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Creating Photographic Loading Sequences in the Field for the Photoload Sampling Technique

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Abstract

The photoload technique provides a quick and accurate means of estimating the loadings of six wildland fuel components including 1 hr, 10 hr, 100 hr, and 1,000 hr downed dead woody, shrub, and herbaceous fuels. It involves visually comparing fuel loading conditions observed in the field with a set of photographed sequences to estimate fuel loadings; the photo sequences are a series of downward-looking oblique photographs depicting a series of graduated fuel loadings of synthetic fuelbeds for each of the six fuel components. The photoload technique has been implemented into multiple inventory and fuel monitoring projects worldwide. However, the original set of photo sequences are somewhat limited in that the fine woody fuel loading sequences were created using only Douglas-fir woody particles, and only seven shrub and four herbaceous species that are common to the U.S. northern Rocky Mountains are available for estimating shrub and herbaceous loading. To increase the accuracy and functionality of the photoload method in other geographic areas, new sequences must be created for more localized fine woody, shrub, and herbaceous fuel components specific to that area. This report details a procedure on how to create a set of photoload sequences in the field with minimal effort.

Keywords: fuel sampling, loading estimation, visual biomass estimation, fine woody fuel, herbaceous fuel, shrub fuel

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Contents

INTRODUCTION

Fuel loading estimates for fire-prone ecosystems of the world are vital for accurately predicting fire behavior and effects (Alexander 2014; Keane 2015). Moreover, fuel loading estimates are needed to monitor treatments that manipulate wildland fuels using mechanical operations and prescribed fire to control adverse effects of unplanned wildfires and to potentially save lives, property, and ecosystems (Graham et al. 2004). Wildland fuel loading estimates also provide critical inputs to models, such as FOFEM (Reinhardt et al. 1997) and CONSUME (Ottmar et al. 1993), to estimate tree mortality, smoke emissions, and soil heating (Brown and Reinhardt 1991; Weise and Wright 2014). The inventory and monitoring of wildland fuels is the benchmark of enlightened fire management (Keane 2015).

Estimating surface fuel loadings in the field is difficult for many reasons. First, conventional fuel loading sampling methods demand a complex integration of several disparate sampling techniques integrated at multiple scales to obtain accurate estimates of loadings for each fuel component within the fuelbed (Brown et al. 1982; Sneeuwjagt 1973; Twidwell et al. 2009). Downed dead woody fuels, for example, are typically sampled using planar intersect techniques (Brown 1971; Wagner Van 1967), which have been implemented into many surface fuel inventory sampling systems (Lutes et al. 2006; Lutes et al. 2009). Dead and live shrub and herbaceous fuels must be measured by using time-consuming, destructive methods that involve clipping and weighing the biomass or by using indirect techniques such as allometric regression equations from cover and height estimates (Keane 2015; Lutes et al. 2006). Duff and litter loadings are often estimated from the product of their depths and bulk densities (Brown et al. 1982; Lutes et al. 2006; Lutes et al. 2009). Often, the scales and sources of error for surface fuel measurements are incompatible and inconsistent across the different fuel components and the methods used to sample them (Keane et al. 2012b). Log loadings, for example, frequently vary at greater spatial scales than fine fuel loadings (Keane et al. 2012a). The photoload technique was introduced to provide an inexpensive, easy, and quick fuel sampling technique for consistently estimating loading across six surface fuel components at the levels of accuracy required by most fire behavior and effects models (Keane and Dickinson 2007a,b).

The photoload sampling technique uses visual assessments to estimate loadings of surface fuel components (Keane and Dickinson 2007b). A series of downward- and/or sideward looking photographs of synthetic fuelbeds of gradually increasing fuel loadings are used as reference for estimating fuel loadings in the field by eye (fig. 1). The fuel loading conditions observed on the ground are simply matched with one of the photoload pictures in the sequence for that fuel component (Holley and Keane 2010). Adjustments for spatial distribution, diameter distribution, degree of decay, and depth of loading across the sample space can also be made to improve assessment estimation accuracies. The photoload technique can be used to estimate fuel component loadings at a microplot (1 m^2), macroplot (100–1,000 m^2), stand (1,000–10,000 m^2), or landscape (> 10,000 km^2) scale with varying levels of effort depending on the sampling objectives and available resources (sampling time and funds) (Keane and Dickinson 2007b). However, this technique is only used to estimate loading of surface fuels and does not provide a means to estimate canopy fuel characteristics. Moreover, photoloads are not designed to

