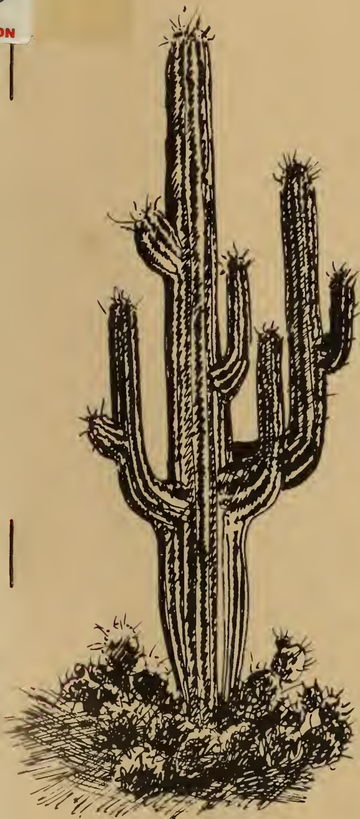

Cooperative National Park Resources Studies Unit

ARIZONA

TECHNICAL REPORT NO. 27

LIVE FUEL MOISTURE SAMPLING METHODS FOR CHIRICAHUA NATIONAL MONUMENT

by

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COOPERATIVE NATIONAL PARK RESOURCES STUDIES UNIT
University of Arizona/Tucson - National Park Service

The Cooperative National Park Resources Studies Unit/University of Arizona (CPSU/UA) was established August 16, 1973. The unit is funded by the National Park Service and reports to the Western Regional Office, San Francisco; it is located on the campus of the University of Arizona and reports also to the Office of the Vice-President for Research. Administrative assistance is provided by the Western Archeological and Conservation Center, the School of Renewable Natural Resources, and the Department of Ecology and Evolutionary Biology. The unit's professional personnel hold adjunct faculty and/or research associate appointments with the University. The Materials and Ecological Testing Laboratory is maintained at the Western Archeological and Conservation Center, 1415 N. 6th Ave., Tucson, Arizona 85705.

The CPSU/UA provides a multidisciplinary approach to studies in the natural and cultural sciences. Funded projects identified by park management are investigated by National Park Service and university researchers under the coordination of the Unit Leader. Unit members also cooperate with researchers involved in projects funded by non-National Park Service sources in order to obtain scientific information on Park Service lands.

[redacted]

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Wildland Resource Management
134 Journey's End
Walnut Creek, CA

December 1989

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ROLE OF LIVE FUEL MOISTURE CONTENT IN FIRE MANAGEMENT

Fire Behavior Prediction

Fire behavior and effects of fire are influenced not only by slope, temperature, and structure of the fuel bed, but also by the abundance and moisture content of living vegetation. The significance of live fuel moisture increases as the ratio in the fuel complex of live to dead fuels increases (Deeming 1985). Living foliage either serves as a heat sink (retarding fire spread and intensity), or contributes to the energy of the fire (increasing fire's spread and intensity). Because of their moisture content, live fuels will seldom burn "by themselves" (Countryman 1974). Rather, a fire almost always will be sustained by the dead material in the fuel bed. Moisture content can greatly reduce heat output from burning matter. Moisture contents of intermixed live and dead fuels do not always rise and fall in the same pattern, so they must be evaluated separately to determine the flammability of the complex at any given time (Schroeder and Buck 1970).

Besides moisture and extractives (also known as crude fat content and include oils, waxes, fats and terpenes), the slope, depth of flaming zone, fuel continuity and arrangement, and wind speed also affect flame prorogation. If any of these other factors increase, ignition in live or dead fuels can occur at a higher moisture content and still burn with the same flame length.

Fires have recently demonstrated an ability to carry in chaparral stands without dead material, contrary to the common belief that chaparral fires require 25% dead material to burn well (Anderson and Cohen 1988). Young chaparral stands (those under 15 years of age) have proportionally more of their live biomass as fine fuels than do older stands. These fine fuels that constitute the young chaparral stand burn more readily, at higher moisture contents, and with less dead fuels than do older stands which have more living material that is larger in diameter. This is especially relevant in Chiricahua because low proportions of dead material were observed in chaparral stands on Sugarloaf (at the head of Echo Canyon).

Deeming (1985) stated "a foliage-sampling program may be warranted where the condition of live plants is very important to fire-danger rating". Because live fuel moistures are considered a major factor in fire behavior, a monitoring program was established throughout California by the USDA Forest Service and California Department of Forestry and Fire Protection. Within the USDI National Park Service, Cabrillo and Pinnacles National Monuments have also initiated on-going live fuel moisture monitoring programs.

Live Fuel Moisture

Live fuel moistures is the weight of water compared to the weight of dry material in the biomass. While dead fuel moisture contents often range from five to 50%, live fuel moistures commonly exceed 100% (because there is more water than dry material in a leaf).

Live fuel moistures reflect long term trends (such as amount and distribution of rainfall) and short term events (such as high temperatures and strong dry winds). While most species follow a general trend of increased moisture in late spring and early summer followed by a decrease, variations in levels of moisture, rates of drying, responses to weather, and absolute values exist between species.

Fuel moisture in living foliage is controlled by the genetic composition and physiological functions of plants as well as environmental conditions. Root structure and leaf physiology are examples of genetic factors and plant features that affect response to atmospheric and environmental conditions. Substantial variations may also be due in part to species-related differences in morphology, phenological development, stomatal activity, as well as micro-habitat preference. Although most research has focused on drought indices and the effects of soil moisture, chief environmental factors regulating activity in shrub foliage are temperature, light, rain, and relative humidity (Rice and Martin 1986).

OBJECTIVES

The staff at Chiricahua National Monument is improving their fire management program. The fire management plan is currently being revised, and several prescribed burns have been conducted in the park in order to provide research and operational information necessary to guide the overall program. Further prescribed burns and manual treatment of fuels and overstory are planned in the future to enhance public safety through fire hazard reduction and to restore vegetation structure and composition. Refining the prescription (in planning prescribed burns) to achieve desired fire behavior and thus desired effects is an ongoing process. Wildfire potential is also being considered. A main factor in understanding and predicting fire behavior is the moisture content of the material to be burned. While the staff of Chiricahua has monitored litter in the past, little work has been done with live fuels. Thus a process is required to monitor live fuel moistures in order to better gauge wildfire potential and describe conditions under which desirable fire behavior can be achieved.

The purpose of this project is to develop a live fuel moisture monitoring program. The first objective is to establish a trend of live fuel moistures for selected, characteristic species. Within this objective are three goals, which are to determine the effects of: (1) varying aspect; (2) topographic position; and (3) species on the level and trends of live fuel moistures. An additional objective is to determine the effects of rain after extended dry periods on live fuel moistures, concentrating on the timing and magnitude of the rise in moisture content.

LITERATURE REVIEW

Differences Among Species

Levels of moisture content and rates of increase and decrease are not identical for all species, but major changes often occur about the same time. For example, greenleaf manzanita (*Arctostaphylos patula*) peaks at 145% moisture content with new growth emergence in July in California, then declines to 100%. Chamise (*Adenostoma fasciculatum*) old growth peaks at 100% with a flush of new growth (slightly before manzanita) and declines to 70% in the summer drought (Olsen 1959).

