Final Report to the Joint Fire Sciences Program

Project Title: Comparison of Live Fuel Moisture Sampling Methods for Big Sagebrush (*Artemisia tridentata spp.*) in Utah
Project ID: 05-2-1-70
Project Location: Bureau of Land Management, Salt Lake Field Office, Northwest Utah.
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Summary of Findings

- The variation among the means of all live fuel moisture collection procedures decreases as the fire season progresses. By August, there was very little difference in live fuel moistures when using the different collection procedures.

- When sample weights were taken in the field, samples were an average of 0.2g lighter than when the same samples were weighed approximately two hours later after transport back to the field office. This time difference translates to live fuel moisture values that are an average of 5 percentage points higher (a statistically significant difference) when using weights taken after storage and transport.

- Collecting a mix of old and new vegetation in each sample in proportion to what is found on the shrub is preferable to collecting separate samples of old and new vegetation then averaging the two to get fuel moisture values. Collecting two samples is time consuming and there is no evidence that this method provides different results than using one sample can and including both old and new vegetation.

- No definite conclusion could be made regarding the effects of including or excluding branchwood or from clipping or pulling samples. However, various combinations of collection techniques were very difficult to implement and resulted in long sampling times (sometimes up to 45 minutes per sample). These timeframes were considered when deciding which procedure to recommend as a standard procedure.

Recommendations

- When weighing samples, care should be taken to consistently weigh as soon as sample collection is done to avoid getting the false higher moisture values found when samples are stored for periods of time.

- Clipping a mix of old and new vegetation (including branchwood up to 1/8 inch) in proportion to what is found on the shrub is recommended as a standardized procedure. This procedure provides a streamlined method for collection as it is easy to collect, provides for a representative collection of vegetation, and results in relatively low average fuel moistures, as compared with other procedures.

- Update live fuel moistures after every collection period on the National Fuel Moisture Database located at: http://smoke-fire.us/lfm/NFMD/index.php . This updated database allows for easy comparison of live fuel moistures over time as well as between collection sites and management areas.

Deliverables

Proposed	***Delivered***	***Status***
Utah Fuel Moisture Website	This website grew from being specific to Utah to include the Eastern Great Basin in the spring of 2006. By the spring of 2007 it had grown to the national level with the implementation of the National Fuel Moisture Database. The Utah Live Fuel Moisture Guide and suggested collection protocol are included on this site. http://smoke-fire.us/lfm/NFMD/index.php	Done
Utah Fuel Moisture Collection Guide	An update on the 2003 version is in the process of being printed and includes findings from this research. The new version has been available on the National Fuel Moisture Database since May 2007.	In progress (June 2007)
M.S. Thesis	Submitted through Colorado State University in May of 2007 (attached)	Done
JFSP Progress Reports/Final Report		Done
Publication	Research findings and recommendations submitted to management publication such as Fire Management Today	In Progress (July 2007)
Publication	Research findings submitted for publication in a peer-reviewed journal	Planned for October 2007
Poster Presentation	Tall Timbers 23rd Fire Ecology Conference: Fire in Grassland and Shrubland Ecosystems. October 2005	Done
Poster Presentation	3rd International Fire Ecology and Management Conference in San Diego. November 2006	Done
Poster Presentation	IAWF 2nd Fuels and Fire Behavior Conference. March 2007	Done
Field Training for LFM Collection	Offered to all field personnel involved in LFM collection in Utah in April 2007	Done

Conclusions

Six procedures for measuring live fuel moisture in big sagebrush (*Artemisia tridentata*) were compared in terms of advantages, disadvantages, and differences in calculated values. Live fuel moistures computed from the various procedures differed significantly early in the collection season (i.e., May), but means converged as the season progressed. Details of the analysis and findings are included in Brown (2007, attached). Manuscripts (2) are in progress to disseminate study results to practitioners and other scientists. Reprints will be provided to the Joint Fire Science Program upon publication.

Literature Cited

Brown, A. 2007. Live fuel moisture sampling methods for Wyoming big sagebrush in Utah. M.S. thesis, Colorado State University.

Attachment

THESIS

LIVE FUEL MOISTURE SAMPLING METHODS FOR WYOMING BIG SAGEBRUSH IN UTAH

Submitted by

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Department of Forest, Rangeland, and Watershed Stewardship

In partial fulfillment of the requirements

for the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Summer 2007

COLORADO STATE UNIVERSITY

March 27, 2007

WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY ANNIE BROWN ENTITLED LIVE FUEL MOISTURE SAMPLING METHODS FOR WYOMING BIG SAGEBRUSH IN UTAH BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

Committee on Graduate Work

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Advisor

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Department Head

ABSTRACT OF THESIS

LIVE FUEL MOISTURE SAMPLING METHODS FOR WYOMING BIG SAGEBRUSH IN UTAH

Live fuel moisture has been identified by managers, as well as scientific literature, as a key driver of fire behavior in fuel types dominated by live vegetation (i.e., shrublands). Recognizing this, fire managers in Utah use live fuel moisture values in making strategic decisions in fire suppression and prescribed burning. Current methods to quantify live fuel moisture through field sampling have been based on publications developed for fuel types that are very different than those found in the Great Basin. The overall objectives of this study are:

- To help understand how variations in data collection affect live fuel moisture values in Wyoming big sagebrush (*Artemisia tridentata* ssp. *Wyomingensis)*
- Increase comparability between sampling areas throughout the Great Basin
- Recommend standardized techniques for use by managers to allow for comparisons across land management boundaries

Live fuel moisture sample weighing and collecting methods suggested in the literature, as well as those most commonly utilized by field technicians, were compared. The resultant live fuel moisture values were analyzed to determine the influence of each procedure on live fuel moisture values.

Results suggest that waiting to weigh samples may affect final live fuel moisture values. When sample weights were taken in the field, samples were an average of 0.2g lighter than when the same samples were weighed approximately two hours later after transport back to the field office. This time difference translates to live fuel moisture values that are an average of 5 percentage points higher when using weights taken after storage and transport.

The variation between the means of all procedures decreases as the sampling timeframe progresses. Collecting a mix of old and new vegetation in proportion to what is found on the shrub is preferable to collecting separate samples of old and new vegetation for each sample and averaging the two to get fuel moisture values. No solid conclusions could be made regarding the effects of including versus excluding branchwood from samples, or from clipping versus pulling samples.

Because there were no solid conclusions to be made regarding specific collection techniques, Procedure 1 (clipped, mixed vegetation, including branchwood) is recommended for use as a standardized procedure, as it allows for methodical collection of vegetation and provides the most accurate representation of the phenological stage of the shrub. In addition, this procedure is an easy and quick method of collection. Weighing samples in the field, immediately after collection, is recommended as part of a standardized collection procedure as well.

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Introduction

Live fuel moisture content is a key influence on fire behavior in fuel types dominated by living vegetation, such as Great Basin shrublands (Countryman and Dean 1979; Loomis et al. 1979; Norum and Miller 1984; Brown et al. 1989; Cohen et al. 1995). However, the magnitude of this influence is unknown due to an apparent threshold for fire spread in live fuels. At some point in the flaming front live fuels stop acting as a heat sink and become a heat source, thereby contributing to fire spread and intensity (Brown et al. 1989; Burgan 1979; Cohen et al. 1995).

Fuels can be described in terms of living and dead vegetation. Fuel moisture content is defined as the amount of water in a fuel, expressed as a percent of the oven dry weight of that fuel. Dead fuel moisture is the moisture content of dead grasses and forbs, small to large diameter dead woody vegetation and surface litter. Dead fuel moisture is determined by external environmental conditions. In contrast, this study focuses specifically on live fuel moisture, which is the moisture content of living twigs and leaves of shrubs as well as live grasses and forbs. Live fuel moisture is governed by seasonality and phenological state of the plant.

Unlike dead fuels, the moisture content of live fuels plays a marginal role in fire ignition but is critical in fire propagation because the amount of water is directly related to the rate of fire spread (Chuvieco et al. 2004). In the case of prescribed fire planning and wildfire suppression, fire spread in live fuels may be a “go/no-go phenomenon under certain conditions” (Weise et al. 1998).

Live fuel moisture for sagebrush is typically assessed for fire management purposes using two methods: the National Fire Danger Rating System (NFDRS) model for estimating woody fuel moisture (Cohen and Deeming 1985) and field collection. In the first method, climatological data are collected through Remote Automated Weather Stations (RAWS) and calculated by the NFDRS to produce woody fuel moisture values. The NFDRS inputs for woody fuel moisture include: 1000-hr time lag fuel moisture (based on longer-term weather calculations), green-up date, and climate class (Cohen and Deeming 1985). This calculated value is used to calculate fire danger components such as the Energy Release Component and the Burning Index. The NFDRS-calculated values for live fuel moisture do not always correlate with samples collected in the field (Schlobohm and Brain 2002). The NFDRS values are generally lower than field collected live fuel moisture values, thereby under-estimating actual plant moisture (Loomis et al. 1979; personal observation). Field sampling techniques cannot be adequately replaced by models (Chuvieco et al. 1999), further strengthening the need for standardized collection procedures.

In 1995, a task force was commissioned to report to the Interagency Management Review Team (IMRT) of the South Canyon Fire on the utility of live fuel moisture data (Cohen et al. 1995). The task force found that "currently available, operational fire behavior prediction methods in the U.S. are not generally reliable for predicting fire behavior in fuels dominated by living vegetation" (Cohen et al. 1995, p 3). The task force report recommended a live fuel moisture monitoring program to gather data throughout the West, with eventual plans to archive and use these data to develop correlations with fire behavior in specific vegetation types. Standardizing methods is the first step allowing future comparisons of, and studies relating to, live fuel moisture and fire behavior (Norum and Miller, 1984). However, simply employing standardized methods isn't enough; it is important to know how the sampling techniques chosen affect the end result.

Field technicians utilize a variety of sampling techniques to collect live fuel moisture. However, without scientific testing, fire managers are unsure of which specific techniques to recommend as standards. A statistical comparison of several techniques and methods will provide the information needed to determine the most appropriate protocols for collecting live fuel moisture in the field. This will provide data that can be compared across jurisdictions and that support correlations between live fuel moisture, fire behavior and fire effects. In addition, more information will improve decision making and aid in fire behavior modeling for fire suppression, prescribed fire and wildland fire use.

The overall objective of this study is to help understand how variations in data collection affect live fuel moisture values in Wyoming big sagebrush (*Artemisia tridentata* ssp*. Wyomingensis)* and to recommend standardized techniques. This study involves collection of samples using several commonly employed methods with varying sampling and weighing techniques to test differences in live fuel moisture results.