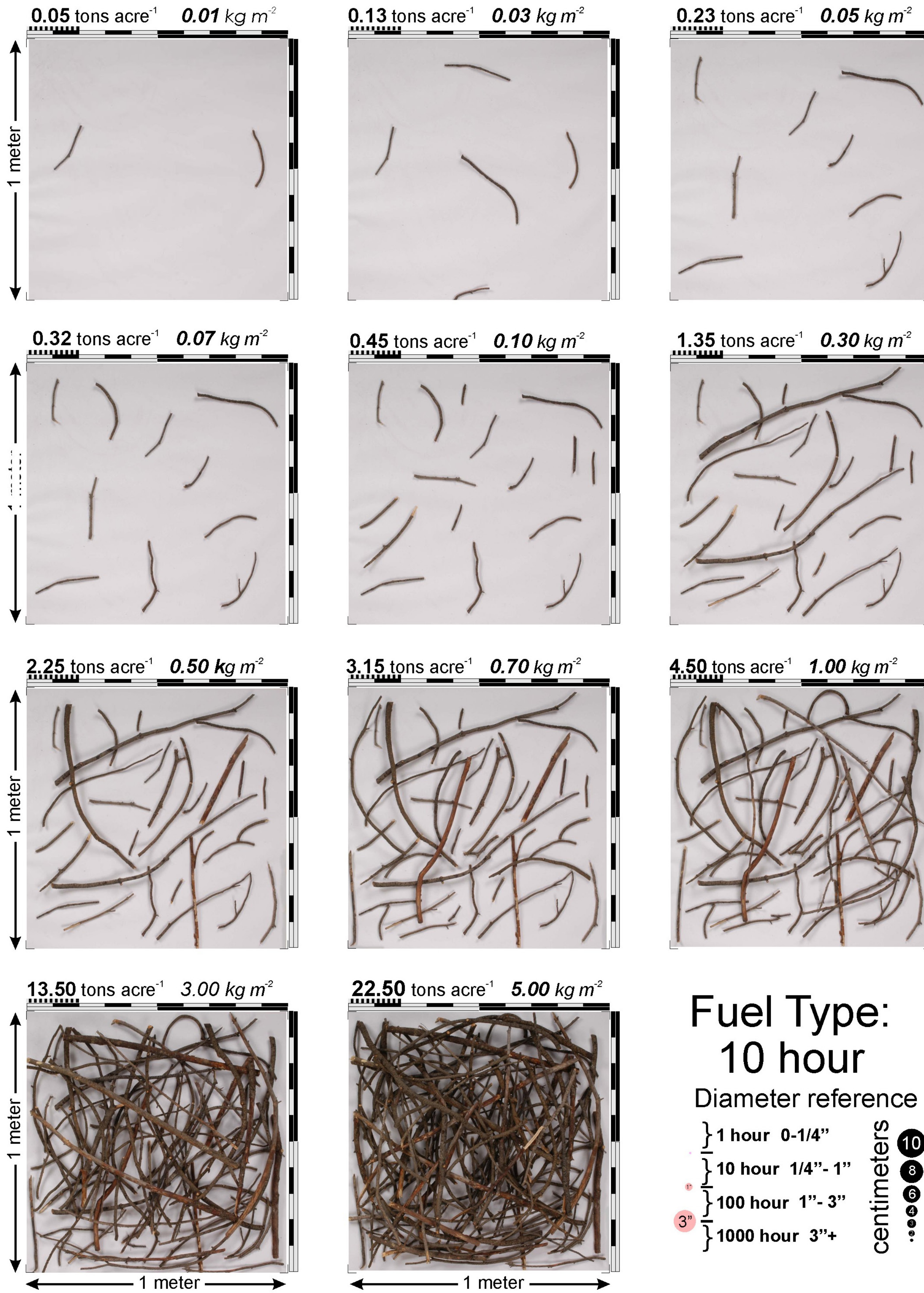


Figure 1—An example of a photoload sequence for 10 hr downed dead woody fuels from Keane and Dickinson (2007b). Each photo is compared to conditions in the field to visually estimate 10 hr woody fuel loading.

estimate loadings of duff and litter layers because respective layer thicknesses are not visually evident from photos and must be directly measured at each location (Keane 2015).

Despite the popularity of the photoload method, the original photoload photographic sequences were developed specifically for a small set of fuel components found only in the U.S. northern Rocky Mountains (Tinkham et al. 2016). Applying the limited Keane and Dickinson (2007b) set of reference photos to fuel sampling in other ecosystems or geographic areas, especially for shrub and herbaceous loadings, could result in high errors due to major differences in species composition, fuelbed structure, and plant morphology (McColl-Gausden and Penman 2017). Downed woody fuel particle diameter and density distributions, for example, vary greatly across species, time since disturbance, biophysical setting, and ecosystem (Harmon et al. 2008; Russell et al. 2013; Woodall and Monleon 2010). More importantly, the species that comprise shrub and herbaceous fuels are different across ecosystems. Creating a comprehensive set of photos of all possible plant species for general use in all fire-prone ecosystems of the world would have been impossible because of the wide diversity of species that comprise wildland fuelbeds (Scott et al. 2014). What is needed is a procedure to quickly, easily, and economically create a set of photoload sequences to represent the six surface fuel components for local applications.

