developed only from the SFWS data. Prediction equations were grouped by community type.

The variables chosen for the development of the prediction equations were those most likely to be used for field applications. The equations are based on total fuel loads (tons per acre) and were tested against the original data set to determine relative accuracy with the sum of deviation for each cover type and corresponding dependent variable (Table 5).

Based on r^2 values, the air photo percentage crown cover analysis resulted with a relatively moderate to high degree of accuracy for the Ponderosa Pine and Mixed Conifer community types (equations 1 and 4). For the Ponderosa Pine and Pinyon–Juniper community types, ground measured percentage crown cover (equations 2 and 8), as well as the stand basal area for Ponderosa Pine (equation 6)

Table 5. Percentage sums of deviation from true fuel loads in tons per acre of the prediction equations for the Santa Fe Watershed (SFWS) and Los Alamos National Laboratory (LANL) sites

No aerial photographs were available for the LANL site. Data followed by a * represent significance at $P = 0.1$

Independent variable	SFWS Ponderosa Pine	SFWS Mixed Conifer	SFWS Pinyon–Juniper	LANL Ponderosa Pine	LANL Mixed Conifer	LANL Pinyon–Juniper
Photographs	11.9*	8.2*	–0.2			
Crown	–5.6*	181.1	0.0*	–2244.1	505.9	–904.5
Basal area	873.1*	78.3	–0.3	861.6	232.6	993.4

were also relatively accurate. All other prediction equations failed to meet the 0.1 level of significance.

Use of the watershed equations on the LANL data set proved to be unreliable, which may indicate that equations may not be suitable for use outside of the immediate region from which they were developed.

Discussion

The results of the Mixed Conifer and Ponderosa Pine analysis may be explained by the variation in stand composition found in these communities. The mixed conifer cover type may be dominated by any or all of a variety of species, including Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco), white fir (*Abies concolor* (Gord. & Glend.) Lindle. ex Hildebr.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), limber pine (*Pinus flexilus* James) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), and may include a number of individual Ponderosa Pine at the lower elevations or more southern aspects. The Ponderosa Pine cover type may include Douglas-fir, blue spruce (*Picea pungens* Engelm.) and quaking aspen (*Populus tremuloides* Michx.). While ground data collection would be able to identify this type of variation in this region (Gardner 1999), aerial photographs of the scale used in this study would be less effective. Lack of significant results in the Pinyon–Juniper cover type may be explained by a low number of plots (3) at the SFWS site.

When utilizing the aerial photographs the significance, or lack of significance, may be explained by the reduced variation observed within the Mixed Conifer cover type, and an increased in variation found in the Ponderosa Pine cover type. The variation in the Ponderosa Pine cover type may be due to the presence of other species within these sample plots, potentially resulting in a misclassification of the plots. The presence of these other species not accounted for may have had a significant impact on the fuel complex. The process used in this study classified plots by the majority of species present within a sample plot. This may be avoided in the future if a sub-classification process were used to identify sample plots by gradients of composition. Insufficient data may be responsible for the lack of correlation for many of the variables in the Pinyon–Juniper cover type.

When the prediction equations, developed from the percentage crown cover derived from air photos, on-site percentage crown cover and on-site stand basal area, were tested against the SFWS data set and then against the LANL data set, a stark contrast was revealed. For the SFWS data set the air photo prediction equations were relatively accurate for the Ponderosa Pine and Mixed Conifer cover types, while the on-site percentage crown cover prediction equations were accurate for the Ponderosa Pine and Pinyon–Juniper cover types, and on-site basal area prediction equations were accurate for only the Ponderosa Pine cover type.

The same prediction equations for on-site percentage cover and on-site basal area were applied to the LANL data set. Both sets of equations resulted in grossly inaccurate predictions for all three cover types. This might indicate that such prediction equations are not suitable for use outside of the immediate region from which they are developed. Conditions sampled in the LANL research area could have been altered over time due to land management by LANL personnel, thereby creating a distinctly different fuel and stand complex even if the present stand conditions appeared similar. Further research in the use of prediction equations and remote sensing might identify some of the errors experienced in this project and result in more accurate prediction equations.

