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Assessing Fuel Loads in Sagebrush Steppe and PJ Woodlands

Purpose: To define wildland fuels and review some of the approaches used to assess fuel loads in Great Basin ecosystems. Assessing wildland fuel loading is important for quantifying potential fire hazards, for monitoring the effectiveness of fuel treatments, and for predicting fire behavior, soil heating, fuel consumption, and emissions.

What are wildland fuels?

Understanding the different components of wildland fuels is the first step for developing valid estimates of fuel loads. **Total fuel** is all plant material, both living and dead, that can burn in a worst-case situation. **Consumable fuel** is the portion of total fuel that would be consumed by fire under specific conditions and is related to factors like fuel moisture content, season, weather conditions, time of day, and plant growth stage or phenology. **Biomass estimates** differ from **fuel loading estimates**. Above-ground biomass includes all the plant organic material on a site (including litter and duff). Fuel only includes the portion of biomass that may be consumed by fire. Biomass is more than 'fuel' and provides many ecological functions. **Herbaceous fuel** (grasses and forbs) is commonly separated into living and dead, or current and previous years' growth. **Woody fuel** is also separated into living and dead components. Typically, living woody biomass is not readily consumed in a fire, and at times even living herbaceous material will not burn. Dead woody fuels may persist on the landscape for many years and sometimes decades. Large-diameter woody material will not readily burn under most conditions. Thus, these types of organic materials are included in biomass estimates but not usually in fuel loading estimates.

Herbaceous fuels are typically separated into live and dead material because they may burn under different conditions. Dead herbaceous material varies in fuel moisture level depending on the atmospheric conditions. The moisture content of living herbaceous material is dependent upon soil moisture, temperature, and plant phenology. New growth of plant material has a high moisture content, which declines as the plant matures.

Dead woody fuel is often separated into diameter size classes because it has been found that this greatly influences the likelihood of consumption during fire as well as fire intensity, severity, and spread. The diameter size classes include those

In Brief:

- Managers have developed several approaches for assessing fuel loads that vary with landscape scale, required data accuracy and precision, and resources available for data collection.
- Understanding and quantifying the different components of wildland fuels, such as total fuel, consumable fuel, and time-lag fuels, is the first step for developing valid estimates of fuel loads.
- Methods vary from those that are rapid and more qualitative to those that are quantitative. They include fire behavior fuel models, photo series, photoload methods, the planar-intersect method, and remote sensing.
- Approaches vary in accuracy and in time and effort required for sampling. Fire behavior fuel models or photo series guides are effective for rapidly assessing fuel loads on multiple sites, but more intensive methods such as the planar intersect method are useful during the personnel-training phase.

Wildland Fuel Terms

Total Fuel	All plant material, both living and dead, that can burn in a worst-case situation.
Consumable Fuel	The portion of total fuel that would burn, depending on fuel moisture, weather, plant stage, and more.
Biomass Estimates	All above-ground plant organic material at a site, including litter and duff.
Fuel Loading Estimates	The portion of the total biomass that may be consumed in case of a fire.
Herbaceous Fuel	Grasses and forbs, commonly separated into living and dead
Woody Fuel	Wood, also separated into living and dead. Living woody biomass is not readily consumed in a fire.

that are: <¼, ¼ to 1, 1 to 3, and >3 inches. They are frequently referred to as 1-hour, 10-hour, 100-hour and 1000-hour **time lag fuels** because of the rate at which they equilibrate with changing atmospheric relative humidity. The diameter of each piece of dead woody fuel greater than 3 inches is usually measured since a small increase in diameter greatly increases the amount of biomass. In mature juniper (*Juniperus* spp.) woodlands, litter and duff beneath the tree canopies may also constitute a significant amount of the site's fuel.

Why assess wildland fuel loading?

Estimates of fuel loading are useful in many applications (Table 1). The initial need for fuel loading estimates resulted from the development of fire behavior prediction systems such as BehavePlus. Knowing levels of fuel loading helped managers predict fire behavior using these systems. More recently developed software programs such as FARSITE and FlamMap are now used to predict broad-scale fire behavior across multiple vegetation types. All require fuel loading data and sometimes other types of data as well. These software programs have proven useful in predicting fire behavior in both wildfire and prescribed fire applications, including strategic planning.

Pre-fire fuel loading can be compared to the estimated reduction in fuel load after fire to interpret burn severity and subsequent fire effects. **Burn severity** is generally defined as the degree of ecological change due to fire. Both field and remotely sensed observations are used to map burn severity. The differenced Normalized Burn Ratio (dNBR) can be used to infer burn severity from remotely-sensed data. The Monitoring Trends in Burn Severity Project (MTBS) is a database of large fires for which dNBR has been mapped within each fire perimeter. Methods based on field observations include the Composite Burn Index (CBI).