In this report, we present a comprehensive protocol for quickly creating new photoload loading series by photographing local fuelbeds in situ rather than reconstructing them in a studio. The original methods employed by Keane and Dickinson (2007a) would be difficult to implement because they require time-consuming reconstruction of fuel component loadings in a studio environment (fig. 2). This new method involves taking pictures of fuel components in the field, then collecting the photographed material and drying and weighing it to estimate the loading for that picture. The full range of loadings observed in the field for a fuel component are represented by the set of photos with corresponding field-measured loadings. Creating new sets of photoload sequences for those woody, shrub, and herbaceous species not represented in the Keane and Dickinson (2007b) manual would accomplish the following:

1. More accurate estimations of fuel loading to more accurately predict fire behavior, smoke emissions, and fire effects, especially plant response.
2. More comprehensive set of pictures for use in other sampling activities, such as forage biomass estimation for range management.

Terminology

There are some wildland fuel science terms that are used in the steps below that need to be appropriately defined and described to improve understanding of this procedure. Following Keane (2015), a wildland fuelbed is composed of ground, surface, and canopy fuels (fig. 3); this report, however, only considers the estimation of loading for *surface* fuels (biomass within 2 meters of the ground) but does address a means of estimating duff ground fuel loadings. Surface fuels are composed of a wide variety of fuel *components*, which are defined for specific applications, including fire management. There are seven major surface fuel components that are used in most applications, along with duff ground fuels (table 1). Each fuel component is

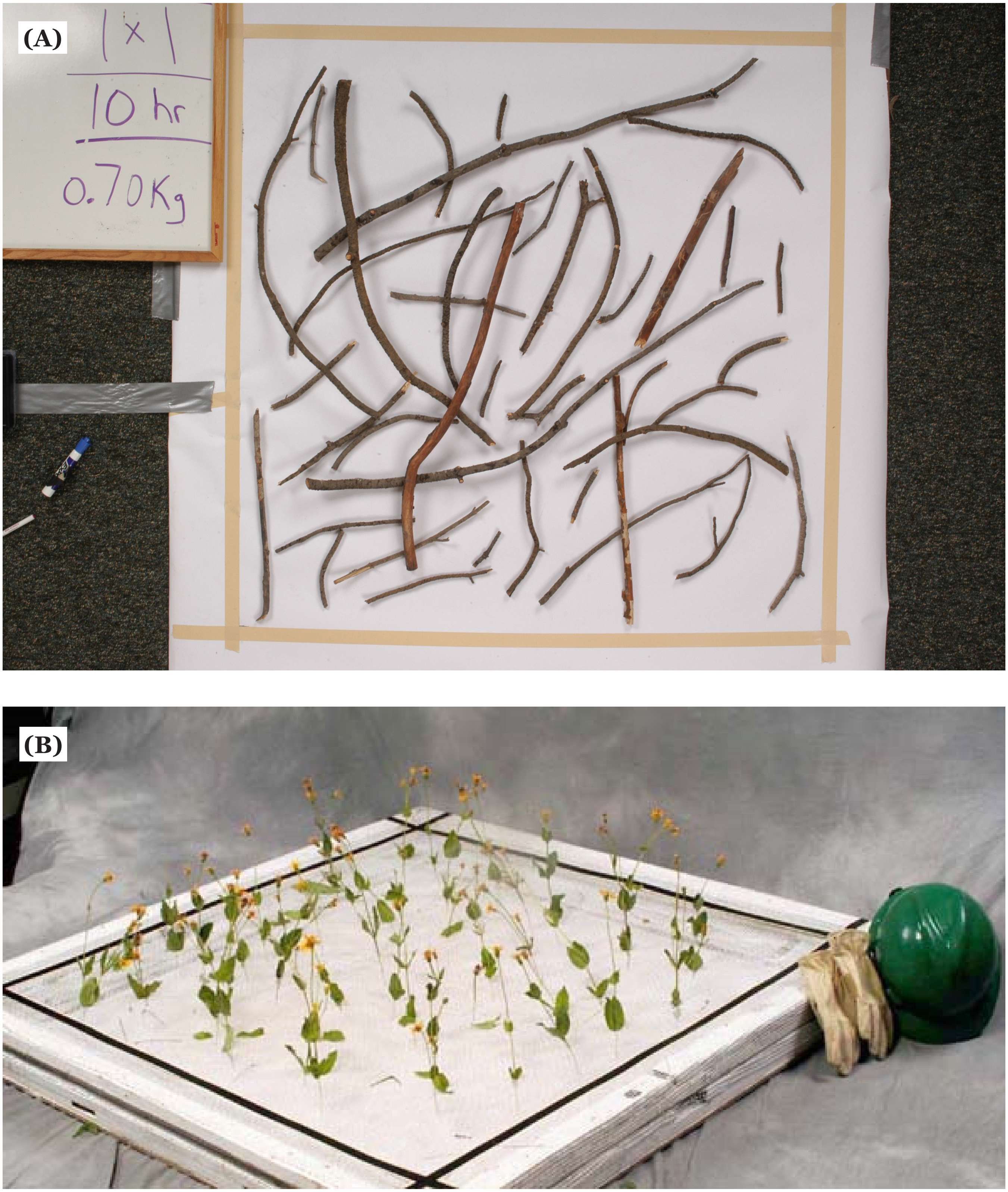


Figure 2—Construction of the photoload fuelbeds for creating the original photoload sequences in Keane and Dickinson (2007b). (A) Constructing a highly visible fuelbed for 10 hr woody fuels, and (B) placing *Arnica* (spp.) plants into the special plot frame in the studio.