Additionally, the seasonal trend in moisture contents varies with the growth type: deciduous or evergreen. Schroeder and Buck (1970) maintain the foliage of evergreen species tends to be more combustible than deciduous species because all of the deciduous foliage is the current year's growth. Current growth is "new" growth, which is generally higher in moisture content than old growth. Both new and old foliage of evergreen species maintains high moisture during most of the season. The moisture content of evergreen species may exceed 250% in the spring. These leaves may emerge quickly or over an extended period. The average moisture content drops rapidly to 150% with the onset of drought. As new leaves grow in size until midsummer, the moisture content declines, and matches the moisture content of older foliage near the end of the growing season. Evergreen species have much lower average foliar moisture during the growing season than deciduous species. In addition, old-growth foliage may be 80% of the foliage.

The moisture content of deciduous species may in fact be lower than of evergreen shrubs and trees (Rice and Martin 1985a). Sage (*Salvia mellifera* and *S. leucophylla*) and sagebrush (*Artemisia californica*) are examples of very flammable deciduous species (Veverka 1985). Whether the deciduous oaks in Chiricahua are higher or lower in moisture content than the evergreen trees intermixed in the forest is a point of interest.

Critical levels of moisture content for manzanita have been defined as 80%, where generally fires can burn in chaparral crowns without any dead material to support flames (Countryman and Bradshaw 1980). Sustained runs, however, without significant amounts of dry, dead material in the stand are unlikely above the critical moisture level.

Another variation in live fuel moisture among species is the rate of drying when rains cease. Some species (primarily soft chaparral) such as sage and sagebrush are sensitive to atmospheric conditions. These fine-leaved plants have steeper rates of desiccation and recovery but simultaneously drop to the same minimum as those hard-leafed species (manzanita, ceanothus, and chamise). On the other hand, the moisture content of hard chaparral follow longer term trends with little response to atmospheric moisture (Rice and Martin 1986).

Some species are dormant in the winter; so once the foliar moisture drops in the fall, the levels remain low until new growth appears (in the spring) (Countryman 1974). Again, other species have no winter dormancy, so a great variation will exist, especially during winter, regardless of winter weather conditions.

Soil Moisture and Weather

A chief weather characteristic controlling foliar moisture content is temperature because it affects the time new plant growth starts. If weather in late winter and spring is warm, the moisture content will increase more quickly and earlier than if it is cold. Soil moisture will also reach a higher level when peak moisture occurs (Countryman 1974). If rainfall is deficient, plants remain dormant or grow slowly. If the deficiency persists throughout the season, the foliar moisture content does not rise to normal levels, and drops more quickly and often falls to a lower than normal point in the autumn. Differences in the changes or moisture contents are typical between local species and climates. The timing of the changes in moisture contents are tempered by deviations from normal weather, such as amount and spacing of precipitation or occurrence of unseasonably warm or cool temperatures (Schroeder and Buck 1970). Olsen (1959) also found that short-term weather fluctuations have a significant effect on live fuel moisture contents.

Olsen (1959) found a definite positive correlation between soil moisture trends and chaparral foliar moisture trends.

Moisture content of all new foliage is highest at time of emergence when it commonly may be two to three times the dry weight. Peak moistures decline rapidly during leaf growth and development, then more slowly to a terminal value leading to death or dormancy in the fall. The decrease in plant foliar moistures is usually not smooth, but an irregular succession of ups and downs. These irregularities may result from periodic changes in food manufacturing demands, change in weather, or variations in available soil moisture (Schroeder and Buck 1970).

Levels of foliar moisture change with soil moisture and atmospheric conditions. Higher soil and atmospheric moisture often raise the foliar moisture content. A lower foliar moisture content can be expected with higher topographic positions since plots closer to the ridge are more exposed to desiccating factors. Likewise, sample locations on south facing slopes will have lower foliar moisture contents than other locations because the southern facing slope receives more light and is generally under a drier soil and atmospheric moisture regime (Rice and Martin 1985a).

In all species, the leaf stomata are the main path of water loss so it is logical that moisture contents change diurnally and are related to factors affecting stomatal behavior such as light, moisture availability, and temperature. This diurnal fluctuation is a major reason for consistently sampling between 1300 - 1600 hours. As soil moisture decreases, the size of openings and length of time stomata remain open decreases. The pattern of drying consists of an initially sharp drop in moisture then a gradual slowing in its decline (Radtke and Wakimoto 1981).

Dry, strong winds cause live fuel moistures to decrease rapidly, often to extremely low levels. Dry winds and resultant lower fuel moistures make ignition and flame propagation easier since less pre-heating is required. Winds also transfer heat to fuels ahead of the flame, increasing fire intensity and spread. Reduced fuel moistures can persist for several days after the drying winds cease (Countryman 1974).

Response to Rain

Except after periods of rain, live fuel moistures change slowly. The live fuel moisture contents of shrubs do not increase as soon as rain starts to fall. Shrubs often require two to five days to "mobilize forces", move water through the roots, and raise the moisture content of the foliage (Rice and Martin 1985b). Live fuel moistures can then jump as much as 20 percentage points in one day (an average of 12 percentage points in chamise) (Veverka 1985). However, in one study, manzanita in the Sierra Nevada showed no increase at all after almost three inches of rain during the end of the summer drought (Philpot 1963b).

Factors determining the lag time and speed of the rise in moisture content as well as the extent of the effect of rain are: (1) previous weather; (2) duration of rain; and (3) amount of rain. The rapid rise in live fuel moistures is likely to occur only if there has been 90 days of drought before the rain, if the rain is over two hours in duration, and if rain is at least one-half inch in amount (Richard Harrell, USDA Forest Service Region 5, personal communication 1986). While the amount of increase in moisture content varies with different species, the delay is similar in many types of chaparral (Rice 1987).

The season of rain affects shrub growth response but this phenomenon is not well understood. If the plant has not entered dormancy, a complete growth cycle (including shoot elongation and flowering) may occur. When shrubs enter a new growth cycle the flush of new growth has a very high moisture content and decreases the flammability of the fuel bed for a significant period of time. However, if rain occurs later in fall or early winter plants will not respond to the added moisture (Richard Harrell, USDA Forest Service Region 5, personal communication 1986). Whether the regulating mechanism is length of day, temperature, or another factor is unknown.

SAMPLING DESIGN

Field Sampling

Samples should be collected every two weeks at roughly the same time each day, between 1300 - 1600 hours (Countryman 1974). The diurnal fluctuation in moisture content of species to be sampled in Chiricahua is not known, but live fuel moisture minimas generally occur in mid-afternoon. During rain, or if dew or fog leaves water droplets on the leaves, sampling should be postponed until the water has evaporated. Under monsoon patterns of afternoon rains, sampling should take place the next mid-morning if water has evaporated. If water persists between rains, sampling must be postponed until the pattern stops. Foliage samples should put in soil sampling cans that are four inches (10.16 cm) in diameter and have tightly closing lids. Each can with lid is a sampling unit with the same number etched on each. If samples are collected on hot days or if the collector will be in the field for over four hours before samples are weighed, cans should be taped shut with masking tape and placed in a large plastic bag inside a backpack in order to minimize moisture loss. At least .35 ounces (ten grams) dry weight of foliage should be collected for each sample. Each species collected has a different density, so some plants will take up more space than others in the can (some plants are fluffy). Since dry weight will be determined only after oven drying, the collector will need to learn to judge the volume needed for a given species.