Table 1. Commonly used tools and software that utilize fuel load data[1]

Technology or tool	Primary use by land managers
Fire Behavior Fuel Models (FBFMs)	Data from FBFMs are used as inputs for BehavePlus, FOFEM, FARSITE and many other programs for prediction of fire behavior and fire effects such as soil heating and smoke.
BehavePlus	The BehavePlus fire modeling system is an application that involves modeling fire behavior and fire effects. The system is composed of a collection of mathematical models that describe fire behavior, fire effects, and the fire environment. The program simulates rate of fire spread, spotting distance, scorch height, fuel moisture, wind adjustment factor, and many other fire behaviors and effects; so it is commonly used to predict fire behavior in several situations.
FlamMap	The FlamMap fire mapping and analysis system is a PC-based program that describes potential fire behavior for constant environmental conditions (weather and fuel moisture). FlamMap does not calculate fire spread across a landscape or simulate temporal variations in fire behavior caused by weather and diurnal fluctuations.
Fire Area Simulator (FARSITE)	FARSITE is a fire growth simulation modeling system. It uses spatial information on topography and fuels along with weather and wind files. It incorporates existing models for surface fire, crown fire, spotting, post-frontal combustion, and fire acceleration into a two-dimensional fire growth model.
Composite Burn Index Photo Series (CBI)	The CBI photo series uses plot data and photos to illustrate the range of burn severity encountered in ecosystems of the U.S. The series offers a way to calibrate field interpretations, providing a sense of what the CBI represents visually on the ground. It offers insight into the variety and combinations of fire effects that make up the overall post-fire condition on a site.
Fuel Characteristic Classification System (FCCS)	FCCS calculates and classifies fuelbed characteristics and their potential fire behavior.
Monitoring Trends in Burn Severity (MTBS)	MTBS is a program that is designed to map the perimeters and severity of all fires within the United States since 1984 based on satellite images.
LANDFIRE	LANDFIRE provides broad scale geo-spatial products and information related to vegetation, fuel, and disturbance at the national level.

[1] *Descriptive material has primarily been drawn from FRAMES (https://www.frames.gov/) or directly from the software web material.*

Currently many land managers are completing fuel treatments using livestock grazing, prescribed fire, and mechanical methods for achieving numerous objectives. Monitoring can utilize fuel assessment methods to quantify or qualify the short- and long-term effectiveness of the fuel treatments in modifying fuels as well as the effects of fuel treatments on the plant community.

In many regions air quality and smoke production from fires is a major concern. Fuel loading assessment methods used in conjunction with smoke production models such as FOFEM and Consume (FBFMs) can be used to predict fire effects on air quality and can be useful in predicting emissions from both wild and prescribed fires.

Figure 1. Estimating fuel loading on the Snake River Plain in southern Idaho using the photo series method.

What approaches exist for assessing wildland fuels?

The assessment of wildland fuels can vary from rapid visual approaches to more time intensive direct sampling strategies. Methods to predict fuel loading using remotely-sensed data have also been developed. Each method has its advantages and disadvantages as discussed by Keane (2015). The appropriate method depends on the assessment objectives, the required accuracy of the estimate, the spatial scale of the assessment, the urgency of the assessment, and the resources available for collecting data.

Fire Behavior Fuel Models (FBFM). One of the initial methods to estimate fuel load was the use of the Fire Behavior Fuel Models. Originally there were 13 models from FBFM that represented various vegetation types found throughout the United States (Anderson 1982). Through the use of descriptive material and photographs, managers selected the fuel model that best represented their site. Fuel loading information was available in tabular form and was also preloaded into the Behave program. Sagebrush (*Artemisia* spp.) steppe and juniper woodlands were poorly represented in these initial models. Scott and Burgan (2005) described 40 additional fuel models which contained more examples of sagebrush steppe and juniper woodland vegetation commonly found in the Great Basin. Thus, land managers with site specific data have the option of creating their own custom fuel models.

Photo Series. Another method for fuel loading assessment is the photo series, which is the most rapid and least costly approach. These consist of a sequence of photographs illustrating examples of different fuel loading in various vegetation types (Figure 1). Several photo series are available for Great Basin sagebrush steppe and juniper woodland vegetation (Stebleton and Bunting 2009, Bourne and Bunting 2011, Ottmar et al. 2000). This method involves matching as closely as possible the manager's sites with the photographs included in the series. Many authors suggest matching the photos by vegetation layer or fuel strata rather than trying to find a single photograph to fit a site. For example a manager would use one photograph to quantify the herbaceous component and another to predict the overstory fuel. Fuel loading of the site can then be derived from the tabular data associated with the photo. Once the observer is well trained in this method, multiple sites can be assessed quickly, each taking less than five minutes. This allows the observer to sample across the gradient of sites, which helps them gain a measure of the fuel heterogeneity on the landscape.

Photoload Method. A related method, the photoload method, uses photographs of artificial fuels of different types and sizes (large woody, herbaceous, shrub, litter etc.) to represent the site's actual fuel (Keane and Dickinson 2007). The manager matches the site's fuel to photographs of each fuel strata. As with the photo series, fuel load values for the site are derived from tabular data. At this point photoload guides are not available for sagebrush steppe and juniper woodland vegetation.