Most public land managers across the West are monitoring live fuel moisture in the field, utilizing adaptations of the techniques described in two publications on live fuel moisture sampling methods written for southern California chaparral (Countryman and Dean 1979) and Alaska fuel types (Norum and Miller 1984). For example, the Bureau of Land Management (BLM) Utah State office has developed a fuel moisture sampling guide, with standardized sampling procedures, that is based primarily on recommendations for Alaskan vegetation. A variety of methods are currently utilized throughout Utah and the Great Basin. No studies compare methods for live fuel moisture sampling in Utah or Great Basin fuel types. No standardized techniques have been decided upon; yet live fuel moisture values are compared across land management boundaries that often use different methods for collection.

Approximately 20% of BLM land in Utah is covered by some species of sagebrush (Utah GAP Analysis 1995). No research has focused on the sampling methods proposed for big sagebrush fuel types that dominate Utah and the Great Basin. Several species of sagebrush are found in Utah; however, big sagebrush species, including Wyoming big sagebrush (*Artemisia tridentata* ssp. w*yomingensis*), basin big sagebrush (*Artemisia tridentata* ssp. *tridentata*), and mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) are the most common and widespread (West et al. 1978). For this study, the sample site is located at a lower elevation exclusive to Wyoming big sagebrush (*Artemisia tridentata* ssp. w*yomingensis*) (A. Winward, personal communication, October 13, 2006).

Numerous general studies focus on the relationship between shrub ecology and fire (see Frandsen 1983, Rosentreter 2004, Sapsis and Kauffman 1991, and West et al. 1978). In addition, a handful of conflicting studies assess the effects of topography on live fuel moisture (see Kalish 1992, Ogle 1989, and Sharif and West 1967). Despite this research, information regarding the effects of sampling and weighing procedures on final live fuel moisture values is sparse.

Two key publications produced in the last 25 years recommend procedures for live fuel moisture collection. Countryman and Dean (1979) published a field user's manual on measuring live fuel moisture in California's chaparral. This manual and the sampling procedures within are based on phenological variations specific to California chaparral. Likewise, Norum and Miller (1984) included sampling procedures based on physiological properties specific to vegetation in

Alaska. In addition to these sources, Cohen et al. (1995) suggest several methods for measuring live fuel moisture in various fuel types. However, Cohen's methods are based on Norum and Miller's work in Alaska. Due to the lack of available information, most fuel moisture monitoring programs rely on some combination of these methods, even though fuel types can be markedly different in terms of phenology and seasonal drying patterns.

Live fuel moisture sampling involves several steps where errors or inconsistencies may occur. Questions relating to sample collection and sample weighing are addressed in this study. Sample collection and weighing procedures compared were determined by reviewing available literature (Countryman and Dean 1979; Norum and Miller 1984) and agency-produced live fuel moisture sampling guides (Cohen et al. 1995; Pollet 2003; Great Basin Live Fuel Moisture Program 1984).

Some sampling procedures are recommended in the available guides or are more widely accepted as compared to others. Clipping vegetation was found to be more common than stripping or pulling the vegetation. In addition, clipping is assumed to be the least variable method for live fuel moisture collection, though the effects of clipping samples were not tested (Cohen et al. 1995). Other common methods of collection include: incorporating new and old vegetation in each sample rather than separating old and new vegetation, and including branchwood to .32 cm rather than excluding small branchwood. Previously published protocols, such as Countryman and Dean (1979), suggest vegetation up to .32 cm is acceptable to include in samples. The effects of weighing samples immediately at the time of collection in the field versus weighing samples in the ”lab” are unclear.

It is clear that live fuel moisture plays an important role in fire management − yet there are currently no accurate ways to determine live fuel moisture besides actual field collection. This review of available literature and agency guidelines shows the lack of testing behind currently utilized live fuel moisture collection procedures. This review of previous work also provides a rationale for the research questions posed and methods used in this thesis. Before describing my study in greater detail, I provide overviews to sagebrush physiology and the study area.

Sagebrush Physiology

Big sagebrush is considered an evergreen broadleaf shrub (see Figure 1). Live fuel moisture in big sagebrush is most highly correlated with the physiology of the shrub and therefore the season of observation (Sapsis and Kauffman 1991; Kalish 1992; Sharif and West 1967). Big sagebrush found in northern Utah maximize photosynthesis from April to June and therefore exhibit the highest live fuel moisture values during these months (DePuit and Caldwell 1973). Later in the summer, as leaves age, temperatures increase and available moisture decreases, photosynthesis drops markedly as the shrub exhibits stomatal control in an effort to diminish water loss (Caldwell 1979). DePuit and Caldwell (1975) found that big sagebrush *(Artemisia tridentata* spp. *tridentata)* have low photosynthetic rates compared with other species in sagebrush steppe communities.

Sagebrush produces two types of leaves throughout the year: ephemeral and perennial (see Figure 2). When new growth begins in spring, early ephemeral leaves are formed from small leaf buds at the stem apex (Caldwell 1979, Miller and Schultz 1987). Early ephemerals start to shed at the onset of drought, which is generally sometime in July in the study area (Miller and Schultz 1987). Caldwell (1979) suggests that the generous number of large early ephemeral leaves produced during the spring growing season greatly contributes to the success of the species by allowing it to maximize the photosynthetic process during the most profitable time of year.

In addition to these large *early* season ephemeral leaves, as the growing season progresses, smaller *later* season ephemeral leaves will start growth in conjunction with many perennial leaves on new reproductive stem growth (DePuit and Caldwell 1973). Perennial leaves are the smallest leaves to grow on the shrub. The later season ephemerals will be shed sometime in the fall of the same season they are developed. The perennial leaves persist through the winter and usually last on the shrub about a year, shedding at the same time as the early ephemerals the following year (Miller and Schultz 1987). The presence of perennial leaves allow for the shrub to start utilizing nutrients and water early in the growing season, as opposed to deciduous shrubs that start over with new leaf growth every year (Miller and Schultz 1987).

Though there is reduced vegetative growth in late summer, flower buds are developing at this time and are fully developed by fall (DePuit and Caldwell 1973). Fruit develops and sheds quickly afterward in the fall as the shrub enters dormancy when winter arrives (DePuit and Caldwell 1973, West and Wein 1971).

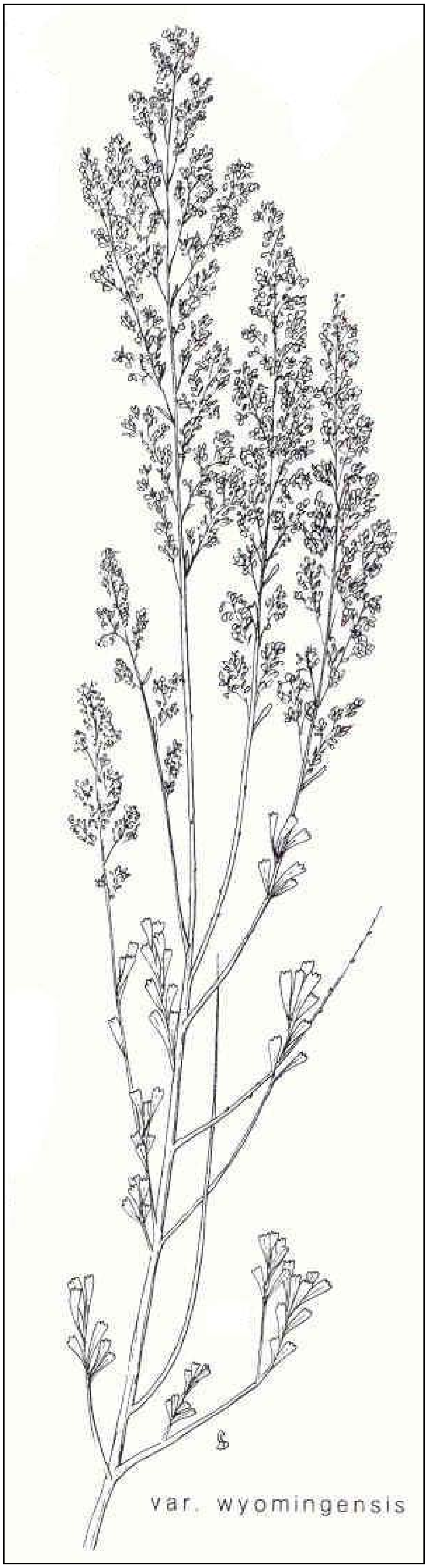


Figure 1. Drawing depicting growth form for *Artemisia tridentata* spp. *Wyomingensis.* (From Cronquist 1994).