A larger volume will have to be collected when live fuel moistures are at their peak than when they are low because more of the weight will be water. Material should not be stuffed or compacted into the can because this will not allow consistent or complete drying. Material that is bent tends to straighten out during the drying process, so it is better to cut it (this applies particularly to beargrass samples). Material that is bowed in order to fit in the can will also stiffen and straighten, resulting in loose leaves outside the can and a dramatic error in calculations.

Species to be Sampled

Samples should be taken of species that play a major role in the spread of fire. These species may be the most abundant plant cover or else highly flammable. The significance of live fuel moistures increases as the ratio in the fuel complex of live to dead increases (Deeming 1985). In California, live fuel moisture is sampled in chaparral where that is the dominant fuel/vegetation type. However, fire managers are recognizing the importance of sampling tree foliage when it constitutes part of the same fuel complex (Deeming 1985, and Rice and Martin 1986). This is often the case when branches form ladder fuels, i.e., carries ground fire into the forest canopy. This is relevant to Chiricahua where foliage of silverleaf and Arizona white oak often burn even in low intensity fires with flame lengths of two feet. In this case, the foliage of the two oak species should be included in a live fuel moisture sampling program.

The following species are recommended for sampling in this initial phase. They are common species that can be used as indicators of fire behavior possibilities:

(1) Silverleaf oak (*Quercus hypoleucoides*)
(2) Arizona white oak (*Quercus arizonica*)
(3) Emory oak (*Quercus emoryi*)
(4) Arizona cypress (*Cupressus arizonica*)
(5) Pointleaf manzanita (*Arctostaphylos pungens*)
(6) Beargrass or sacahuista (*Nolina microcarpa*)

Silverleaf oak, white oak, and to a lesser extent, Emory oak are a focus of prescribed burns where the objective is to reduce the forest density by up to one half (Murray, 1982). Silverleaf and white oak are extremely common in Chiricahua National Monument and can make up a significant proportion of understory fuels.

Arizona cypress is a common tree that has a ladder-fuel branching habit. With this species the interest is to determine minimum foliar moisture levels at which cypress becomes a ladder fuel. Arizona cypress is especially common around the visitor center.

Pointleaf manzanita comprises a significant proportion of the plant cover and available standing live fuel in Chiricahua National Monument. In any prescribed burn or wildfire where this species occurs the foliage will be the major fuel carrying the fire. In Upper Rhyolite Canyon, past stand-replacing fires in manzanita cover was evident. Foliar moisture content of this species is thus a crucial factor in predicting potential fire behavior.

Beargrass is of interest because it is reported to increase locally the fire intensity and flame height. While this species is not continuous in its horizontal distribution, scorch and char heights on trees are dramatically higher when fire burns into beargrass growing beneath trees.

Other species were sampled during the visit to Chiricahua, but they were not in enough abundance to merit long-term sampling in Rhyolite Canyon. These were Toumey oak (*Quercus toumeyi*), green sumac (*Rhus choriophylla*), and silktassel (*Garrya wrightii*). In expanding this program to other areas in the monument, staff may find these species worth sampling because of significance in the fuel complex.

If after three years, there is no difference in levels or trends of live fuel moistures between the species (oaks, for example) sampling can be simplified. Only one oak would need to be sampled, and/or all oaks could be treated as one species (i.e. any canister may have in it white, silverleaf and Emory oak).

Material to Collect

Leaves and petioles should be taken in equal proportions from the top, bottom, and all sides of a variety of shrubs. When sampling trees, all sides should be included in the sample, and materials should be collected from the base of the tree to a point as high as possible. When sampling a species, collect material from several plants of that particular species. This gives a more comprehensive analysis of live fuel moisture level throughout sample area.

All material should be less than 1/8 inch (.317 cm) in diameter, and no dead material of any kind should be included. Thus leaves with brown spots, galls, or dead twigs would not be collected. Likewise, flowers and seeds need to be removed when collecting.

New growth is plant matter that appears at the onset of the growing season each year. At Chiricahua it is important to remember there are cool and warm growing seasons, so the collector will need to become familiar with the sample species. New growth is collected separately from old growth. Often old growth consists of leaves off a main (perhaps woody) stem, while new growth is material that is from a new (green) stem. All foliage ages to the point it is considered old growth; generally this is a process of hardening and losing moisture. Changes in cell structure may also take place during maturation making the difference between old and new growth easier to distinguish.

Each species should be collected in a different can. Three samples of each species should be collected at each sample location. Thus 18 cans (three samples each of six species) are required at each sampling location.

Sampling Locations

To achieve the first objective, sampling locations need to be selected that will establish a baseline for species, aspect, and topographic position.

Rhyolite Canyon is recommended for the initial phase of establishing baseline live fuel moisture profiles for indicator species. This program can easily be expanded to other areas of the monument to gain more comprehensive knowledge and understanding of fuel moisture characteristics. Subsequent sampling can be compared to the original baseline established for Rhyolite Canyon.

Each sample area needs to be three to ten acres (1.2 to four hectares) in size and have enough of the selected species to permit repeated collection of foliage without affecting the vigor of the plant. The collector should meander through the area collecting from the different species available.

Sampling areas for a long-term program need to be located in places which will not be disturbed and are away from roads and trails. Three locations in Rhyolite Canyon drainage are recommended for the initial program in Chiricahua. They are selected with consideration for protection of human life and property as well as to provide information for prescribed burning and wildfire control. They are: (1) above the visitor center; (2) in the Meadowood area (in the canyon bottom); and (3) south-facing slopes of lower Rhyolite Canyon (see Figure 1). The exact location should be close to, but not influenced by areas of prescribed burning.

These sampling locations address several issues. The visitor center is the focus of protection concerns where the highest potential of damage exists for loss of life and property (and biota). This sampling location will also represent vegetation growing on a north aspect. The second sampling location will represent vegetation growing on the canyon bottom. Additionally, prescribed burns are planned here to reduce some of the understory species sampled (cypress and oaks). Sampling foliage on the southern aspect of Rhyolite Canyon will allow comparison between the north and south aspects, indicate when wildfires could threaten the visitor center, and help predict fire behavior in any planned prescribed burns on that slope. Sampling around Sugarloaf Mountain can be included in the first expansion of the program in order to refine the effects of elevation and exposure on moisture contents.

Period of Sampling

Sampling should be started before new growth occurs in the spring in order to record the drop in moisture through the early summer and the rise in moisture due to the mid-summer monsoons. It would also indicate when shrubs become dormant with low moisture contents in the fall, and whether levels of live fuel moisture content rebound with fall rains. Sampling can end when live fuel moistures are consistently above 200%, and no dry period of two weeks or more is anticipated.

After fuel moisture profiles, i.e. levels and trends, are established for the key indicator species in question, the sampling period can be shortened. Then sampling can begin with the month of peak moisture, continue through the fire season, and end when levels of moisture reach 150% and persist.