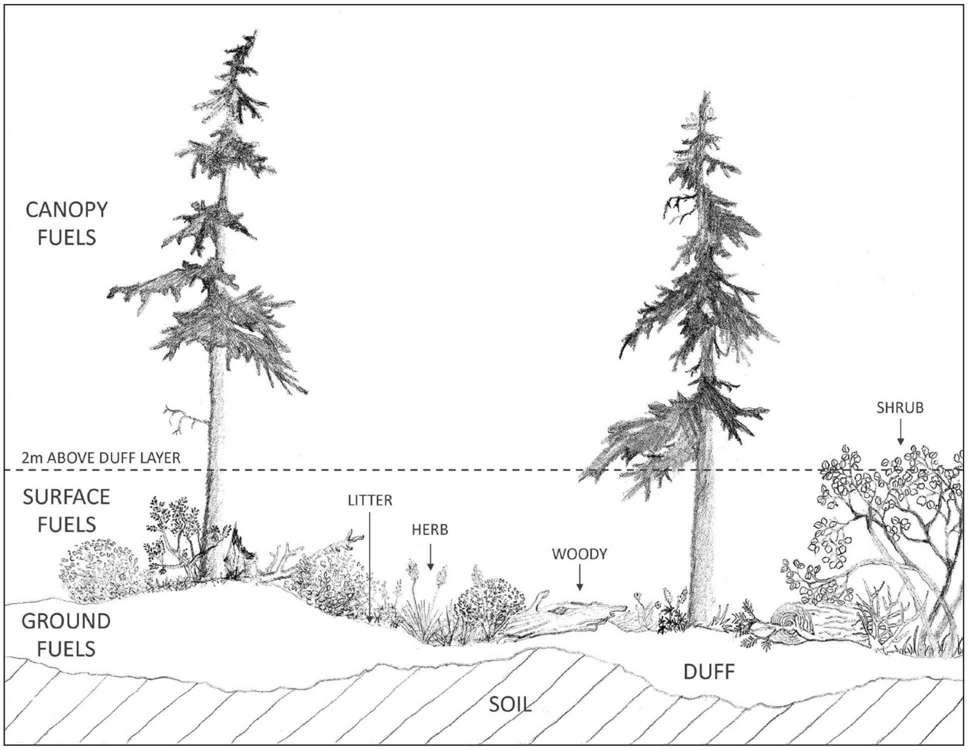


Figure 3—A wildland fuelbed and its components. There are three fuel layers—ground, surface, and canopy. The surface fuel layer includes shrubs, herbs, litter, and all downed woody. Taken from Keane (2015) and drawn by Ben Wilson.

Table 1—Descriptions of the eight major surface fuel components used in most wildland fuels projects. Duff and litter fuels are not included in the photoload technique because it is impossible to measure litter and duff depths using visual estimations.

General fuel type	Fuel component	Common name	Size	Description
Downed dead woody	1 hr woody	Twigs	< 1 cm (0.25 inch) diameter	Detached small woody fuel particles on the ground
	10 hr woody	Branches	1–2.5 cm (0.25–1.0 inch) diameter	Detached small woody fuel particles on the ground
	100 hr woody	Large branches	2.5–7 cm (1–3 inch) diameter	Detached small woody fuel particles on the ground
	1,000 hr woody	Logs	7+ cm (3+ inch) diameter	Detached small woody fuel particles on the ground
Shrubs	Shrub	Shrubby	All shrubby material less than 5 cm diameter	All burnable shrubby biomass with branch diameters less than 5 cm
Herbaceous	Herb	Herbs	All sizes	All live and dead grass, forb, and fern biomass
Litter	Litter	Litter	All sizes, excluding woody	Freshly fallen nonwoody material, which includes leaves, cones, pollen cones,
		Ground fuels		
Duff	Duff	Duff	All sizes	Partially decomposed biomass whose origins cannot be determined

composed of a number of *particles*; a fuel particle can be a twig, branch, leaf, or cone. In this report, a fuel component can be generally or specifically defined; shrub fuels, for example, can be treated as a lifeform (e.g., all shrubs) or as an individual species (e.g., sagebrush). *Litter* is technically defined as a surface fuel (Keane 2015), but it is not estimated using photoload techniques because it is impossible to visually determine the depth of the litter. This is also the reason duff fuels do not have photoload series. Duff is the organic matter below the litter layer that is identified by fuel particles for which the origin of the particle is indeterminate (Keane 2015). Generally, one cannot determine if the duff particle is decomposed needle, twig, branch, or some other vegetation plant part simply through field observation.