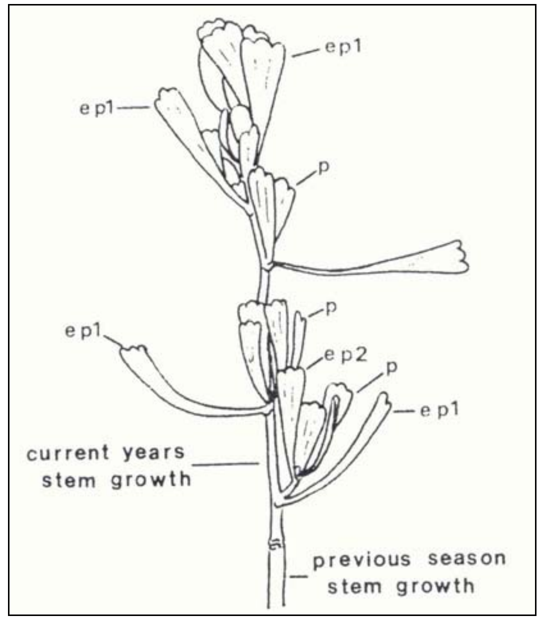


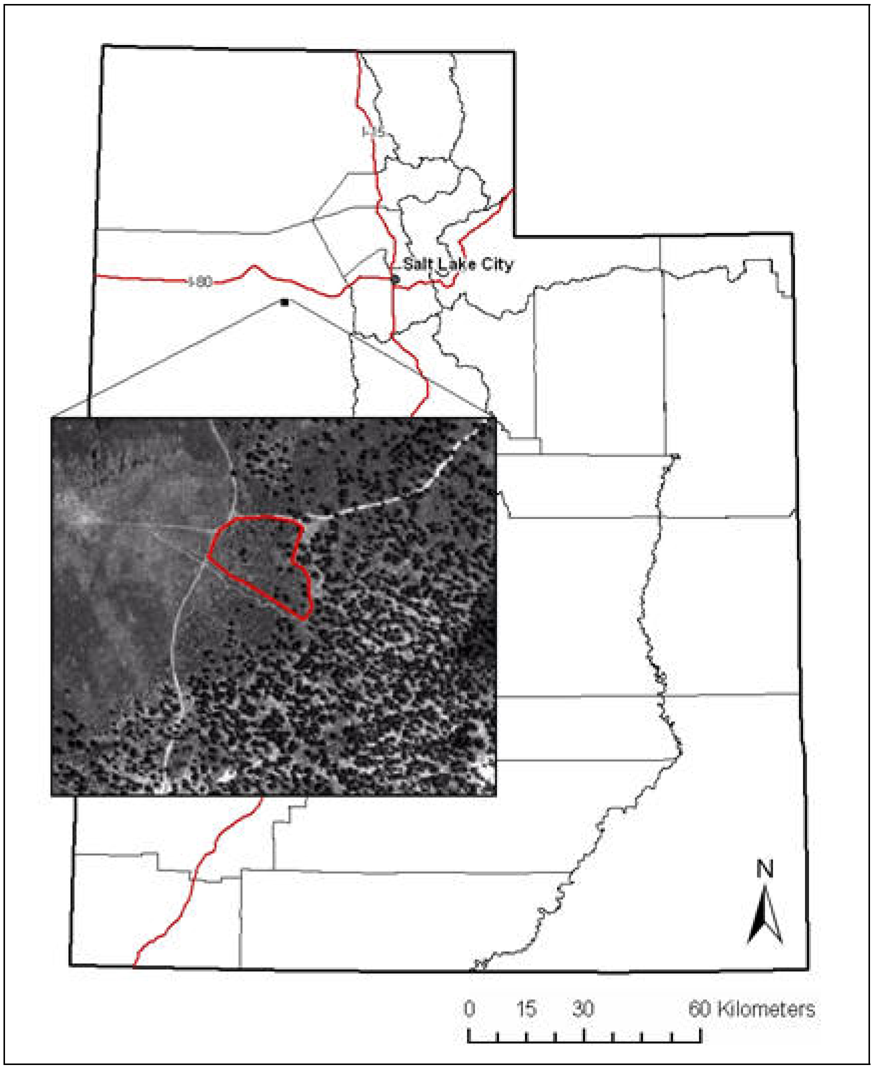
Figure 2. Drawing depicting current year's growth for *Artemisia tridentata* spp. *Wyomingensis,* near the end of development. Drawing indicates early ephemeral leaves (ep1), later-developing ephemerals (ep2), and perennial leaves that will last over the winter (p). (From Miller and Schultz 1987)

Study Area

Samples were collected at one site (N 40° 37.68' W 112° 40.32') in the BLM's Salt Lake Field Office (SLFO) management area. The site is located in northwestern Utah, approximately 96 km west of Salt Lake City (see Figure 3). The elevation of the site is 1454 m and has an approximately 0% slope, though the aspect is slightly west-facing as it abuts the Stansbury mountains to the east. The site is located approximately 3 km from any paved roads or bodies of water that might influence fuel moistures. However, secondary dirt roads surround half of the site. No shrubs were sampled if located within 3 m of the road.

This site was chosen because it is co-located with a current live fuel moisture collection site used by the SLFO. This facilitated the comparison of historical data with observations from this study and ensured the site remained relatively undisturbed during the sampling period (i.e., not subject to fuels treatments or grazing). Samples were collected within one 0.8 ha plot. This site provided sufficient shrub abundance to sample throughout the season. Sample area aspect and elevation were kept constant throughout the study plot to ensure site homogeneity and to reduce varying aspect and elevation that may affect results.

Figure 3. Map indicating general location of study area. Aerial photo inset shows study site (not to scale).



The study site is dominated by Wyoming big sagebrush (*Artemisia tridentata* spp.*wyomingensis)* and cheatgrass (*Bromus tectorum*) with some encroachment by Utah juniper (*Juniperus osteosperma)* (R. Hardy, personal communication, January 10, 2007; A. Winward, personal communication, October 13, 2006). In addition, Sandburg bluegrass (*Poa sandbergii)*, blue bunch wheatgrass (*Pseudoroegneria spicata*), crested wheatgrass (*Agropyron cristatum*), and low rabbitbrush *(Chrysothamnus viscidiflorusare)* are present. This site is characterized by Fire Behavior Fuel Model 6 (Anderson 1982) as well as an NFDRS Fuel Model G (Schlobohm and Brain, 2002). Additionally, this site is described by Scott and Burgan (2005) as a dynamic Fuel Model GS2 (122). Fuel loading is approximately 6 metric tons/ha based on Southwest Sagebrush (SWSB) 04 in the Stereo Photo Series for Quantifying Natural Fuels (Ottmar et al. 2000). Vegetation is typical of surrounding areas. Soils are upland gravelly loam and derived from limestone, quartzite and sandstone (NRCS 2006). The physiographic features of the site indicate it is located on a previous terrace from Lake Bonneville.

The Cedar Mountain RAWS is the closest weather station to the study site, located approximately 16 km to the southwest. The original location of this RAWS was approximately 1.6 km west of the study site, where it was positioned for 10 years, from 1990-2000. This RAWS was relocated to its current position in 2000 to reduce weather influences from the Great Salt Lake. Due to its close proximity to the site, climatological data over this 10 year period are summarized below (see Table 1).

Table 1. Climatological data from Cedar Mountain RAWS during a 10 year period from 1990-2000. During this time the RAWS was approximately 1.6 km to the west of the study site.

	Mean Temp. (°C)	**Mean RH (%)**	**Precipitation (cm)**
May	16	56.6	.99
June	21	44.1	.15
July	26	32.1	.92
August	26	32.0	.35

Study Description

Six collection procedures were identified for comparison (see Table 2.) Collection procedures were limited to those most commonly employed so all samples could be collected during the same collection period (on the same day, between 1100 and 1600 hours). While three variables were included for each procedure, two were held constant for each comparison. This design allowed for replicated comparisons of actual field techniques.

Table 2. Matrix describing live fuel moisture collection procedures compared in this study. Procedures are subsequently referred to by number throughout this thesis.

Procedure	Clipped vs. Pulled	Old, New or Mixed	Branchwood or No Branchwood
1	Clipped	Mixed	Branchwood
2	Pulled	Mixed	Branchwood
3	Clipped	Old	Branchwood
4	Clipped	New	Branchwood
5	Clipped	Mixed	No Branchwood
6	Pulled	Mixed	No Branchwood

Six research questions were identified to test the seasonal variability for collection procedures, the difference between sample weighing procedures, and the difference between live fuel moistures using each of the six collection procedures. Hypotheses are stated as research questions below.

Question 1: Do some procedures produce more variable results over the course of the sampling timeframe than other procedures?

Standard deviations were compared for each procedure over the course of the sampling timeframe. Standard deviations were also compared by procedure, for each month of collection. The rationale is that if one procedure produces highly variable results, this procedure may not be appropriate for use as a collection method. This variability could be due to a variety of causes, including the way individuals take the samples, type of material included in the samples, or due to complicated or confusing sampling techniques.

Question 2: Does the variability among procedures change as the season progresses?

Each procedure was assessed by month of collection to determine the variability of live fuel moisture among procedures throughout the sampling timeframe. This relationship is important in determining the precision of live fuel moisture estimates derived from each collection procedure as well as for the assumptions underlying statistical tests employed.

Question 3: Do live fuel moisture values differ when weighing in the field versus weighing in the lab?

Live fuel moisture calculations require weighing field samples. Various fuel moisture collection programs adhere to different protocols for weighing samples. This question compares every sample and does not consider procedure. Some protocols suggest weighing directly after collection and some don't specify when to weigh. This question aims to determine whether live fuel moisture values differ between samples weighed in the field versus samples weighed approximately two hours later in the lab. Inferences about the time that elapses between collection and weighing may be possible.

Question 4: Do live fuel moisture values differ when old and new vegetation are sampled separately versus mixed together (in proportion to what is found on the shrub) in the same sample?

This question compares Procedures 1, 3 and 4, as well as an average combining Procedures 3 and 4 (referred to in the results as Procedure 3/4). Vegetation up to .32 cm in diameter was clipped (not pulled) for these procedures.

Publications that reference live fuel moisture sampling vary in their recommendation on whether to mix old and new foliage, or to separate the old and new foliage. Inexperienced field technicians experience difficulty in determining old versus new foliage on sagebrush, and biases may be introduced when personnel mistakenly separate old and new foliage.

New vegetation was characterized by large ephemeral leaves and green, pliable stems up to .32 cm during the May and June collection periods. New vegetation during August would be the second round of ephemeral leaves in addition to green, pliable stems up to .32 cm. Due to the constraints of collecting all samples during one collection period, Procedure 4 was not utilized during August as it proved extremely time consuming in earlier sampling periods. Old vegetation was characterized as previous year's perennial growth as well as current, more lignified stems that still supported leaf growth, up to .32 cm. (see Table 3).

Question 5: Do live fuel moisture values differ when including small diameter branchwood (up to .32 cm) versus only including foliage?

This question compares Procedure 1 versus 5 and Procedure 2 versus 6. Procedures 1 and 5 involve clipping a mix of new and old vegetation and comparing moisture estimates with and without branchwood. Procedures 2 and 6 involve pulling a mix of new and old vegetation and comparing moisture estimates with and without branchwood.

Fuel moisture collection protocols vary regarding the inclusion of small branchwood or only foliage. Branchwood was characterized as anything green or lignified that supported leaf growth, up to .32 cm. (see Table 3).

Question 6: Do live fuel moisture values differ when clipping versus pulling vegetation?

This question compares Procedure 1 versus 2 and Procedure 5 versus 6. Procedures 1 and 2 involve collection of a mix of new and old vegetation including branchwood and compares clipping versus pulling. Procedures 5 and 6 involve collection of a mix of new and old vegetation excluding branchwood and compares clipping versus pulling (see Table 3).

Some inconsistencies may be introduced by clipping versus stripping/pulling, thus increasing the variability of samples. Certain parts of sagebrush vegetation are easier to pull at different times of the year. If personnel are instructed to hand pull vegetation they might be inclined to take the most easily removed parts, rather than sampling all available foliage, thus introducing bias into the final result.

Table 3. Summary of sample collection research questions involving comparisons between procedures. Procedures and techniques tested are described for each question. Research questions 1 and 2 examined the variability of all procedures. Question 3 focused on the time delay in weighing samples in the field versus in the lab.

Research Question	**Procedures Tested**	**Techniques Compared**	**Techniques Held Constant**
(4) Do final live fuel moisture values differ when old and new vegetation is sampled separately versus mixed together in the same sample?	1, 3, and 4	Including only old, new or mixed vegetation in samples	Including branchwood, clipping vegetation
(5) Do final live fuel moisture values differ when including branchwood versus only including foliage?	1 versus 5	Including versus excluding branchwood	Clipping, mixed vegetation
	2 versus 6		Pulling, mixed vegetation
(6) Do final live fuel moisture values differ when clipping versus pulling vegetation?	1 versus 2	Clipping versus pulling vegetation	Mixed vegetation, including branchwood
	5 versus 6		Mixed vegetation, excluding branchwood

Methods

Samples were collected in the summer of 2005. Sample size pre-tests were conducted using historical data collected by the SLFO as well as from preliminary samples collected in early May, 2005. Sample size was set to eight per procedure for every collection period. However, during the collection period fewer than eight samples were collected for some procedures due to the lengthy collection time (see Table 4). Only foliage and branchwood up to .32 cm were collected. No flowers, flower buds, fruit or dead twigs were included.