Sampling Methods to Evaluate Effect of Rain

Foliage should be sampled from the same six key species. If rainfall of 1/2 inch (1.26 cm) or more occurs within the normal two week sampling period, additional samples should be taken. These collections should be taken daily the five days following the rain. Sampling on the first day after a rain

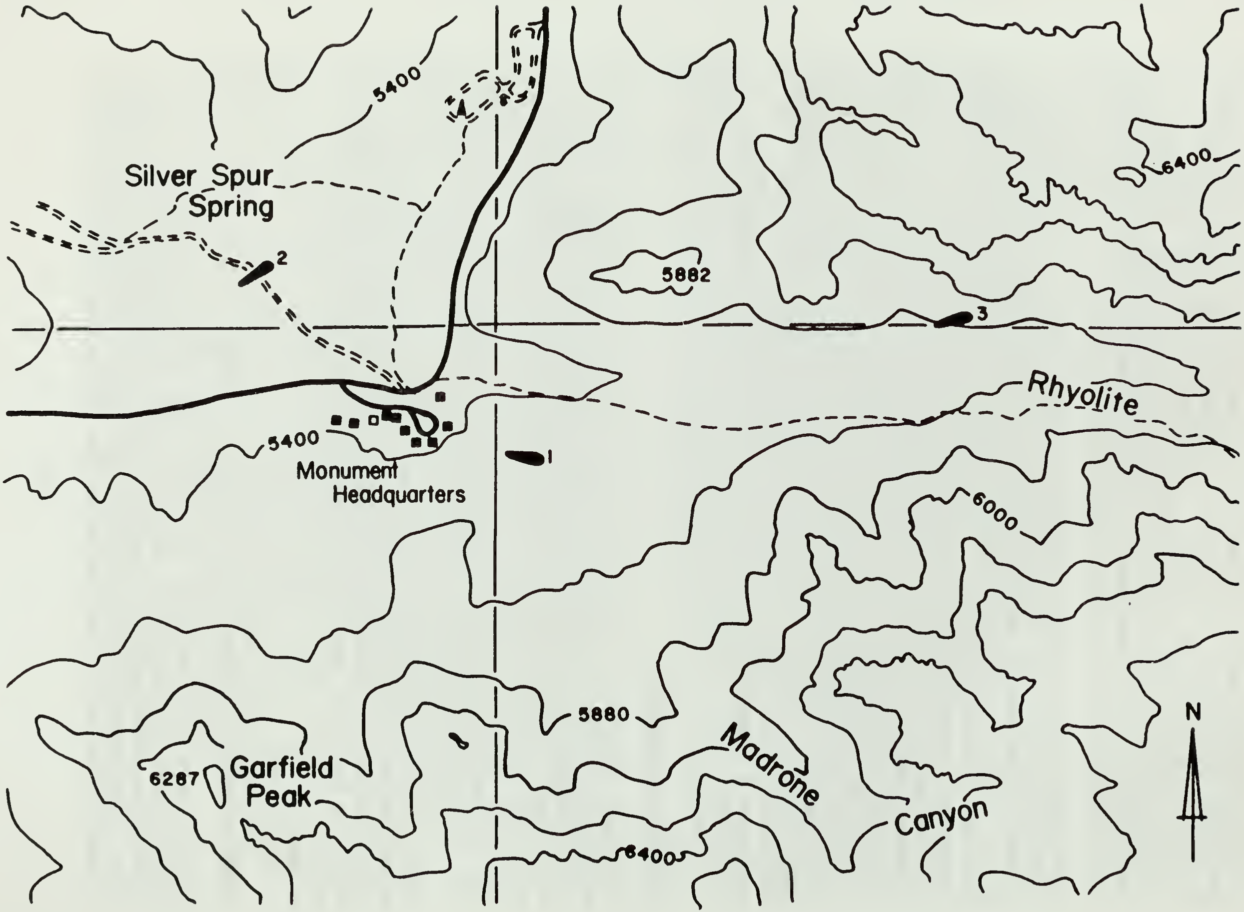

Figure 1. Map of sample locations

may be precluded by the presence of water on the leaves; thus four sampling days can be used. The same sample plots and techniques used to establish trends and comparison of moisture contents between species should be used (Rice 1987).

Sampling Procedures for Prescribed Burns

The sampling procedure should be slightly different when determining live fuel moistures for prescribed burns. Samples of major species in the burn area should be collected, even if they are different from the six species recommended for the monitoring program. For example, grass species should be taken in meadow burns. This sampling design will allow the fire manager to use areas of plants with high moisture as barriers to fire spread or manipulate ignition patterns around pockets of plants with extremely low fuel moistures.

Sampling should take place any time the week before the burn if no rain or unusually dry weather occurs. If hot, dry weather occurs, sampling should be done one to two days before the burn, allowing enough time for the sample to dry and calculations to be made. The closer in time the sampling takes place before the burn, the more accurate the data will be. Sampling should be done every day since the rain occurred if the rain happened within five days prior to the planned burn date. This frequency is required to determine if an increase of 20 or more percentage points in moisture has taken place in any day, or over the entire five day period. The number of samples (three), amount, and type of foliage should be the same as for the monitoring program. The location should be throughout the burn, including plants from the driest areas and representative areas.

LABORATORY TECHNIQUES

Samples should be weighed as soon as possible after collection to minimize the effects of post sampling moisture loss on the accuracy of the calculations. This is especially important in times of hot and/or dry weather. Excessive heat also decomposes the material, so care should be taken to keep the canisters from direct sun.

When collectors arrive in the laboratory, they should immediately weigh the cans (complete with lids and samples). Weight should be measured to the hundredth of a gram so all readings will be XXX.XX grams. Samples should be left in the cans and placed in an oven set to no more than 200 degrees Fahrenheit (93 degrees Celsius). Higher temperatures will decompose organic material and drive off extractives in addition to removing water, and essentially bake the samples (Countryman 1974). The lids to the cans should be removed, and placed under the can. Cans can be placed on top of each other to form a pyramid arrangement as long as air is free to move about inside the can. The circulation switch at the base of the oven should be set to allow air flow. A completely full oven will slow the drying process as will a compacted sample in the can.

After drying 24 hours, the cans, complete with lids and samples, are taken out of the oven (to speed the cooling process). The lid is replaced and the can is allowed to cool to room temperature. Be sure the number of the lid and can match. Samples should be weighed twice to double-check for errors in reading weights. Weighing is an exacting process and care needs to be taken to minimize errors. The process becomes even more important when the sample dry weight is small (under ten grams). The triple beam balance is a delicate piece of equipment and should be stored in a plastic bag, kept clean, maintained and oiled regularly.