Planar-intersect Method. A number of field sampling approaches have been developed. Perhaps the most commonly used in land management monitoring for surface woody fuels is the planar-intersect method (Brown 1970, Brown et al. 1982) (Figure 2). This method involves using multiple line transects along which the relevant fuel data are recorded. Usually multiple lines are sampled for a given site (five or more), and multiple sites are sampled within the area of interest. By sampling multiple sites, this method can also provide a measure of fuel heterogeneity. A more complete description of the planar-intersect method can be found at the FIREMON website (https://www.frames.gov/partner-sites/firemon/firemon-home/). While not part of the planar intersect method, FIREMON also contains suggested methodology for sampling herbaceous and shrub fuel and biomass (most of which include clipping, drying and weighing of samples).

Remote Sensing Methods. Methods to estimate fuel loading using remotely-sensed data are available (Keane et al. 2001). These methods do not measure fuel loading directly, but rather they assess the landscape cover of vegetation and other cover types from remotely sensed data which is then classified into similar groups. The classified groups are then associated with typical fuel loading data. The fuel loading data for the groups have generally been developed through intensive field sampling such as those described previously (Figures 3 and 4). Using these methods, managers can assess large spatial areas quickly. This method may also provide a measure of fuel heterogeneity, but this depends on the pixel size of the remotely-sensed data, the accuracy of the vegetation map, the variability of fuels within the vegetation classes, and other factors.

Figure 2. Sampling fuel loading using the planar intersect method at Lava Beds National Monument in northeastern California.

Figure 3. Composition and fuel loading values of a Wyoming big sagebrush steppe in northern Nevada. Low herbaceous fuel loading and high levels of bare ground reduce the probability of fire under low intensity burning conditions.

Canopy coverage

Shrubs: 35%
Perennial grass: 21%
Bare ground: 34%

Fuel

Total shrub: 18.3 t/ac
Live herbaceous: 311 lb/ac
Dead herbaceous: 350 lb/ac

Figure 4. Composition and fuel loading values of a typical Phase 2 western juniper woodland in southwestern Idaho. Juniper woodlands are characterized by having low fine fuel loading and heterogeneous fuel distribution.

Canopy coverage

Trees: 14%   Shrubs: 24%
Perennial grass: 26%   Bare ground: 20%

Fuel

Total live tree: 4.9 t/ac   Dead tree: 0.5 t/ac
Total shrub: 0.6 t/ac
Live herbaceous: 104 lb/ac
Dead herbaceous: 43 lb/ac

Comparison of methods

Figure 5. Fuel loading varies at all scales within the landscape. Fuel heterogeneity can dramatically influence fire spread and behavior, particularly with respect to moderate and low intensity fires. Top: Fine scale [mountain big sagebrush steppe (L), western juniper woodland (R)]; Middle: community scale [Wyoming big sagebrush steppe (L), western juniper woodland (R)]; Bottom: Landscape scale [mountain big sagebrush and low sagebrush steppe, and aspen woodland (L); western juniper woodland and mountain big sagebrush steppe (R)].

Skikink and Keane (2008) compared five field techniques for estimating surface fuel loading in montane forests. The planar-intersect method was determined to be the best method tested. The photoload method compared well with the planar-intersect method. The photo series method tended to result in greater fuel load estimates for the fine wood debris and coarse woody material. However, ponderosa pine-dominated sites (*Pinus ponderosa*) were primarily sampled in this study, and no shrub or herbaceous-dominated sites were included.

Fuel loading varies greatly at all spatial scales, fine to broad. This variation can influence fire behavior and thus fire effects on the ecosystem. The non-spatially explicit fire behavior models, such as BehavePlus, generally assume that the fuel load is homogeneously distributed within the area modeled. The spatially explicit models, such as FARSITE, assume that there are varying fuel loads within the area of concern but that fuel is homogeneous with the smallest pixel represented in the data. Consequently, depending on the pixel size and the heterogeneity, fuel loading may or may not be well represented. Representing fuel load heterogeneity across all the relevant scales is still challenging (Figure 5).

Summary

The different methods developed to assess fuel loads in sagebrush steppe and juniper woodland vegetation vary in accuracy, and in time and effort required for sampling. Many sagebrush steppe and woodland areas have heterogeneous fuels across a treatment area. Identifying areas of high and low fuel loading helps during the planning and implementation phases of a project. Different actions may be required to hold a prescribed fire in areas of a unit with high fuel loading. Also, variable fire intensity and burn severity is attributed to variable fuel loading. Thus, it is important to obtain multiple estimates that are representative of the variety of fuel loading amounts within a heterogeneous landscape, particularly the low fuel loading sites. FBFMs or photo series guides are effective methods to rapidly assess the fuel loads on multiple sites. However, more intensive sampling methods such as the planar intersect method are useful during the personnel-training phase.

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