Table 4. Number of samples collected for each procedure during each month of collection. Empty cells indicate no samples were collected for that month.

	Number of Samples Collected		
Procedure	**May**	**June**	**August**
1	8	8	8
2	8	8	6
3	6	7	3
4	8	8	0
5	4	8	0
6	6	8	8

Through observation and analysis of historical data collected by the SLFO, it was determined that seasonal variability could be captured by collecting samples during three critical periods: during the green-up period (toward the end of May);

when shrubs were losing moisture (end of June); and when shrubs were beginning to cure and lose ephemeral leaves (middle/end of August). Therefore, samples were collected during these time periods, referred to by their month of collection. The entire summer is referred to as the sampling timeframe. Collection took place only if no precipitation had occurred in the area during the previous 24-hour period. This was determined by checking the hourly precipitation readings from the Cedar Mountain RAWS posted on the MesoWest website maintained by the University of Utah (http://www.met.utah.edu). Because live fuel moisture varies significantly throughout the day, with afternoon values being lowest (Sharif and West 1967), all samples were collected between 1100 and 1600 each sampling day. To ensure a constant oven temperature of 105° C for drying the samples, a thermometer was placed in the convection drying oven.

Sample Collection

Using a permanent marker, small (85 gram capacity) aluminum sample cans were numbered 1 through 8 for each of the six procedures, for a total of 48 cans. Each can was labeled (top and bottom) with the can number and tare weight, recorded to the nearest 0.1 gram. Six sets of cans, numbered 1 through 8, were divided into large plastic bags which were labeled with the corresponding procedure. These bags were placed in a collection container to facilitate easy transport.

Four people collected samples for this study. Each person was trained on specific collection methods for each procedure. No attempt was made to isolate error contribution by each collector. Upon arrival at the study site, cans were removed from their bags as samples were collected. Collection criteria and definitions are listed below.

- Samples from several shrubs were included in each sample can.
- For procedures with clipped vegetation, small pruning shears were used to remove vegetation (foliage and/or branchwood). No part of the clipped sample was hand pulled.
- Pulled vegetation involved hand-pulling all vegetation to be included in the sample. No pruning shears were used in these samples.
- Mixed vegetation is defined as a mix of old and new vegetation collected in each sample can. New and old vegetation were collected in proportion to what was visually observed on the shrub.
- Old vegetation was identified as the previous year's perennial growth as well as more lignified branchwood (<.32cm) that still supported leaf growth. In August, old vegetation may have included some early ephemeral leaves that had not dropped.
- New vegetation was identified as large ephemeral leaves and green pliable branchwood during the May and June collection periods. New vegetation was harder to identify and collect during the August collection period due to location (farther down in the shrub) and smaller

size than the more obvious early ephemeral leaves. New vegetation in August included late ephemeral leaves and new perennial leaves, in addition to green, pliable branchwood.

- Branchwood was limited to .32 cm in diameter and was measured using a transparent ruler.
- When branchwood was excluded from the sample, only leaves were included in the sample.

Each procedure involved a combination of collection techniques (see Table 2). When all samples were collected, they were each weighed before leaving the collection site (with the lid on the can) using the same scale used previously to measure the tare weight. Care was taken to weigh samples in the vehicle so wind did not affect the reading on the scale. All samples were then placed in their corresponding bags, put back in the collection container and transported to the drying oven. Total transport took approximately two hours. Samples were then re-weighed (with lids on) using the same scale used for earlier measurements and weights recorded next to previously recorded field weights. Lids were removed and placed under cans in the oven. Samples were dried at 105° C for 24 hours. Samples were removed from the oven and lids replaced to prevent moisture absorption. Lids were removed for weighing of all samples.

Two fuel moisture values were calculated, one each using the field weight and the lab weight. Moisture values were calculated according to the standard equation in Norum and Miller (1984) and Countryman and Dean (1979):

$$\text{Percent live fuel moisture} = \frac{\text{(Wet Weight – Dry Weight)}}{\text{Dry Weight}} \text{x100}$$

Statistical Analysis

Using Levine's test (Ott and Longnecker 2001), it was determined that variances in live fuel moisture values for procedure as well as for month were significantly different. Therefore, the transformation $ý = e^{1/y}$ was used to stabilize the variance. The R statistical program (R Development Core Team 2006) was used for the transformation.

A paired *t*-test was used to test the difference between field and lab weights as well as the difference between live fuel moisture calculated with field weights versus lab weights.

All data were pooled and a blocked Analysis of Variance (ANOVA) model (Conover 1999) was used to determine if procedures were significant in estimating live fuel moisture values. Procedure was specified as the random factor and month as the blocked factor as the effect of procedure was being tested for. The blocked model was used because of the obvious downward monthly trend in live fuel moisture values. Tukey's test of means (Ott and Longnecker 2001) was used to determine the difference of means between *all* procedures. No specific pairwise comparisons were made from this test. The blocked ANOVA just described will be referred to as ANOVA #1. The equation for the blocked ANOVA is:

$$\text{Live fuel moisture value}_{i(j)} = \text{mean} + \alpha\ \text{procedure}_i + \beta\ \text{month}_{(j)} + \varepsilon_{ij}$$

A blocked ANOVA was again used to better determine the effects of specific techniques within certain procedures on live fuel moisture values (i.e., pulling versus clipping vegetation). Tukey's test of means was used to make *pairwise* comparisons between procedures, as set forth in the hypothesis questions (see Table 3). This blocked ANOVA, to test comparisons between specific procedures, will be referred to as ANOVA #2.

Though it was expected that live fuel moisture values would decrease for every procedure as the sampling timeframe progressed, the actual effects of procedure on live fuel moisture values during each month of collection was not known. One-way ANOVAs with Tukey's test were used to make comparisons between specific procedures, as set forth in the hypothesis questions (see Table 3), by month, to determine if procedures had differing effects on live fuel moisture values during each month of collection. The equation for the one-way ANOVA is:

$$\text{Weight}_i = \text{mean} + \alpha\ \text{procedure}_i + \varepsilon_i$$

All procedure comparisons were performed using transformed live fuel moisture values calculated with field weights, as opposed to lab weights. All analysis was performed using Minitab (Ryan 1972), except for the blocked ANOVA and corresponding Tukey comparisons which were performed using SAS (Goodnight 1976). The confidence level was set to 95% for all analysis.

Results and Discussion

When all the data were pooled and month was blocked (ANOVA #1), the procedure affected the response variable, live fuel moisture ($p \leq .05$). The six procedures appeared to have a different relationship than when individual pairwise comparisons were made for procedures using ANOVA #2. Some procedures were not significantly different when looking at ANOVA #1, but were different when looking at the pairwise comparisons made in ANOVA #2. This was expected due to smaller sample sizes, which increased sensitivity to variance when making these pairwise comparisons.

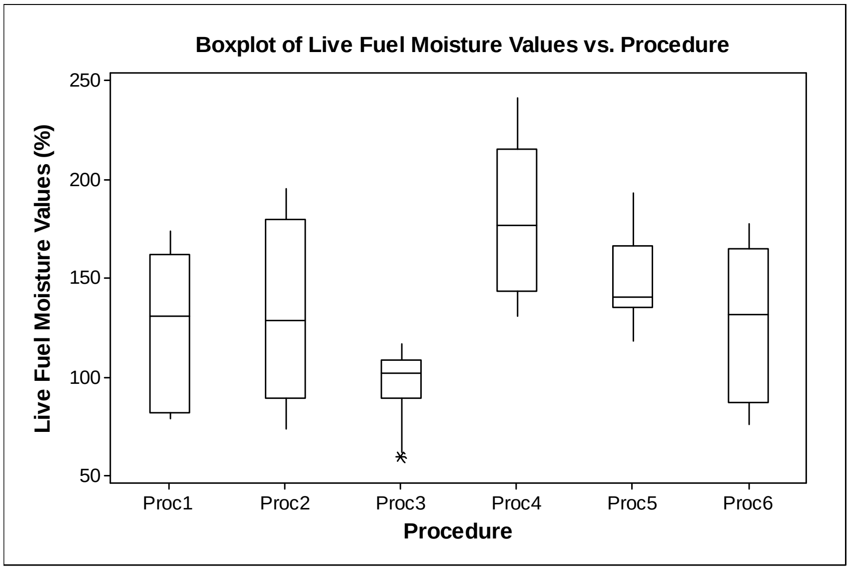
Tukey's test indicated that overall, live fuel moisture estimates produced using Procedures 3, 4 and 5 were each significantly different than those produced using every other procedure ($p<.05$). Procedures 1, 2, and 6 resulted in live fuel moisture values with similar means.

The significant difference between Procedures 3 and 4, as well as their difference from every other procedure, is not surprising as Procedures 3 and 4 respectively involved collection of only old or only new vegetation. Procedures 3 and 4 produced markedly lower and higher (respectively) live fuel moisture values in relation to other procedures, throughout most of the sampling timeframe.

The difference between Procedure 5 and Procedures 1, 2 and 6 is more difficult to characterize. This difference in means may be due to the lack of data for Procedure 5 (no samples were collected in August) or may be due to the act of collection using Procedure 5 and is discussed below.

Figure 4 displays the median live fuel moisture values for each procedure (month is not differentiated) as well as the general variance for each procedure. The outlier for Procedure 3 was identified with a normality plot and a scatterplot in Minitab. This small value may be due to the specific sample that was collected. A review of the recorded field and lab weights for this sample indicate it weighed approximately 1 g less than other samples collected using Procedure 3 during the August collection period. The field and lab weights were similar so it is unlikely this outlier is due to a recording error on the data sheets. The reduced weight itself does not translate to a lower fuel moisture value as there may have been a smaller amount of vegetation included in the can, as opposed to other samples using the same procedure. The vegetation included in the sample may have been made up of a higher percentage of extremely dry vegetation as compared to other samples. Therefore, the extreme low value is likely due to human error in collection.

Figure 4. Pooled live fuel moisture estimates for each procedure. Overall, Procedures 3, 4 and 5 produce significantly different live fuel moisture values than every other procedure. Procedures 1, 2, and 6 produce live fuel moisture values that are not significantly different. * indicates an outlier that is likely due to human error.



Question 1: Do some procedures produce more variable results over the course of the sampling timeframe than other procedures?

Variances changed the most with Procedure 1 over the course of the sampling timeframe ($p=0.044$, Levine's test). Procedure 6 results in live fuel moisture values with the least variable results over the course of the sampling timeframe. After comparing the means and standard deviations of all procedures, it was evident that while Procedure 1 showed the most variability over the course of the sampling timeframe, Procedure 1 was not the most variable procedure when comparing procedures within each month of collection (see Table 5). The monthly comparison is the more important comparison for this research question as it indicates the variability attributable to the techniques within each procedure.