During the trip to Chiricahua, the following factors were found to contribute to potential errors in weighing samples: (1) dirty (even just dusty) cans; (2) leaning on the table; (3) dirty scale and sticky rocker arm of scale; (4) varying temperature of cans (let them cool); and (5) open garage door. Tips are given to avoid these errors: The cans and scale dish need to be kept clean and must be completely dry when samples are weighed. Additionally, the rocker arm should be tapped lightly after the can is put on the scale dish; this action keeps the arm from sticking. Remember to weigh the cans when cool because warm cans create convection currents which actually cause significant weighing errors. The scale should also be calibrated before and while the samples are weighed (when the samples come in from the field as well as when they are weighed after drying). The balance was found to gradually "weigh heavy" as more cans were weighed. Weighing can be facilitated by looking for an even swing above and below the zero mark. The zero adjust knob below the sample dish calibrates the scale. The zero setting of the balance should be checked after five or six cans have been weighed, as the scale may be sensitive to temperature changes and the scale changes as it gets "exercised". After using the cans, wipe them clean before storing. This will remove dust from the previous collection. Lastly, the door of the fire cache needs to be closed during weighing because breezes cause the arm of the balance to swing and incorrect readings result.

The weights of each empty can should be recorded on a permanent form next to their numbers. Thus empty cans need not be weighed every time. However, at least three cans should be weighed each collection period to ascertain if the weights are the same as recorded. If can weights are more than 1% higher or lower than recorded (i.e., .38 grams on a 38 gram can), the balance should be calibrated and all empty cans reweighed.

The cans will be hot when they are to be removed from the oven. The use of a hot pad is advised so samples will not be dropped. Likewise, a cookie sheet on which to place sample cans is helpful for transporting many cans at once to the place where they will cool before being weighed.

VARIATION, ERROR, AND ACCURACY

Live fuel moistures are quite variable. Moisture contents are different within the same plant depending on the part of the plant sampled, different on each plant of the same species depending on its location, and different for each species. When sampling is done perfectly, a variation of 20% is still common. Variation can be minimized by collecting several samples at the same location, and ensuring each sample has the same proportion of material from the parts of the plant, and the same fraction of each plant sampled.

One method to minimize error is by using meticulous laboratory techniques, as outlined above. Management decisions (such as decisions concerning the opening of fire season, or whether to close areas because of high fire danger) can tolerate a variation of approximately 15%, but when the moisture content of plants decreases below 100%, the accuracy of the information becomes more important. Prescriptions should specify a spread of 50 percentage points in moisture content, so a variation of 15% above or below the actual level barely fits into a range of acceptably accurate information.

DATA ANALYSIS

Figure 2 is the form for recording and tallying live fuel moistures, which are expressed as the percent of water on a dry matter basis. This same calculation is done for dead fuels (duff, litter, 10 hour fuel sticks); however, frequently live fuel moistures will be over 100%. This simply means that over half of the weight of the foliage is water.

Once the calculations above have been made, data should be separated by aspect, position on the slope, and species. Moisture contents can then be separated by location and species as well as by new and old growth.

Differences between these categories can be determined simply by looking at averages of the categories, but simple non-parametric (ranking) statistical tests can help identify whether any apparent differences are large enough to be significant. The ranking tests would not require use of a computer if the sample size is small (under 20). As the program continues, data should be kept on LOTUS 123 because the program is quite helpful in the ranking and procedures required to do the statistical tests.

If a computer program is available that is compatible with LOTUS and runs the Wilcoxon Rank Sum Test (when comparing two groups) or the Kruskal-Wallis (K-W) Test (when comparing more than two groups), these tests between the categories are recommended. When tracking differences between the data collected on the same day, the Wilcoxon Matched Pair Signed Rank Test is appropriate (Wilcoxon, 1949; see page 5, "Paired Replicates"). The manual procedure for Wilcoxon Rank Sum Test appears on page 4 ("Unpaired Replicates") of Wilcoxon, 1949. Graphs of live fuel moistures from: (1) different species; (2) different aspects; or (3) varying positions on the slope; and (4) before and after rain can be developed to display results.

Live Fuel Moisture Sampling Form

AGENCY	ADMIN. UNIT	CLIMATIC ZONE	SAMPLE AREA

COLLECTION RECORD

BY	DATE	TIME

MOISTURE DETERMINATION RECORD

BY	TIME IN	DATE	OVEN LOCATION

TIME OUT	DATE

NO.	CONDITION		SPECIES	POSITION ON THE SLOPE		CHECK CAN NUMBER ACTUALLY WEIGHED	A	B	C	D	E	F
							GROSS WEIGHT		CAN WEIGHT	DRY WEIGHT	WEIGHT LOSS	% MOISTURE
	OLD	NEW					WET	DRY				
1					→							
2					→							
3					→							
4					→							
5					→							
6					→							
7					→							
8					→							

PHYSICAL OBSERVATION

NEW GROWTH:
- STARTING ☐
- CONTINUING ☐
- COMPLETE ☐
- NONE ☐

FLOWERING:
- STARTING ☐
- PEAKING ☐
- DECLINING ☐
- DRYING ☐
- NONE ☐

FRUIT:
- PRESENTING ☐
- FALLEN ☐
- RIPE ☐
- NONE ☐

WEATHER

DRY BULB _____ ° RELATIVE HUMIDITY _____ %

WET BULB _____ ° % CLOUD COVER _____ %

$(B - C) = D$; $(A - B) = E$; $(E \div D) \times 100 = F$

REMARKS:

Figure 2. Form and tally for live fuel moisture samples

EQUIPMENT NEEDS

Chiricahua National Monument has the basic equipment needed to start a live fuel moisture monitoring program. The following is a list of equipment available on site:

- Oven (laboratory)
- Soil cans, two inch diameter, numbered on sides and lids
- Triple beam balance

Additional equipment recommended is listed below:

- Hot pad
- Cookie sheet (for transferring cans to balance when hot)
- Soil cans, four inch diameter (available through Ben Meadows, catalog no. 221610), numbered on lid and side with permanent felt tip pen or etched and weighed
- Oil for balance (sewing machine or 3-in-one)
- Calculation forms (attached)
- Map of sample areas
- Masking tape (one roll per hundred large soil cans)
- Large 3 to 10-millimeter thickness plastic bags to put samples in during collection
- Hand-held pruning shears to clip foliage
- Backpack

INFORMATION NEEDS

Chiricahua National Monument has information available, such as vegetation types; however, the weather data needs to be compiled. For example, total precipitation should be summarized by month so live fuel moistures can be related to rainfall for each season. Periods with both high temperatures and strong winds should be highlighted as this type of weather can cause dramatic changes in live fuel moistures. Ideally, temperature and rain events would be graphed on the same scale, and even the same graph as the live fuel moistures. An example of such a graph appears in Figure 3.

EXTRACTIVES

One important factor in determining fire behavior of various plants is the amount of ether extractives in the plant. The greater the proportion of extractives, the more flammable the material is. Each species fluctuates in its total combustibility because of changing amounts of ether extractives, oils, ash, or mineral content (Philpot and Mutch 1971). Ether extractives (as a percent of dry weight) can rise from 8.3% to 15% during the summer, making the foliage more easily ignited (Philpot 1969).