Conclusions

The use of air photos at a scale of 1 : 15 840 for predicting fuel loads appears to be a feasible method. This method does have certain limitations. There was a noticeable lack of accuracy when performing this method. This may be unavoidable when considering the inherent variation between forest stands within the same cover type and the factors involved; for example, interpreter-introduced error and image clarity. If the prediction models are used, the photo interpreter needs to be familiar with the community types involved in such a way as to be able to properly identify them from a photograph. It is essential for the proper use of the prediction equations.

This method is flexible with regard to photo type, scale and age, as long as the photos available are recent and have the appropriate scale to determine community type and percentage crown cover. The photos used in this study were natural color 1 : 15 840 scale and were sufficient for the task. Black and white photos may also be useful for this procedure, as they tend to have more clarity than color photos when used with a minus-blue filter, but it may prove more difficult to determine species composition within a cover type with the lack of color. Color infrared photos may be useful as well by making available more information about a site. It could be possible to better identify species type by reflectance signature as well as provide additional information such as moisture stress, which could be useful for fire planning. Different photo scales may also prove useful as long as the photos used exhibit enough detail to accurately make percentage crown cover measurements. Use of larger scale photos may increase the accuracy of percentage crown measurements but more photos would be necessary to sample the same area. As the photo scale is reduced the photo images will decrease in clarity but cover more area. The benefit of using a small scale photo with this procedure would be that large areas might be sampled rapidly.

Gathering the necessary information to use the prediction equations takes very little time and there is no need for special equipment. All that is necessary are air photos, a visual density guide to determine percentage crown cover, and a stereoscope. One of the clear benefits of using prediction equations for estimating fuel loads is that it is much faster and potentially less costly than gathering data from the field.

References

Brown JK, Oberheu RD, Johnson CM (1982) Handbook for inventorying surface fuels and biomass in the interior West. USDA Forest Service, Intermountain Forest and Range Research Station General Technical Report INT-129. Ogden, UT. 48 pp.

Cable DR (1958) Estimating surface area of Ponderosa pine foliage in central Arizona. *Forest Science* **4**(1), 45–49.

Dodge M (1972) Forest fuel—a growing problem. *Science* **177**, 139–142.

Ffolliot PF, Clary WP, Davis JR (1968) Some characteristics of the forest floor under Ponderosa pine in Arizona. USDA Forest Service, Rocky Mountains Forest and Range Experiment Station Research Note RM-127. Fort Collins, CO. 4 pp.

Ffolliott PF, Larson FR, Thill RE (1977) Some characteristics of Arizona's Mixed Conifer forest floor. USDA Forest Service, Rocky Mountains Forest and Range Experiment Station Research Note RM-342. Fort Collins, CO. 4 pp.

Gardner SL (1999) Community classification in the ponderosa pine, mixed conifer and spruce-fir zones of the East side of the Jemez Mountain, New Mexico. M.S. Thesis, Stephen F. Austin State University, Nacogdoches, TX. 105 pp.

Jain A, Ravan SA, Singh RK, Das KK, Roy PS (1996) Forest fire risk modelling using remote sensing and geographic information system. *Current Science* **70**(10), 928–933.

Kittredge J (1944) Estimation of the amount of foliage of trees and stands. *Journal of Forestry* **42**, 905–912.

Oswald BP, Fancher JT, Kulhavy DL, Reeves HC (2000) Classifying fuels with aerial photography in east Texas. *International Journal of Wildland Fire* **9**(2), 109–113.

Reeves HC (1988) 'Photo guide for appraising surface fuels in east Texas.' (College of Forestry, Stephen F. Austin State University: Nacogdoches, Texas) 89 pp.

SAS Institute Inc. (1990) 'SAS® Users Guide: Statistics, Version 5 edition.' (SAS Institute Inc.: Cary, NC) 956 pp.

Sackett SS (1979) Natural fuel loadings in Ponderosa pine and Mixed Conifer forests of the Southwest. USDA Forest Service, Rocky Mountains Forest and Range Experiment Station Research Paper RM-213. Fort Collins, CO. 10 pp.

Wright HA (1988) Role of fire in the management of Southwestern ecosystems. In 'Proceedings, Effects of fire management of Southwestern natural resources'. USDA Forest Service, Rocky Mountains Forest and Range Experiment Station General Technical Report RM-191, pp. 1–5.