When comparing the data this way, Procedure 5 shows the highest variability during the May collection period. Procedure 3 shows the highest variability during June and Procedures 2 and 3 have the highest variability during the August collection period. Despite these numbers, I am hesitant to make claims that one procedure is more variable than another due to the small sample sizes involved in the comparison. For example, Procedure 5 appears the most variable during May, but only four samples were collected during this time. Further, the true population variance cannot be estimated unbiasedly by the methods employed in this study.

Table 5. Mean live fuel moisture (%) for each procedure by month. Std. deviations parenthesized. Empty cells indicate no samples were taken during that time.

	May	***June***	***August***
Procedure 1	*165 (7)*	*131 (5)*	*81 (1)*
Procedure 2	*183 (6)*	*128 (4)*	*81 (6)*
Procedure 3	*107 (8)*	*100 (8)*	*64 (6)*
Procedure 4	*215 (13)*	*143 (6)*	
Procedure 5	*172 (15)*	*135 (7)*	
Procedure 6	*172 (5)*	*132 (4)*	*83 (5)*

Question 2: Does the variability among procedures change as the season progresses?

As shown with Figures 5 and 6, the variation among the means of all procedures decreases as the sampling timeframe progresses. Except for Procedures 1 and 3, no comparisons among procedures produce significantly different results in June or August. While some procedures produce differing results in May, by

June procedures 1, 2, 4, 5, and 6 start to produce similar live fuel moistures. Live fuel moistures are even more similar in August. The convergence of means as the sampling timeframe progresses is most likely due to the lack of readily available vegetation and branchwood that was previously found in May. The convergence of means may also be due to the increasing likelihood that all samples contain a higher ratio of older and drier vegetation (this may include last year's perennial leaves, late season ephemerals and new perennials) as the sampling timeframe progresses.

The differences between the means are important to characterize so fire managers will understand the effects of their procedures on live fuel moisture values at different times of the year. In May, procedures can produce very different results from each other; however, by August, the effects of individual procedures are mitigated by the overall decrease in available vegetation and the drop in live fuel moisture throughout all parts of the shrub.

Figure 5. Average trend in live fuel moisture values for each procedure. Mean fuel moisture values appear to converge as the sampling timeframe progresses. Variation among procedures decreases later in the season.

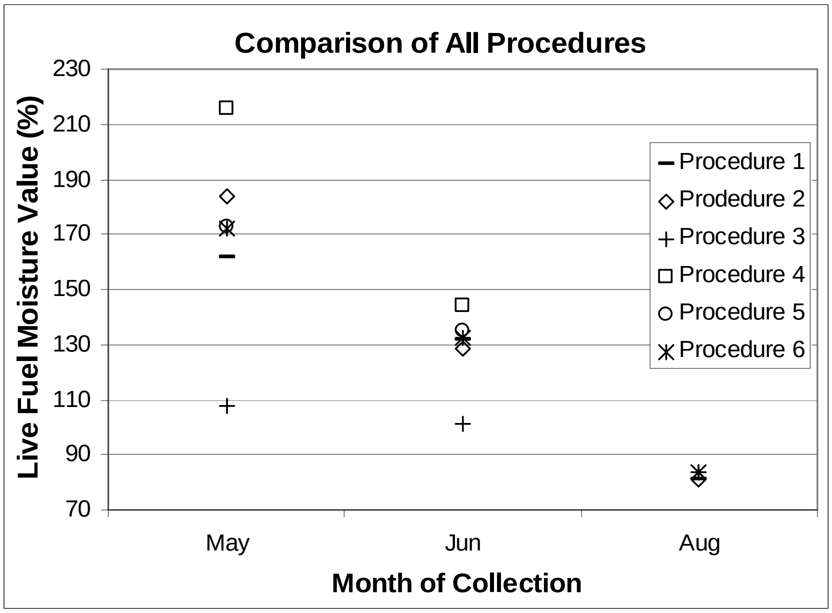


Figure 6A. Series of three boxplots depicting the decreasing variability in live fuel moisture estimates between procedures during May, June and August.

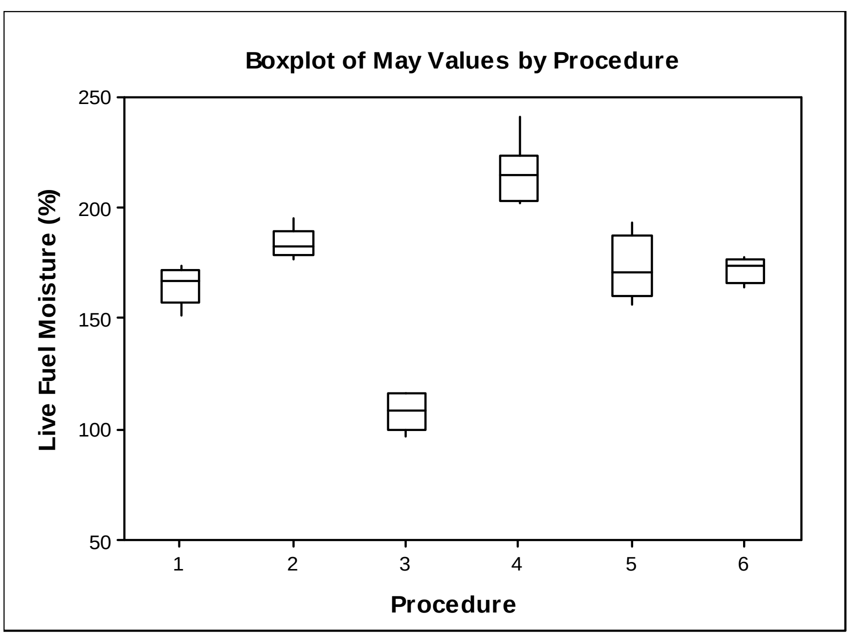


Figure 6B. Series of three boxplots depicting the decreasing variability in live fuel moisture estimates between procedures during May, June and August.

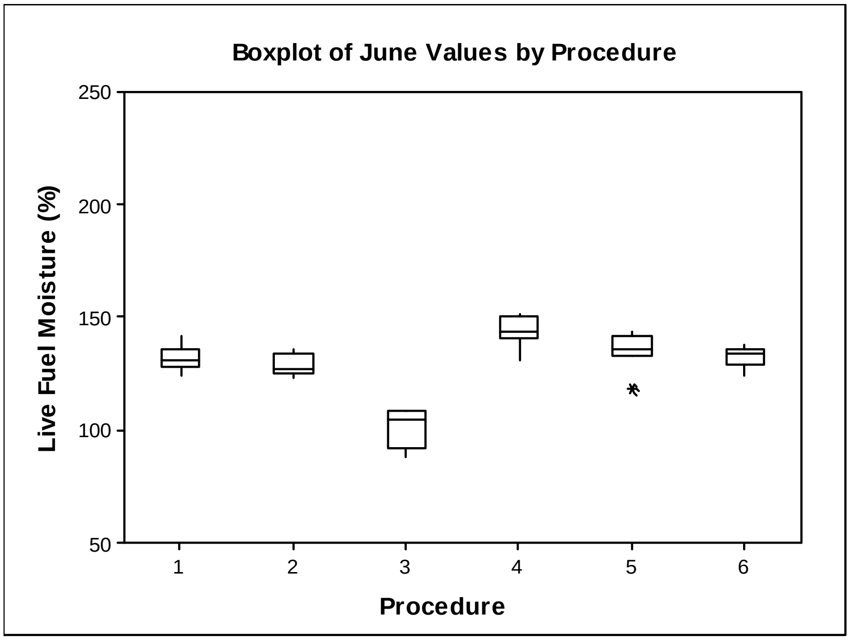
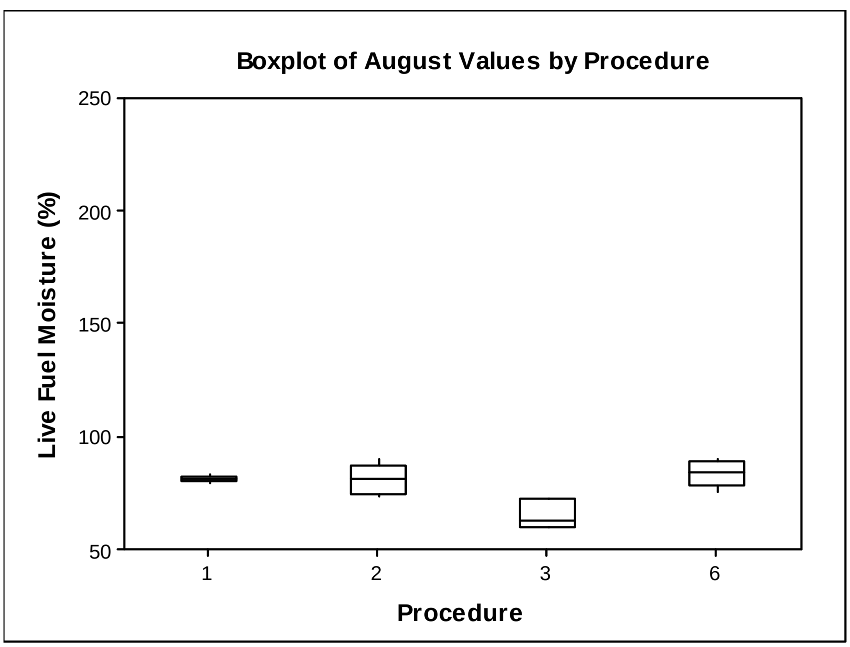


Figure 6C. Series of three boxplots depicting the decreasing variability in live fuel moisture estimates between procedures during May, June and August.



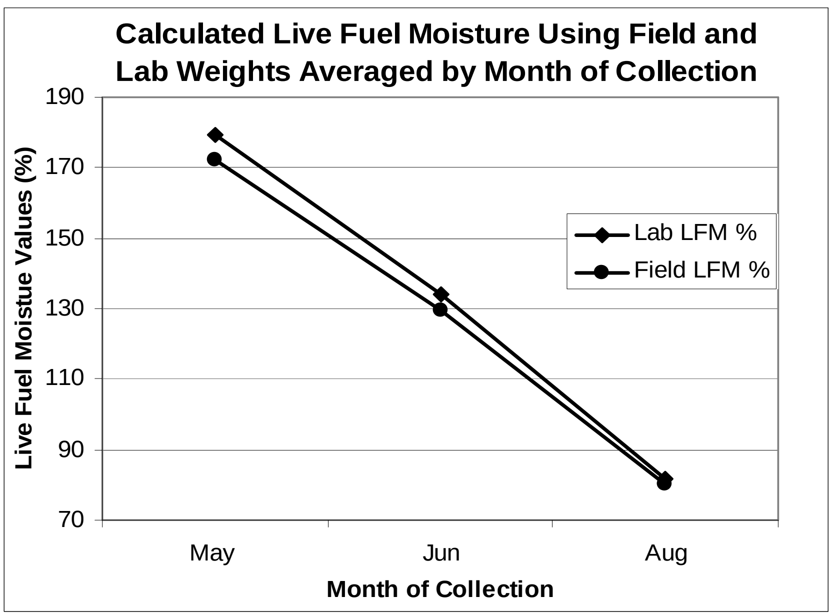
Question 3: Do final live fuel moisture values differ when weighing in the field versus weighing in the lab?