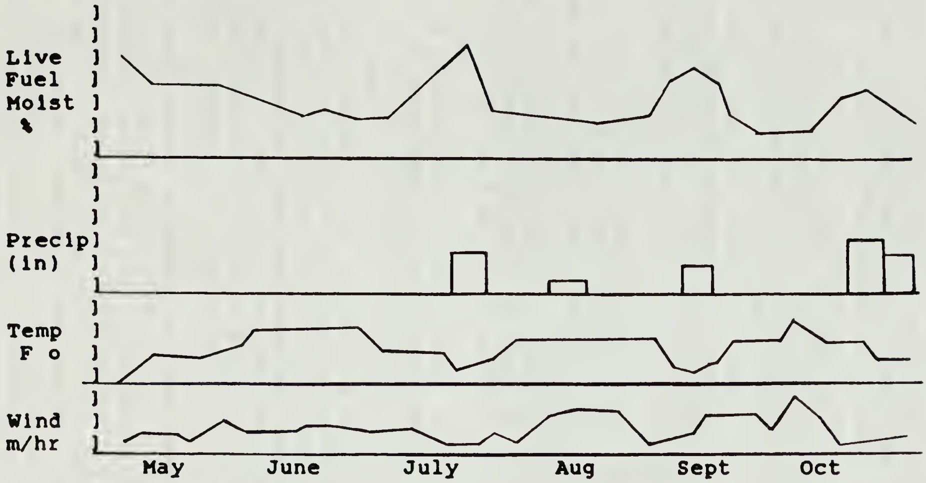

Figure 3. Example of compound graph showing live fuel moisture, precipitation, temperature and windspeed.

The energy content of ether extractives themselves is generally found to be 23,000 BTU/lb (vs. 8300 - 8900 BTU/lb in Douglas fir and ponderosa pine needles). Because ether extractives have a high vapor pressure, they are more available to burn. Oils dramatically affect fire behavior in plants by increasing the extent of crowning and generally increasing the ease of ignition and heat released when burning. Moisture in both living and dead fuels acts to dilute volatiles and exclude oxygen from the combustion zone immediately around the plant. Fluctuation in amounts of moisture and extractives (up to 100% change in a season) can vary independent of the other (Philpot and Mutch 1971).

In the early 1980's, a study of total extractives was performed for several species in Chiricahua National Monument. These showed that Arizona white oak had a ether extractive content of 8.43% and 8.70%, manzanita had 10.20% and 9.00%, Emory oak had 10.75%, and silverleaf oak had 7.74%. Unfortunately, foliar moisture content, date of sampling, or location were not recorded so we don't know if this data reflects peak levels or if the ether extractive is at the nadir (Bennett 1986). Regardless, an extractive content over 10% is quite high and indicates high crowing potential. Philpot and Mutch (1971) found levels of 8.5% to 10.5% ether extractive levels in ponderosa pine (*Pinus ponderosa*) and a level of 9.5% in Doulgas fir (*Psuedotsuga menziesii*) at its peak in August to September. As another example, the ether extractive content in chamise, a highly flammable species, varies from 8.5% in spring to 12% in fall (Philpot 1969).

USING LIVE FUEL MOISTURE DATA

Current fire behavior prediction models require that quantitative estimates of moisture content be developed where these live fuels are a significant fuel component. Results of moisture content studies are used for predicting difficulty of fire control and/or effects of actual or anticipated fires (Loomis et al. 1979). Most monitoring has focused on hard chaparral, (specifically manzanita and chamise) but the foliar moisture of all fuels in the complex, including conifers, is beginning to be monitored to determine crowning potential during a fire and to refine fire behavior estimates (Rice and Martin 1986). Additionally, live woody fuel moistures enter into the National Fire Danger Rating System (NFDRS) in the computation of the spread component, which in turn enters into the Burning Index. Calculated live fuel moistures rely on the 1,000 hour time lag fuel moisture function, adapted by four climate classes. The NFDRS provides the option for directly entering live fuel moistures, and bypassing that automatic calculation (Bradshaw et al. 1985).

Variation in live fuel moistures allow fire managers to use the proportion of species in the fuel complex to either dampen fire behavior or provide heat and increase fire vigor. For example, meadows can be used as a fireline in spring because of the high live fuel moisture content of grass. Likewise, species composition will affect the number of ignitions, given the same risk.

Plants break dormancy generally at different times in accord with species specific phenology and habitat. Their leap in moisture content (sometimes coupled with flowering) can be used in spring burning. For example, chamise is found to be dormant with low moisture contents until spring, and south aspects tend to break dormancy first. Burns on north facing slopes are conducted after the south facing slope has broken dormancy, but the north facing slope still has low live fuel moistures.

Control is enhanced at the ridgetop because of the difference in live fuel moistures. Live fuel moistures might be 200% on the south facing slope and 80% on the north facing slope.

Because the number of days since last rain is often used as a parameter in prescriptions for burning, the delay of plants' response and the sharp increase in live fuel moistures are important considerations. Thus, fires with prescriptions calling for two to five days since rain will have extremely variable results. By the time the samples are dry, moisture levels of plants in the field may have risen dramatically. Once the extent and lag time of any rise in moisture content after rain is established at Chiricahua, profiles of moisture contents can be developed. Fire behavior and its resulting effects can therefore be better estimated. This may make the difference between undesirable fire behavior and a successful burn.

Knowledge about live fuel moisture levels and trends for key species can be used to improve prescriptions in the use of fire. For example, control is enhanced when burns are conducted when tree foliage has a high live fuel moisture content. Burning when the live fuel moisture is high in oaks and when duff and litter moisture is low will still transfer heat to the base of the trees and to the roots, but chances of crowning are minimized. Flame lengths may be long, (ten to twenty feet) but flames will not carry as well in the upper levels of the fuel complex (i.e. high into the forest canopy). This may be an effective method when burning the stand the first time (with deep duff level and presence of ladder fuels) when a burn objective is to reduce stand density, i.e. cook and kill small stemmed trees. Subsequent prescribed fires might have a different prescription because the objective may be to kill the oak sprouts in stands where litter duff layers are shallow and where dead leaves and branches are still on trees. Here live fuel moistures should be low and dead fuel moistures moderate to high.

Also, live fuel moistures are very useful in determining when danger of resource and property damage is high. Similar information is used in California to determine manning levels (even vacation schedules), closure of forests, fire season, and justification for budget augmentations.

OTHER CONSIDERATIONS

The majority of work in live fuel moistures has been done in Mediterranean climates (Countryman 1974, Olson 1959, Philpot 1963, Rice and Martin 1985a). The trends of plants that are subjected to summer monsoon rains are not well known. Lindemuth and Davis (1970) studied the foliar moisture content of chaparral near Prescott, Arizona from September to April from 1964 to 1967. They collected live and dead material together so fuel moisture levels cannot be directly compared to results of this monitoring program. Their findings are possible indicators of what to expect of live fuel moisture monitoring in Chiricahua for that seasonal period. Surprisingly, minimum moisture contents for the eight month period occurred in mid-October to mid-November whereas most minimas reported in the literature occurred in September to mid-October. It is possible that lower levels occurred during the months (May to August) that were not sampled.

SUMMARY OF RESULTS FROM FIELD TRIP

The results of the live fuel moisture sampling done November 10 and 11, 1987 are summarized in Tables 1 and 2 and 3.