There is also a specialized terminology used to describe this specific photoload sequence development procedure. The *project objectives* are the reasons why the new photoload sequences are being created; those objectives should be used to identify the desired resolution and detail for these sequences (Step 1). The *target area* is the spatial domain for which the new photoload sequence(s) are designed to represent and where it will be applied once finished; ponderosa pine forests on the Salmon-Challis National Forest (SCNF), for example, would be a target area. The *representative location* is a smaller area within the target area that contains some or all of the possible unique fuel loading conditions across the gradient of fuel loading conditions for a target area. There may be more than one representative location in a target area; for example, each new shrub species may have its own representative area. The *sample site* is the area identified for the sampling of a target fuel loading for a selected fuel component (e.g., low sagebrush loading in a ponderosa pine forest of the SCNF). The *fixed area plot (FAP)* is the predefined area used to represent the fuel component in the photographs (e.g., 1 m x 1 m or 1 m^2 area is used to spatially delimit the sagebrush fuel conditions). The *plot frame* is the apparatus used to delineate the border of the FAP. This plot frame is also used to "frame" the photo. A *fuel component* in this report is defined more broadly than is used by Keane (2015) in that a fuel component can be narrowly defined to facilitate its sampling rather than stove-piped using the seven components in table 1. Shrub fuel components, for example, can be by species, guilds, plant functional types, and lifeforms.

Quick Description of the Photoload Sampling Technique

Estimating fuel loading with the photoload technique involves matching the conditions observed on the ground with the appropriate conditions in a set of photographs of known loadings provided in the photoload sequences (fig. 1). You do this by starting with the photograph showing the lowest loading for that fuel component and comparing it with conditions on the ground. If they don't match, you should move on to the next photo and continue to do such until the amount of fuel in the photo represents relatively more than the fuel loading observed on the ground. Then visually compare the loading on the ground with the previous photo and the photo that is considered to represent more than the actual loading. From there, estimate a loading value that is somewhere between the loadings of the two photos. This is just the first step, and is the only step for 1, 10, and 100 hr downed dead woody fuel components.

If the fuel component is shrub or herbaceous, then another step is required. Measure or visually estimate the *height* of the shrub or herbaceous layer and then divide that height by the height in the photo within the photoload sequences. The estimated fuel loading is then multiplied by this ratio to adjust for the size of the plants. If there are several species of vegetation on a plot, it is necessary to sum the individual loadings to make a final loading estimate of the shrub or herbaceous component.

There are several important things to consider when estimating loadings of fine woody, shrub, and herbaceous fuels. First, include only the material that lies within the FAP frame. Do not include woody fuel that extends beyond the plot frame. Only shrub and herb biomass that lies *within* the plot frame should be considered in the loading estimate—that is, consider the plot frame a physical boundary and foliage or branches observed within that boundary are included in the loading estimate Remember, surface fuels are biomass below 2 m in height, so do not include material that is above 2 m as that biomass is measured as canopy fuels. And last, only include fuel components that are visible in the visual estimates—do not include portions of woody fuel particles that extend into the litter and duff.

Estimating log (1,000 hr downed dead woody fuel) loadings is a bit more complicated. Manipulating log loading in a studio or controlled environment was impossible because of the immense weight of logs (Keane and Dickinson 2007a), so the original photoload sequences were taken with 6-inch and 10-inch tubes that were painted brown (fig. 4) and the weight of each log was calculated as the volume of the tube multiplied by the density of Douglas-fir wood (380 kg m^{-3}). Moreover, because logs vary at spatial scales much greater than fine woody debris, we used a 100 m^2 plot that was designed to be easily photographed (fig. 5). In subsequent tests of this method using the brown tubes, we found that while useful, there was a great deal of uncertainty in the visual estimates and it was difficult to repeat across multiple users (Sikkink and Keane 2008). It turns out that differences in diameter, decay, and bark thickness both within and across logs on the plot, coupled with the uncertainty of photographic comparison, made accurate loading estimates of 1,000 hr fuels using photographs difficult. Therefore, a companion

Figure 4—A picture showing the 30 cm diameter brown tubing cut at various lengths and put on the 100 m^2 plot to approximate a loading.