When pooling data for every sample collected and analyzing both field and lab weights, regardless of procedure or month of collection, there was a significant difference in final live fuel moisture values when using weights taken in the field versus using weights taken back in the lab (paired *t*-test, p=0.000). Samples weighed in the lab were an average of 0.2 grams heavier than those same samples weighed in the field. Average live fuel moisture values were 5 percentage points higher when weights taken in the lab were used in the live fuel moisture calculation (see Figure 7).

The larger weights observed when samples were stored for approximately two hours before weighing again (in the lab) may be due to trapping vapor produced from the sample within the can during this time period. After being weighed in the field, samples were put back in their respective bags and placed back in the collection container for transport back to the lab. Samples may have experienced an increase in temperature during this time. However, normal field conditions do not always allow for keeping samples at the ambient temperature, especially when collection sites are far away from the drying oven location.

The effects of waiting to dry samples are not known. For this study, it appeared that the longer the delay in weighing samples, the higher the live fuel moisture value for that sample. Differences occurred in final live fuel moisture values when sample weighing locations varied between field and lab, possibly due to wait time.

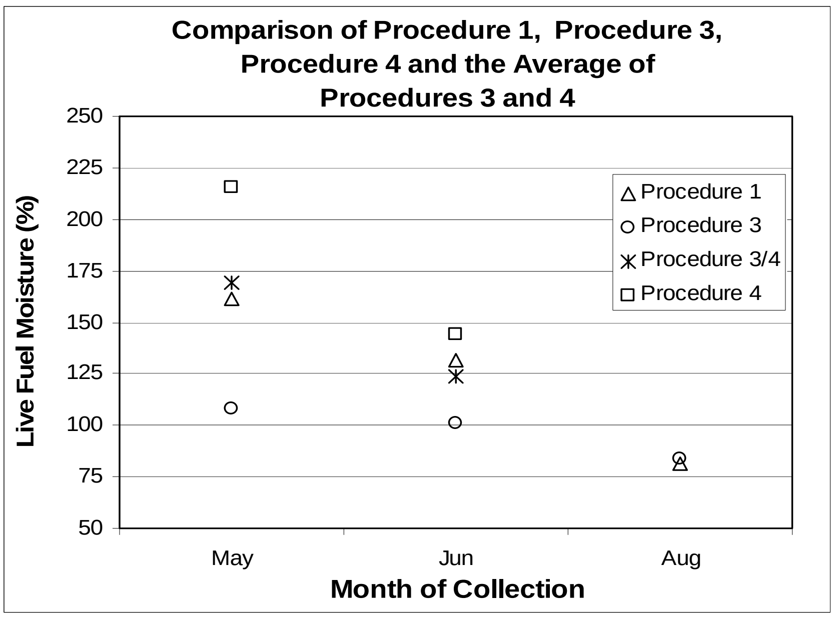
Figure 7. Using lab weights to calculate live fuel moisture produced values that averaged 5 percentage points higher than values calculated using field weights.



Question 4: Do final live fuel moisture values differ when old and new vegetation are sampled separately versus mixed together in the same sample?

This question compares Procedures 1 *(mixed* vegetation*),* 3 *(old* vegetation*),* and 4 *(new* vegetation*).* An average of Procedures 3 and 4 is included in Figure 8 and is indicated as Procedure 3/4. This averaged procedure was not statistically analyzed, but included graphically for comparison as some collection programs take separate old and new samples then use the average live fuel moisture value as a final value.

Figure 8. Comparison of mixed, old and new vegetation. Procedure 4 (new vegetation) was not used as a collection method during August. Procedures 1 (mixed vegetation) and 4 converge and are not significantly different during the June collection period. Procedure 3 (old vegetation) is lower than every other procedure. Procedure 3/4 (average of old and new vegetation) does not appear to produce live fuel moisture values very different from those produced using Procedure 1.



When Procedures 1, 3 and 4 were compared using ANOVA #2, samples taken using Procedure 1 resulted in live fuel moisture values significantly different from those values produced using Procedures 3 and 4. Procedure 1 had a higher mean than Procedure 3 and a lower mean than Procedure 4. Differences between Procedures 3 and 4 were significant as well, with Procedure 4 having a higher mean. This corresponds with the results from ANOVA #1 (see Table 6).

However, results differed when Procedures 1, 3 and 4 were compared using a one-way ANOVA to make pairwise comparisons for each month of collection. All three procedures were significantly different during the May collection period. However, in June, Procedure 1 was significantly different from Procedure 3 but not from Procedure 4. The difference between Procedures 3 and 4 was still significant in June. Only Procedures 1 and 3 were tested in August and results indicate that both procedures were significantly different during this collection period (see Table 6).

Table 6. Comparison of tests for Procedures 1 (mixed), 3 (old) and 4 (new vegetation). Live fuel moistures produced using these procedures yielded significantly different means, except during June. Procedures are described in table 2. Only procedures specific to this research question were reviewed in reference to ANOVA #1, though all procedures were included in that test.

Month and Test	**Procedures Compared**	**Procedures That Are Significantly Different**	**P-Value**
May (one-way ANOVA)	1, 3, 4	1, 3, 4	<.05
June (one-way ANOVA)	1, 3, 4	1, 3 & 3, 4	<.05
August (one-way ANOVA)	1, 3	1, 3	<.05
All months (ANOVA #2)	1, 3, 4	1, 3, 4	<.05
All months (ANOVA #1)	1, 2, 3, 4, 5, 6	1, 3, 4	<.05

Figure 8 indicates that samples collected with Procedure 3 result in live fuel moisture estimates significantly lower than other procedures throughout the sampling timeframe.

These estimates are not surprising as Procedure 3 involved only older foliage. Live fuel moisture is often correlated with growth stage of the shrub and the more mature the foliage, the higher the decrease in fuel moisture (Baeza et al. 2002).

The opposite also appears to be true with live fuel moisture values from Procedure 4 remaining higher than Procedure 3 during the two periods sampled (May and June). While Procedure 4 results in higher live fuel moisture values than Procedure 1 during the beginning of the sampling timeframe, as the timeframe progresses the two procedures start to produce similar live fuel moisture values. I believe if samples were taken using Procedure 4 during the August sampling period, results would show a continuing convergence of live fuel moisture values from Procedures 1 and 4.

This comparison leads to the conclusion that live fuel moisture values vary significantly when separating old and new vegetation into different samples. When looking at the “new” Procedure 3/4 included in Figure 8, it appears that Procedure 3/4 does not produce very different results from Procedure 1, which involves including a mixture of old and new vegetation within each sample. However, collection using Procedure 1 involves less time for collection and analysis since only half the samples have to be collected (as opposed to collecting samples using both Procedure 3 and 4 then averaging the live fuel moisture values).

In addition, Procedure 1 involves collecting old and new vegetation in proportion to what is on the shrub, which presents a more representative example of shrub morphology than a complete sample with old vegetation and another complete sample with new vegetation.

Question 5: Do final live fuel moisture values differ when including small diameter branchwood (up to .32 cm) versus just foliage?

This question compares Procedure 1 *(clipped, mixed* vegetation*, including branchwood)* versus Procedure 5 *(clipped, mixed* vegetation*, no branchwood)* and Procedure 2 *(pulled, mixed* vegetation*, including branchwood)* versus Procedure 6 *(pulled, mixed* vegetation*, excluding branchwood)*.

When Procedures 1 and 5 were compared using ANOVA #2, samples collected using Procedure 1 resulted in live fuel moisture values that were not significantly different from those values produced using Procedure 5 (see Table 7). This result is not consistent with findings from ANOVA #1 in which the means are significantly different. The similar means of the procedures indicates that *including* or *excluding* branchwood in samples may not have an effect on live fuel moisture values.

Procedures 1 and 5 were compared using a one-way ANOVA to make pairwise comparisons for each month of collection. Live fuel moisture values produced from each procedure were not significantly different in May or June. For ANOVA #1, data from all procedures were pooled. Procedure 5 has fewer data points because no data were collected for August. This may have led to the findings of overall significance, whereas analyzing month by month as well as making pairwise comparisons indicated no significant difference.

Table 7. Comparison of tests for Procedures 1 and 5 (with and without branchwood, respectively). Procedures are described in table 2. Procedures are not significantly different when pairwise comparisons are made, or when month of collection is taken into consideration. Only procedures specific to this research question were reviewed in reference to ANOVA #1, though all procedures were included in that test.

Month and Test	**Procedures Compared**	**Significantly Different**	**P-Value**
May (one-way ANOVA)	1, 5	No	0.29
June (one-way ANOVA)	1, 5	No	0.38
All Months (ANOVA #2)	1, 5	No	>.05
All Months (ANOVA #1)	1, 2, 3, 4, 5, 6	Yes	<.05

In comparing Procedures 2 and 6 using ANOVA #2, samples from Procedure 2 resulted in live fuel moisture values that were significantly different from those values using Procedure 6. Procedure 2 had a slightly higher mean. The higher mean of Procedure 2 may indicate that *including* branchwood from samples results in a higher live fuel moisture value. The results from ANOVA #2 are different from the results of ANOVA #1 in which no significant differences were found (see Table 8).

When Procedures 2 and 6 were compared using a one-way ANOVA to make pairwise comparisons for each month of collection, live fuel moisture values produced from each procedure were significantly different in May but not in June or August. Procedures 2 and 6 may be resulting in different live fuel moisture values in May due to the abundance and inclusion of green branchwood in samples collected with Procedure 2. As the sampling timeframe progressed, the branchwood to be included became more lignified and lost moisture with the rest of the shrub. Therefore results from Procedures 2 and 6 became increasingly similar.