The National Fire Danger Rating System (a fire management decision tool) and BEHAVE (a fire behavior prediction system) use 120% moisture content as the point where live fuels either contribute to the fire's energy or retard its spread (Burgan 1979). From this initial sampling, white oak, silverleaf oak and silktassel have high enough moisture contents to dampen fire behavior; all other species would burn well. This is of note because November is not purportedly the month of lowest live fuel moistures in California or in the northwestern and northeastern portions of the United States. This result does, however, correspond with results of Lindemuth and Davis (1970). All species are likely to have lower live fuel moistures in periods of hotter, drier weather. With the weather patterns found at Chiricahua, the low fuel moisture period may be June for warm seasons plants and July to September for cool season plants.

Table 1. Moisture content by sample location.

Locale	Number of samples	Average moisture content (%)	Range of moisture content (%)
Top South	6	118	80 - 135
Visitor Ctr	7	103	82 - 121
Mid North	4	128	101 - 137
Mid South	6	120	108 - 151
Mid Base	1	84	84

Table 2. Live fuel moisture content by species.

	Average moisture content (%)	Range (%)	Number of samples
Arizona cypress	96	84 - 123	3
Toumey oak	98	80 - 115	2
Emory oak	106	98 - 113	2
Bear grass	110	101 - 117	4
Sumac	108	108	1
Pointed leaf manzanita	114	103 - 123	4
Arizona white oak	121	96 - 135	4
Silverleaf oak	129	121 - 137	3
Silktassel	151	151	1

New growth of manzanita was found to be lower in moisture than old growth. New growth was also found to be lower in moisture than old in the Berkeley/Oakland Hills at the end of the summer drought (mid-October), although most literature states new shrub growth is higher in moisture than old (Rice 1987).

Arizona cypress was found to be quite dry in two of the three samples and moderately moist on the third. The potential for crowning is great in this species when these dry branches are placed low in the crown.

The highest moisture content found was for the one sample of silktassel; the lowest was cypress. The range was 80 to 151% moisture content for all samples.

Oak species appear to have a distinct difference, especially Emory and Toumey vs. white and silverleaf. Emory and Toumey oak both had moisture contents around 100%, whereas white and silverleaf oak had moisture contents over 120%.

Table 3. Actual live fuel moistures recorded during initial sampling November, 1987.

			A	B	C	D	E	F
CAN #	SPECIES	LOCALE	GROSS WET	WEIGHT DRY	CAN WT	WT LOSS	SAMPLE WT	% MOIST
Samples from November 10								
014	Toumey oak	TS	48.95	44.31	38.50	4.64	5.81	80
705	Beargrass	TS	59.70	50.13	38.21	11.92	9.57	124
693	Manzanita	TS	54.50	47.20	38.65	8.55	7.30	117
699	White oak	TS	50.10	44.98	38.05	6.93	5.12	135
691	Cypress	TS	54.80	47.39	38.30	9.09	7.41	123
692	Silvr Lf	TS	47.95	43.83	38.50	5.33	4.12	129
698	Cypress	VC	51.50	44.30	38.40	5.90	7.20	82
708	Emory oak	VC	46.04	42.10	38.25	3.85	3.94	98
694	Silvr Lf	VC	47.32	43.33	38.50	4.83	3.99	121
695	Old Manz	VC	56.23	47.76	38.40	9.36	8.47	111
697	New Manz	VC	49.16	44.01	38.70	5.31	5.15	103
686	White oak	VC	46.78	42.57	38.50	4.07	4.21	97
700	Beargrass	VC	63.13	51.35	38.71	12.64	11.78	107
Samples from November 11								
687	White oak	MN	47.61	43.41	38.13	5.28	4.20	126
688	Silvr Lf	MN	49.89	45.06	38.42	6.64	4.83	137
701	Manzanita	MN	60.10	50.28	38.22	12.06	9.82	123
022	Beargrass	MN	70.30	54.73	39.00	15.73	15.57	101
013	Silktassel	MS	48.21	44.24	38.24	6.00	3.97	151
689	Beargrass	MS	65.22	52.24	38.22	14.02	12.98	108
222	Toumey oak	MS	47.14	42.90	38.02	4.88	4.24	115
703	Sumac	MS	48.48	43.50	38.11	5.39	4.98	108
706	Emory oak	MS	48.01	43.37	38.12	5.25	4.64	113
685	White oak	MS	47.89	43.63	38.38	5.25	4.26	124
707	Cypress	MB	47.30	42.40	38.30	4.10	4.90	84

Calculations: B - C = D; A - B = E; and D/E = F.

Legend of Sample Locations:

TS= Top of Rhyolite Canyon, Southern Aspect
VC= Visitor Center
MN= Mid Rhyolite Canyon, Northern Aspect
MS= Mid Rhyolite Canyon, Southern Aspect (at 9/86 burn site)
MB= Mid Rhyolite Canyon, Bottom

The samples taken at the canyon bottom (around the visitor center) were the driest of all collected (See Table 2). Additionally, the top and southern aspect were shown to be drier than the northern aspect. Samples taken midslope appeared to have the highest moisture contents of the sample locations. Possibly the plants situated at the top of the topography are subjected to more drying winds. Plants on the canyon bottom may be shielded from light precipitation which would be intercepted by plants in higher positions.

The range from 80 to 151% moisture content is not wide; samples were fairly uniform. The range was also mid-range in the scale of moisture contents. Shrubs of the Berkeley/Oakland Hills over the 1984 fire season were found to have range of 159 - 195% moisture content (Rice and Martin 1985a), whereas live fuel moistures of chaparral in southern California were lower, below 100% because the plants are dormant during the winter (Veverka 1985).

BIBLIOGRAPHY - RECOMMENDED LITERATURE

Anderson, E.B., T.E. Paysen and J.D. Cohen. 198_. Chamise as a Wildland Fuel -- Another Look. Western Journal of Applied Forestry. In press.

Andrews, P. 1986. BEHAVE: Fire behavior prediction and fuel modeling system - BURN subsystem. Part I. Intermountain For. and Rng. Expt. Sta., Ogden UT. Gen. Tech. Rep. INT-194. 60p.

Bennett, P. 1986. Untitled report about ether extractives in leaf samples taken in Chiricahua National Monument. Unpublished, in Western Archeological Center files in Tucson, AZ.

Blackmarr, W.H. and W.B. Flanner. 1968. Seasonal and diurnal variation in moisture content of six species of pocosin shrubs. Southeastern For. and Rng. Expt. Sta., Macon, GA. Res. Pap SE-33. 11p.

Bradshaw, L.S., J.S. Deeming, R.E. Burgan and J.D. Cohen. Compilers. 1983. The 1978 National Fire Danger Rating System: technical documentation. Intermountain For. and Rng. Expt. Sta., Ogden, UT. Gen. Tech Rep. INT-169. 44p.

Buck. C.C. 1938. Progress report on the measurement of volume of fuel on brush milacre plots on the Shasta Experimental Forest - 1937. USFS California For. and Rng. Expt. Sta., Berkeley, CA. 28pp.

Burgan, R.E. 1979. Estimating live fuel moisture for the 1978 National Fire Danger Rating System. Intermountain For. and Rng. Expt. Sta., Ogden, UT. Res. Pap. INT-226. 17p.

Burgan, R.E. and R.C. Rothermel. 1984. BEHAVE: Fire behavior prediction and fuel modeling system - FUEL subsystem. Intermountain For. and Rng. Expt. Sta., Ogden, UT. Gen. Tech. Rep. INT-167. 126p.