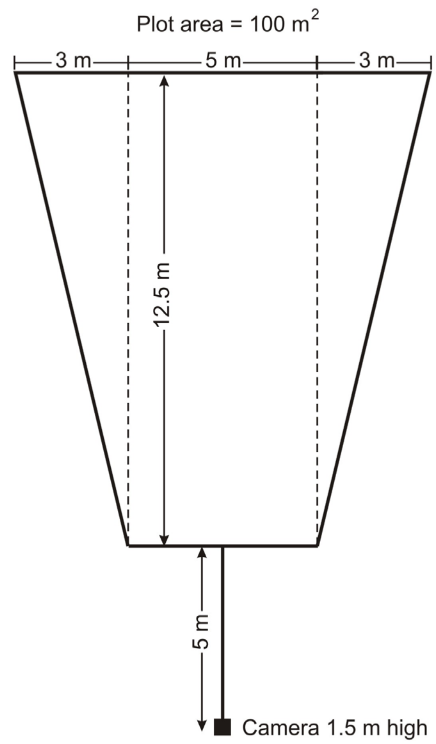


Figure 5—The dimensions and shape of the 100 m² plot used to create the photoload sequences in the Keane and Dickinson (2007b) publication (Keane and Dickinson 2007a).

tabular approach was developed as an alternative to photographic comparison. The approach involved creating a series of tables where rows are diameters and columns are lengths and the cell intersects are loadings (table 2) (Keane and Dickinson 2007a). You should either visually estimate or actually measure the average diameter and length of logs in any 100 m² area and finds the right loading value in the table. This value is then reduced for decay if needed (table 3). These tables are the better alternative for estimating log loading as the method is highly scalable—the method can be used to compute the weight of each log, a set of similar logs, or all logs on the 100 m² area. Moreover, it is much faster to visually estimate diameter and length of logs than to compare photos of brown tubes.

There are a number of tips that users have incorporated into their field estimates over the 10 years since the photoload method was introduced. First, some have found that visually estimating the length of the fine woody fuel particles in the plot frame and comparing that to the length in the photos is easier, is quicker, and produces more confident estimates of loading. Second, the Sikkink and Keane (2008) study found that the most common user error is entering a number with the wrong decimal place (e.g., a 0.1 was entered when the value was really 0.01), so you should check decimals when recording estimates. Through extensive testing, it was also evident that the order in which loadings are estimated by fuel component is important for maintaining high quality. Many found that confusion was minimized if the fuel components with the lowest loadings were estimated first and those with the highest loadings estimated last. We also suggest that you first enter 0 for each fuel component not evident within the sample

Table 2—A table from Keane and Dickinson (2007b), where the loading of a log is shown by diameter and length classes. Loadings are simply summed up for all logs in the 100 m2 area to compute a final loading.

Length (m)	Diameter (cm)									Length (m)
	1	2	3	4	5	6	7	8	9	10	
1	0.04	0.15	0.34	0.60	0.94	1.36	1.85	2.41	3.05	3.77	1
2	0.08	0.30	0.68	1.21	1.88	2.71	3.69	4.83	6.11	7.54	2
3	0.11	0.45	1.02	1.81	2.83	4.07	5.54	7.24	9.16	11.31	3
4	0.15	0.60	1.36	2.41	3.77	5.43	7.39	9.65	12.21	15.08	4
5	0.19	0.75	1.70	3.02	4.71	6.79	9.24	12.06	15.27	18.85	5
6	0.23	0.90	2.04	3.62	5.65	8.14	11.08	14.48	18.32	22.62	6
7	0.26	1.06	2.38	4.22	6.60	9.50	12.93	16.89	21.38	26.39	7
8	0.30	1.21	2.71	4.83	7.54	10.86	14.78	19.30	24.43	30.16	8
9	0.34	1.36	3.05	5.43	8.48	12.21	16.63	21.71	27.48	33.93	9
10	0.38	1.51	3.39	6.03	9.42	13.57	18.47	24.13	30.54	37.70	10

Table 3—Decay classes used to calculate log weight for estimating loading.

Decay class	Description
1	All bark is intact. All but the smallest twigs are present. Old needles probably still present. Hard when kicked.
2	Some bark is missing, as are many of the smaller branches. No old needles still on branches. Hard when kicked.
3	Most of the bark is missing and most of the branches less than 1 inch in diameter also missing. Still hard when kicked.
4	Looks like a class 3 log but the sapwood is rotten. Sounds hollow when kicked and you can probably remove wood from the outside with your boot. Pronounced sagging if suspended for even moderate distances.
5	Entire log is in contact with the ground. Easy to kick apart but most of the piece is above the general level of the adjacent ground. If the central axis of the piece lies in or below the duff layer, then it should not be included in the Coarse Woody Debris sampling as these pieces act more like duff than wood when burned.

unit; do not leave it blank as that implies it was never assessed. Then, enter the loadings for those components with smallest loadings, such as shrubs and herbs. This usually leaves only one or two components, and the loadings for these are easier estimated because all other fuels have been eliminated. We also suggest that log loadings always be estimated last because they are usually done at a 100 m^2 scale.

Photoload techniques are best used when sampling experience is low and sampling time is limited (Sikkink and Keane 2008); the photoload technique is a relatively quick and inexpensive method that provides moderately precise and reasonably accurate fuel loadings. The photoload technique is not intended to replace previously developed protocols and methods. Rather, it was designed as a viable alternative when the objectives of the sampling effort and the resources available to perform the sampling match the design characteristics of the photoload technique (Keane and Dickinson 2007b, Sikkink and Keane 2008).