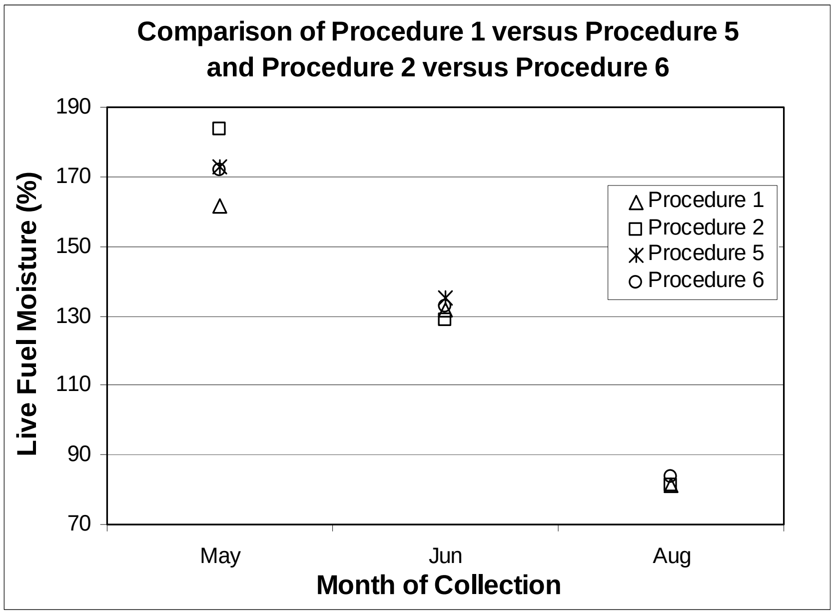
Table 8. Comparison of tests for Procedures 2 and 6 (with and without branchwood, respectively). Procedures are described in Table 2. Procedures were significantly different when pairwise comparisons are made. The Procedures are different in May but not in June or August. Only procedures specific to this research question were reviewed in reference to ANOVA #1, though all procedures were included in that test.

Month	Procedures Compared	Significantly Different	P-Value
May (one-way ANOVA)	2, 6	Yes	0.00
June (one-way ANOVA)	2, 6	No	0.11
August (one-way ANOVA)	2, 6	No	0.42
All Months (ANOVA #2)	2, 6	Yes	<.05
All Months/ (ANOVA #1)	1, 2, 3, 4, 5, 6	No	>.05

In comparing Procedures 1 and 5 as well as Procedures 2 and 6, it is not obvious from the statistical comparison that including or excluding branchwood from samples has an effect on live fuel moisture. When Procedures 1 and 5 are compared there is no statistical difference in their means though there is a possibility that when including Procedure 5 in the comparison, the sample size was too small to detect significance. When Procedures 2 and 6 are compared, there is a difference in their means, indicating *including* branchwood leads to higher live fuel moisture values.

The extent of this effect is not known. A decision to standardize collection procedures regarding the *inclusion/exclusion* of branchwood in samples is acceptable as long as it is strictly adhered to. Insufficient evidence exists to support a firm recommendation to include or exclude branchwood in samples (see Figure 9).

Figure 9. Comparison of samples including and excluding branchwood. Procedure 5 (no branchwood) was not used as a collection method during August. When pairwise comparisons were made, the means for Procedures 1 (with branchwood) and 5 (no branchwood) were similar while Procedures 2 (with branchwood) and 6 (no branchwood) had significantly different means. When pairwise comparisons were made for each month there were no significant differences (except for Procedures 2 and 6 in May). It is difficult to characterize the effects of including/excluding branchwood in samples.



Question 6: Do final live fuel moisture values differ when clipping versus pulling vegetation?

This question compares Procedure 1 *(clipped, mixed* vegetation*, including branchwood)* versus Procedure 2 *(pulled, mixed* vegetation*, including branchwood)* and Procedure 5 *(clipped, mixed* vegetation*, no branchwood)* versus Procedure 6 *(pulled, mixed* vegetation*, no branchwood).* When Procedures 1 and 2 were compared using ANOVA #2, samples from Procedure 1 resulted in live fuel moisture values that were significantly different from those values produced using Procedure 2. Procedure 2 had a slightly higher mean, indicating pulling vegetation may lead to higher live fuel moisture values. The results from ANOVA #2 are different from the results of ANOVA #1. Again, this discrepancy may be due to the much larger sample size used for ANOVA #1 (see Table 9).

Procedures 1 and 2 were compared using a one-way ANOVA to make pairwise comparisons for each month of collection. Live fuel moisture values produced from each procedure were significantly different in May but not in June or August. Procedures 1 and 2 may be resulting in different live fuel moisture values in May due to the higher percentage of large ephemeral leaves likely included in samples collected with Procedure 2.

Table 9. Comparison of tests for Procedures 1 (clipped) and 2 (pulled). Procedures are described in Table 2. Procedures were significantly different when pairwise comparisons were made, but were not different when month of collection was taken into consideration, except during May. Only procedures specific to this research question were reviewed in reference to ANOVA #1, though all procedures were included in that test.

Month	Procedures Compared	Significantly Different	P-Value
May (one-way ANOVA)	1, 2	Yes	0.00
June (one-way ANOVA)	1, 2	No	0.23
August (one-way ANOVA)	1, 2	No	0.87
All Months (ANOVA #2)	1, 2	Yes	<.05
All Months (ANOVA #1)	1, 2, 3, 4, 5, 6	No	>.05

When Procedures 5 and 6 were compared using ANOVA #2, samples taken using Procedure 5 resulted in live fuel moisture values that were not significantly different from values produced using Procedure 6, indicating there is no difference in live fuel moistures when clipping or pulling vegetation. The results from ANOVA #2 are different from the results of ANOVA #1 which shows a significant difference between the means of the procedures.

When Procedures 5 and 6 were compared using a one-way ANOVA to make pairwise comparisons for each month of collection, live fuel moisture values from each procedure were not different in May or June. There was no comparison made between Procedures 5 and 6 during the August collection period as no samples using Procedure 5 were taken during this time (see Table 10).

Table 10. Comparison of tests for Procedures 5 (clipped) and 6 (pulled). Procedures are described in Table 2. Procedures were not significantly different when pairwise comparisons were made or when month of collection was taken into consideration. Only procedures specific to this research question were reviewed in reference to ANOVA #1, though all procedures were included in that test.

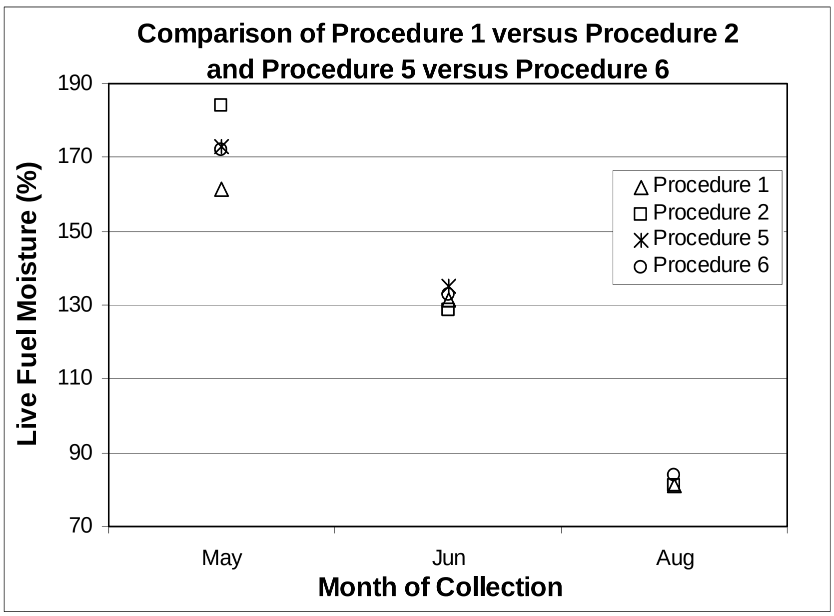
Month	**Procedures Compared**	**Significantly Different**	**P-Value**
May (one-way ANOVA)	5, 6	No	0.99
June (one-way ANOVA)	5, 6	No	0.50
All Months (ANOVA #2)	5, 6	No	>.05
All Months (ANOVA #1)	1, 2, 3, 4, 5, 6	Yes	<.05

A firm conclusion regarding the effects of clipping versus pulling vegetation is difficult to determine just using statistics. In comparing Procedures 1 and 2, pulling vegetation led to higher live fuel moistures. In comparing Procedures 5 and 6 there was no difference between the procedures, though, again, these findings of insignificance may be due to the small sample size used when including Procedure 5 (see Figure 10).

However, after collecting samples in the field and watching technicians pull and clip vegetation, pulling vegetation seems like it would lead to higher fuel moisture values. When vegetation is pulled, technicians may collect the easiest-to-remove parts and disregard how much branchwood is being collected (if the procedure includes branchwood) or whether the same proportion of old versus new vegetation is collected as is present on the shrub. Most of the vegetation that is pulled is likely to be toward the outside and top of the shrub, where plant material is easiest to reach and in immediate view. In contrast, when clipping vegetation, the technicians seem to focus in on collecting from all parts of the shrub, including old and new plant parts in proportion to actual growth on the shrub.

Though field technicians were trained on the techniques required of each procedure in this study, human nature and bias can play a critical role in field collection. When field technicians from various programs collect live fuel moistures, the difference in samples when clipped or pulled may be larger due to lack of proper training or the fact that the same people don't collect samples during each sampling period. Based on the trend of resultant live fuel moistures between procedures (the average fuel moistures become similar as the sampling timeframe progresses), the differences between clipping and pulling vegetation may be negligible as shrubs lose moisture toward the height of wildfire season.

Figure 10. Comparison of means for live fuel moisture samples produced using Procedures 1 (clipped), 2 (pulled), 5 (clipped) and 6 (pulled). When pairwise comparisons were made, Procedures 1 and 2 were significantly different while Procedures 5 and 6 were not different.



Additional considerations

The above discussion does not consider the comparative ease with which samples are collected using the various procedures. The level of difficulty and speed of collection in using each procedure influences decisions to use one procedure over another.

Procedure 1 was simple to implement and, relative to other procedures, it took very little time to collect a full sample as the field technician was able to quickly clip vegetation and could include branchwood in the sample can. Clipping several sections into small pieces in the can was easier than trying to separate the foliage from the branchwood using clippers (such as in Procedure 5). In addition, clipping seems to inherently focus the collection process, resulting in a more methodically collected sample as opposed to collecting the easy-to-pull vegetation on the outside of the shrub (such as in Procedure 6).

Procedure 2 proved to be an easy method for collection, as field technicians could simply pull the vegetation from the shrub and place it in the can. However, as this procedure included branchwood, some bias was included in these samples. It is much easier to clip branchwood (as in Procedure 1) rather than try to pull it off. The same quantity of branchwood was likely not included in samples collected using Procedure 2, as was included in Procedure 1, because branchwood is harder to pull off than clip off.

Procedure 3 was difficult to implement throughout the entire sampling timeframe, though collection in May proved more difficult as compared to August. During collection in May, it was hard to collect only old vegetation as most of the shrub seemed to be made up new ephemeral leaves, making it harder to find the old foliage. Older vegetation was characterized as smaller, not quite as green leaves on the more lignified stems toward the inside of the shrub. Leaves on the lignified stems were last year's perennial growth. More branchwood (as a percentage of the shrub, compared to foliage) was added to these samples to get a full sample can. As the season progressed, the older growth became less difficult to collect as most of the large ephemeral leaves were shed, branchwood became more lignified and older vegetation made up a larger percentage of the vegetation on the shrubs.