Cohen, J. and B. Bradshaw. 1986. Fire behavior modeling -- A decision tool. pp 1-5 In Proceedings of Prescribed Burning in the Midwest: State of Art. March 3-6, 1986. Steven's Point, WI.

Countryman, C.M. 1974. Moisture in living fuels affects fire behavior. Fire Management Notes. Spring, 1974.

Countryman, C.M. 1977. Fuel moisture and fire danger - some elementary concepts. Region 5 USDA Forest Service Aviation and Fire Mgt.; San Francisco, CA. 4p.

Countryman, C.M. and R.L. Bradshaw. 1980. Statewide system for sampling fuel moisture in chaparral. pp 83-87 *In* Sixth Conference on Fire and Forest Meteorology, April 22-24, 1980, Seattle, WA. Martin and others, Editors. Society of American Foresters. 304p.

Countryman, C.M. and W.A. Dean. 1979. Measuring moisture content in living chaparral: A field user's guide. Pacific Southwest For. and Rng. Expt. Sta., Berkeley, CA. Gen. Tech. Rep. PSW-36. 27p.

Deeming, J. 1985. Appendix E: Reflections on the development, application and future of the National Fire-Danger Rating System. pp 41-44 *In* The National Fire-Danger Rating System: technical documentation. Intermountain For. and Rng. Expt. Sta., Ogden, UT. Gen. Tech. Rep. INT-169. 44p.

Dell, J.D. and C.W. Philpot. 1965. Variations in the moisture content of several fuel size components of live and dead chamise. Pacific Southwest For. and Rng. Expt. Sta., Berkeley, CA. Res. Note PSW-83. 7p.

Finklin, A.I. 1983. Summarizing weather and climatic data - a guide for wildland managers. Intermountain For. and Rng. Expt. Sta., Ogden, UT. Gen. Tech. Rep. INT-148. 43p.

Green, L.R. 1974. A guide for collecting fuel samples for moisture determinations. Unpublished report to Region 5, USDA Forest Service, Aviation and Fire Mgt.; San Francisco, CA. 7p.

Lindemuth, A.W. and J.R. Davis. 1970. Foliar moisture content of chaparral in Arizona: accounting for its variation and relating it to prescribed fires. Rocky Mountain For. and Rng. Expt. Sta., Ft. Collins, CO. Res. Note RM-158. 8p.

Loomis, R.M., P.J. Roussopoulos, and R.W. Blank. 1979. Summer moisture contents of understory vegetation in northeastern Minnesota. North Central For. Expt. Sta., Lansing, MI. Res. Pap. NC-179. 7p.

Martin, R.E., H.E. Anderson, W.D. Boyer, J.H. Dieterich, S.N. Hirsch, V.J. Johnson, and W.H. McNab. 1978. Effects of fire on fuels - a state of knowledge review. USDA Forest Service Gen. Tech. Rep. WO-13. 64p.

Murray, W.B. 1982. Fire management plan, Chiricahua National Monument. Unpublished report to the National Park Service 51p.

Olsen, J.M. 1959. Progress report, effects of weather variables on green fuel moisture. Unpublished report. Pacific Southwest For. and Rng. Expt. Sta., Berkeley, CA.

Olson, C.M. 1978. Foliar moisture content and prescribed burning in Lava Beds National Monument. M.S. Thesis, University of Washington. 35p.

Philpot, C.W. 1963a. The moisture content of ponderosa pine and whiteleaf manzanita foliage in the Central Sierra Nevada. Pacific Southwest For. and Rng. Expt. Sta., Berkeley, CA. Res. Note PSW-39. 5p.

Philpot, C.W. 1963b. Vegetation moisture trends in the central Sierra Nevada. MS Thesis, University of California, Berkeley. 53p.

Philpot, C.W. 1965. Diurnal fluctuation in moisture content of ponderosa pine and whiteleaf manzanita leaves. Pacific Southwest For. and Rng. Expt. Sta., Berkeley, CA. Res. Note PSW-67. 7p.

Philpot, C.W. 1969. Seasonal changes in heat content and ether extractive content of chamise. Intermountain For. and Rng. Expt. Sta., Ogden, UT. Res. Pap. INT-61. 10p.

Philpot, C.W. 1977. Vegetation features as determinants of fire frequency and intensity. pg 12-17 *In* Symposium on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. Mooney et al, Editors. USDA For. Serv. Gen. Tech. Rep. WO-3. 498p.

Philpot C.W. and R.W. Mutch. 1971. The seasonal trends in moisture content, ether extractives and energy in ponderosa pine and Douglas fir needles. Intermountain For. and Rng. Expt. Sta., Ogden, UT. Res. Pap. INT-102. 21p.

Radtke, Klaus W.H. and R.H. Wakimoto. 1981. The effect of southern California's fire climate on vegetation and people. Ninth International Congress of Biometeorology, Sept. 23 - Oct. 1, 1981. Osnabruck - Stuttgart, Hohneheim, Germany.

Rice, C.L. 1987. Live fuel moisture, fuel bed characteristics, and fire behavior of vegetation in the Berkeley/Oakland Hills. Master's Thesis. University of California, Berkeley. 41p.

Rice, C.L. and R.E. Martin. 1985a. Live moistures of California North Coastal Scrub species. pp 263-269 *In* Eighth Proceedings of Forest and Fire Meteorology Conference, April 29 - May 2, 1985, Detroit, MI. Donaghue and Martin, Editors. Society of American Foresters. 304p.

Rice, C.L. and R.E. Martin. 1985b. The response of live fuel moistures to rain. pp 276-278 *In* Eighth Proceedings of Forest and Fire Meteorology Conference, April 29 - May 2, 1985, Detroit, MI. Donaghue and Martin, Editors. Society of American Foresters. 304p.

Rice, C.L. and R.E. Martin. 1986. Fuel moisture and fire behavior: an update. Unpublished report, USDA Forest Service Region 5, Aviation and Fire Management, San Francisco, CA. 6p.

Rothermel, R.C. 1983. How to predict the spread and intensity of forest and range fires. Intermoutain For. and Rng. Expt. Sta., Ogden, UT. Gen. Tech. Rep.-INT-143. June 1983. 161p.

Reifsnyder, W. 1961. Seasonal variation in the moisture content of the green leaves of mountain laurel. Forest Science 7(1):16-23.

Schroeder, M.J. and C.C. Buck. 1970. Fire Weather. USDA Agric. Handbook 360. 90p.

Tukey, J. 1949. The simplest signed tank tests. Memorandum Report 17. Statistical Research Group, Princeton University, Princeton, N.J. 8p.

Veverka, R. 1983. Unpublished data of live fuel moistures collected in Los Angeles County. Los Angeles County Fire Department.

Vigil, D. 1985. Fire ecology: management at Chiricahua National Monument. Unpublished report to the National Park Service. 54p.

Younger, V.B. 1973. Effects of waste-water irrigation on chaparral, pp 75-85. *In* Symposium on Living with the Chaparral. Rosenthal, editor. March 30-31, 1973, Riverside, CA. 224p.

Wilcoxon, F. 1949. Some rapid approximate statistical procedures. American Cyanamid Co., New York, N.Y. 2p.

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