CREATING PHOTOGRAPHIC LOADING SEQUENCES

In this section, we detail the 12 major steps involved in creating a set of photoload sequences for a specific project in the field and how to use those new sequences to sample fuel loading (fig. 6 and table 4). Photoload sequences can be created for one or more fuel components in the target area. Steps 4 through 10 are repeated for each fuel component that needs a photoload sequence. The final product at Step 11 is a set of field-ready photoload sequences for the project. Step 12 details how to use the new set of photoload sequences in the field. In the *Discussion* section, we detail some of the problems that will surely arise during the sampling effort and how to solve them. There are also suggestions on how to train field crews to visually assess fuel component loadings using the photoload technique with the newly developed sequences. A list of all the equipment needed to create the photoload sequences is shown in inset 1.

Step 1: Specify Project Objectives

Photoload fuel loading sequences can be created for any fuel component for any set of conditions and for any purpose. Fuel components can be an individual shrub or herb species (e.g., sagebrush, pinegrass, or serviceberry), or a collection of species (e.g., deciduous shrubs), or an entire lifeform (e.g., shrubs or grasses). The selected components can be photographed to represent the range of fuel loadings across a small study site or an entire National Forest. Sequences can also be photographed to represent springtime phenology or plant conditions at the height of fire season. The photoload photographic sequences are primarily used as visual cues to estimate fuel loadings by eye, but they can also be used to facilitate the estimation of other variables, such as canopy cover, species biomass, wildlife habitat, and plant health. Therefore, it is critical that a comprehensive set of objectives be developed before proceeding to the field to provide the important context in which to develop photoload sequences and to ensure that they are highly successful in the future.

Objectives of photoload sequence development set the boundaries and form the foundation of the project. Here is a small list of potential issues that should be addressed when developing objectives for a photoload loading sequence project:

1. **Purpose**. Why are the new sequences needed? Is this a research or management project? Will the visual assessments of loading be used as inputs to fire models or smoke assessments? Will the loading estimates be used for purposes other than fire management?
2. **Scope**. What are the areas that these new sequences must represent? Are they for a specific treatment area (km^2), landscape (100 km^2), or region (1,000 km^2)?
3. **Detail**. How many ecosystems or vegetation types must be represented by the new photographic sequences? How are the new fuel components defined and classified?
4. **Resolution**. How exhaustive must the fuel component sequences be to provide an acceptable estimate? How accurate must the fuel loading visual estimates be for their use in land management?

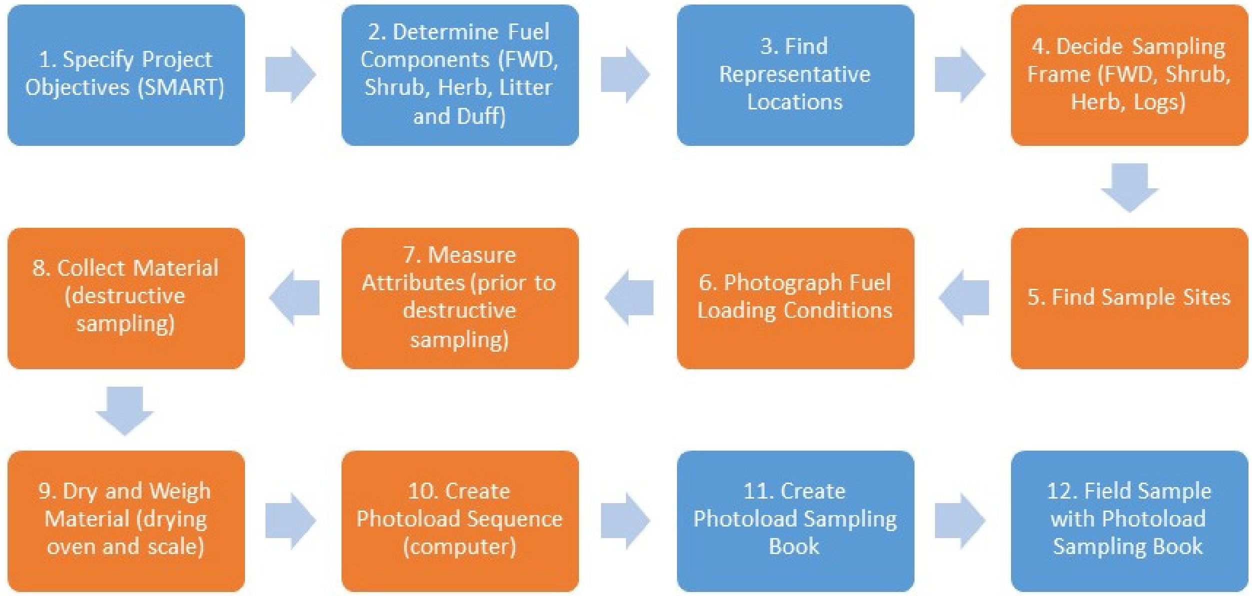


Figure 6—The work flow for the 12 steps to create in situ photoload sequences for local applications. Orange shaded boxes represent steps that are repeated for each fuel component requiring a photoload sequence. Table 4 provides more detailed descriptions of the 12 steps recommended for developing photoload sequences.