Procedure 4 was easy to implement in May but increased in difficulty in June. In May, it was effortless to limit collection to only new vegetation, as shrubs were full with large ephemeral leaves. All field technicians had to do was quickly clip the outside of several shrubs and they would have a complete sample. As the ephemeral leaves were shed, the collection became difficult as the new vegetation was increasingly defined as later ephemeral leaves and new perennials, which are fairly small and not as prevalent as the ephemeral leaves.

Procedure 5 took the longest to implement out of all the procedures. The length of collection time may be a result of the awkwardness and difficulty of the collection process. The collector has to hold the collection can and the stem of the shrub in one hand while using the clippers with the other hand to clip off the leaves without including any branchwood. Procedure 5 is slightly easier to collect early in the season when large ephemeral leaves are more abundant. As the season progresses this method gets increasingly more difficult as you have to clip much closer to the branchwood to include the small leaves.

Procedure 6 was easy to implement and provided for quick collection of samples. This procedure allowed field technicians to simply pull the foliage off the shrub. However, pulling all vegetation does allow for some bias to be introduced into the sample as field technicians are less likely to gather a representative sample (mix of old and new vegetation) of vegetation from the shrub when pulling.

There are no significant disadvantages to using Procedures 1or 6. Since it was not possible to come to definite conclusions regarding the inclusion or exclusion of branchwood or clipping and pulling vegetation, it is hard to characterize if there are advantages or disadvantages to using specific procedures in regard to techniques within the procedure. Therefore, advantages and disadvantages for each procedure based on other considerations are summarized in Table 11.

Table 11. Comparison of the advantages and disadvantages of using each procedure. The length of time to collect samples, as well as the relative ease of using each procedure, can be important in choosing a procedure for a sampling program.

	Advantages	**Disadvantages**
Procedure 1	Easy and quick to collect. Methodical collection, likely the most representative of what is on the shrub.	Have to use clippers to collect samples.
Procedure 2	Fairly easy to collect.	May introduce some bias into samples as technicians try to pull off branchwood.
Procedure 3	None	Hard to collect. Values are different from every other procedure so doesn't allow for comparison. Averaging with Procedure 4 is unnecessary work.
Procedure 4	Easy to collect early in the season.	Harder to collect "new" vegetation later in the season. Values are different from every other procedure so doesn't allow for comparison. Averaging with Procedure 3 is unnecessary work.
Procedure 5	None	Hardest to collect. Takes longer than any other procedure.
Procedure 6	Easy and quick to collect.	Samples may be biased toward collecting the vegetation on the outside of the shrub, which likely includes more new vegetation.

While it is recognized that modeled live fuel moisture values are generally lower than values calculated using field collection, I wanted to determine the sensitivity of the NFDRS model to the varying fuel moistures from each procedure. The objective was to see if the average values for each procedure for each month had such a substantial effect on the ERC and BI as to influence the staffing and dispatch levels for the Salt Lake Desert Fire Danger Rating Area.

I entered data from the Cedar Mountain RAWS corresponding to each day of field collection into the NFDRS calculator in FireFamily Plus (Bradshaw 2000). I held all variables constant, except for live woody fuel moisture, which changed with procedure and month of collection.

The ERC rarely changed with the varying fuel moisture inputs and never changed enough to influence staffing levels. The BI changed with the varying fuel moisture inputs but a change significant enough to influence dispatch levels was only detected from Procedure 1 during the June collection period. The dispatch level dropped from high to moderate using field collected fuel moistures. NFDRS tends to under predict live fuel moisture values and over predict BIs (Bureau of Land Management et al. 2006). This may be an issue as far as NFDRS producing false low values. NFDRS calculated indices can lead to needless red flag days, leading to complacency and possible disconnection with field monitoring.

Conclusions

When all data were pooled, Procedures 1, 2 and 6 resulted in live fuel moistures that weren't significantly different from each other. Ideally, these procedures should be interchangeable. However, this overall comparison of procedures does not consider the underlying relationships between procedures when making pairwise comparisons, nor does the overall comparison take into consideration the individual hypothesis questions.

Question 1: Do some procedures produce more variable results over the course of the sampling timeframe than other procedures?

Procedure 1 resulted in samples with higher variability across the sampling timeframe than any other procedure. This demonstrates that there was a difference between standard deviations for each month, for this procedure. However, when standard deviations were compared for all procedures, for each month of collection, Procedure 1 no longer had the highest variability, as compared to other procedures. Procedures 5 (May), 3 (June) and Procedures 2 and 3 (August) all resulted in samples with higher variances during specific months of collection, though claims about population variance cannot be made with these data.

Question 2: Does the variability among procedures change as the season progresses?

The variation among the means of all procedures decreases as the sampling timeframe progresses. This indicates that the effect of standardizing procedures is more important earlier in the sampling timeframe than later on when procedures are producing very similar results.

Question 3: Do final live fuel moisture values differ when weighing in the field versus weighing in the lab?

When weighing samples, care should be taken to consistently weigh as soon as sample collection is completed to avoid getting false higher moisture values obtained when samples are stored for periods of time. In addition, when samples are stored after collection, controlling the period of time and conditions in which samples are stored can be difficult. Scales are easily transported with other collection equipment so samples can be weighed directly after collection. If a standardized method for weighing samples is not adhered to (both within monitoring programs and across land management boundaries), comparing samples may be difficult.

Question 4: Do final live fuel moisture values differ when old and new vegetation are sampled separately versus mixed together in the same sample?

Procedures 1 and 3 as well as Procedures 3 and 4, resulted in samples with significantly different means throughout the entire sampling timeframe. No analysis was run on Procedure 3/4 but the mean did not appear to be different from Procedure 1 which included mixed vegetation. Given this analysis and the fact that collection with Procedures 3 and 4 takes twice as long I suggest collecting a mix of old and new vegetation in proportion to what is found on the shrub for each sample.

Question 5: Do final live fuel moisture values differ when including small diameter branchwood (up to .32 cm) versus just foliage?

The effect of including or excluding branchwood is hard to define, as in one comparison (Procedures 1 and 5) the difference between the means is not significant. In the other comparison (Procedures 2 and 6), including branchwood leads to higher moisture values. However, a decision to use a procedure cannot be based on statistics alone, especially when the advantages and disadvantages in the actual collection process are considered. A standardized procedure needs to be decided upon and used by all managers across land management boundaries for the sake of comparison. In this case, since the effects of including branchwood are not clear, utilizing the easiest and quickest method of collection is feasible. Out of the six procedures tested, Procedures 1 and 6 fit this description best.

Question 6: Do final live fuel moisture values differ when clipping versus pulling vegetation?

When determining the effects of clipping versus pulling vegetation, a difference in mean live fuel moisture was not apparent when one technique was used over another. When Procedures 1 and 2 were compared by themselves, Procedure 2 had a higher mean. The higher mean of Procedure 2 indicates that pulled samples have higher live fuel moisture values than clipped samples.
The means of Procedures 5 and 6 are not different, indicating no difference between clipping and pulling vegetation.

No evident influence of clipping or pulling on moisture values was determined, as the results change with each comparison. A standardized method needs to be decided upon and used across land management boundaries so moisture values can be compared. As stated above, utilizing the easiest and quickest method of collection is feasible. Out of the six procedures tested, Procedures 1 and 6 fit this description best.

The results from the pairwise comparisons seem to contradict the results of the pooled comparison of all procedures. This overall comparison was made to give fire managers an overview of how their procedures compare with others that may be used. However, the more specific comparisons are important as these comparisons demonstrate the actual effects of the techniques on the live fuel moisture values.

Though different sampling techniques may or may not have an influence on final live fuel moisture values, a standardized method still has to be utilized by managers. For the reasons listed in Table 11, Procedures 1 and 6 could both serve as a standardized procedure for use across land management boundaries. However, Procedure 1 results in slightly lower average fuel moistures than Procedure 6. Though the difference between the two is not significant, I would recommend erring on the low side. In addition, Procedure 1 allows for more methodical and representative samples as clipping the vegetation seems to inherently focus the collection process. Therefore, more attention is given to what is clipped, and where on the shrub samples are being clipped from. Using Procedure 6, field technicians tend to pull the vegetation that is easiest for them to collect, which is generally on the outside and top of the shrub. Thus, I recommend Procedure 1 (clipping, mixed vegetation, including branchwood) as the standard method to use. In addition, I recommend weighing all samples in the field to avoid obtaining the false higher live fuel moistures that result from waiting to weigh samples.

Fuel moisture collection programs that have a large set of data from previous years may choose not to change their collection procedure at this point.

Changing sampling procedures may not allow for comparisons between future and past years data without collection using both procedures and developing correlations between the two. Depending on the procedure managers currently use, they should recognize the effects of specific sampling and weighing techniques when comparing moisture values with those collected by other programs using different procedures.

By implementing Procedure 1 and weighing samples in the field as a standardized method for collection, fire managers can have confidence that their live fuel moisture data are not highly variable due to using different collection techniques within their program or between other management areas. Fire managers can also be more confident in their data when making strategic decisions, such as requesting severity funding. In addition, fire managers know that time isn't being wasted in the field with needless, time-consuming procedures. This information is useful to fire behavior analysts as they use this information to make fire behavior predictions and need to be confident that the information they receive has been collected in a standard and accurate way. Increasing comparability between management areas and agencies is important for fire behavior analysts as well, as they often travel between several geographic areas during the fire season.

Further research could focus on questions related to sample transport (i.e., sealing cans with tape, length of storage/travel time before drying, actively keeping samples cool or at ambient temperature before drying) and sample drying (i.e., temperature and length of drying time). In addition, the implications of recording weather observations during every collection period could be studied. Taking weather observations is recommended for most every live fuel moisture collection program; yet live fuel moisture is correlated with seasonality and phenology rather than external weather influences. These are factors that may have an impact on live fuel moisture values but were outside the scope of this study and were not addressed.

Summary of Management Implications

- The variation among the means of all procedures decreases as the sampling timeframe progresses.
- When weighing samples, care should be taken to consistently weigh as soon as sample collection is completed to avoid getting false higher moisture values obtained when samples are stored for periods of time.
- Collecting a mix of old and new vegetation in proportion to what is found on the shrub is preferable to collecting separate samples of old and new vegetation for each sample then averaging the two to get fuel moisture values.
- No solid conclusion could be made when determining the influence of including or excluding branchwood or from clipping or pulling samples.

- Procedure 1 (clipped, mixed vegetation, including branchwood) is recommended as a standardized procedure as it is easy to collect, provides for methodical and representative collection of vegetation, and results in relatively low average fuel moistures, as compared with other procedures.

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