Table 4—The 12 major steps involved in creating a set of photoload sequences for a specific project in the field. Provided are name for each step, a description on how to sample fuel loading, and an example of how the step would be applied in the field.

Step number	Step name	Description	Example
1	*Specify project objectives*	State why new photoload sequences are needed and how they will be used	Develop fuel sequences for northern Utah because none of the fuelbeds are represented in photoload
2	*Determine fuel components*	Determine set of fuel components needed for fuel sampling	A photoload sequence for sagebrush is needed
3	*Find representative locations*	Identify a suite of areas that are characteristic of the selected fuel components within the target area	Various sagebrush sites are visited and one is selected to be representative of sagebrush within the local area
4	*Find sample sites*	Within selected site, find sampling areas that represent the full range of fuel loading conditions for selected component	Within the site, five areas were selected to represent the full range of possible loading conditions
5	*Decide sampling frame*	Inspect fuel conditions across the range of loadings and decide the frame of sampling	A 1 x 1 m sampling frame was chosen to represent the scale of sagebrush loading
6	*Take photograph*	Take a downward picture of the fuel conditions within the sampling frame	A 1 x 1 m sampling frame is placed on the ground to capture the target fuel condition and a picture is taken
7	*Measure attributes*	Measure various aspects of the fuel components to aid with sampling	Various attributes of the sampling frame are measured, including average sagebrush height and cover
8	*Collect material*	Collect material for the fuel component	All sagebrush plants are clipped at ground-line and placed in paper bags
9	*Dry and weigh material*	Dry the material and then measure its weight to calculate a loading	The collected material is dried in an oven and its final weight is measured on a scale
10	*Create photoload sequence*	Assign loading to each picture and create a sequence	The weights are attached to each of the photos and the photos are arranged to create a sequence for sagebrush loading
11	*Create photoload sampling book*	Arrange all photoload sequences into a book for sampling	The sequence is implemented in a sampling book to be referenced when sampling sagebrush using photoload techniques
12	*Field sample*	Use sampling book in the field to estimate loading	The sampling book is used to sample sagebrush in the field; photoload techniques are applied

Inset 1

Equipment needed to develop photoload sequences in the field. Not all the equipment is needed, especially if fine surface fuel sequences are being developed.

Camera—To take the photoload photos. Should be able to generate high quality, high resolution photos.

Plot frame—Dimensions and construction are detailed in Step 5.

Clippers, snippers—Used to clip biomass for a fuel component.

Small bowsaw—Used to saw larger woody fuels at plot edges.

Carpenter's tape—To estimate plant heights for shrub and herb components.

Go-no-go gauge—Used to quickly assess 1, 10, 100 hr woody fuel diameters.

Field Notebook—To record the details of the photo in the sequence and record ancillary data.

Pencil—Used to write in notebook.

Paper bags—A set of paper bags of different sizes to store the clipped material for transport to laboratory. Large shopping bags are often the best.

Marker—Used to label paper bags as to fuel component and photo number.

If litter and duff components are included:

Clear plastic ruler—Used to measure litter and duff depths and woody fuel diameters.

If the log component is included:

Chainsaw—Used to saw a cookie from a log to compute density.

5. **Evaluators**. Who will be using these photoload sequences? Are they experts in wildland fuel management or are they untrained technicians?
6. **Resources**. How much time is available to create the sequences? Who will create the sequences and what is their level or expertise? How much funding is available to create the sequences?

It may be that a limited amount of available resources (expertise, funding, time) overwhelms all other concerns, such as accuracy and precision. For example, getting the photoload pictures done in a week with only one person may severely limit the quality, quantity, and accuracy of the final set of sequences. Therefore, a succinct and comprehensive statement of objectives will set the stage for all future project decisions.

While there are many guides on how to construct a practical project objective (Keeney 2007), the SMART principles are perhaps the best guidelines for setting objectives for photosequence development. SMART stands for Specific, Measureable, Achievable, Relevant, and Time-based (Bovend'Eerdt et al. 2009; Lutes et al. 2006). Objectives should avoid generalities and be specific about what is needed, such as place, timelines, and people. Once the project targets are set, then it is important that the specified objective be *measureable* so that it is apparent when the project is successfully finished. It is also important that the measured variables link directly to the intended use of the sequences. Any objective must be *achievable* and *relevant*; key indicators of success must be integrated into the objective statement (e.g., sequences are needed for sagebrush in southern Idaho ecosystems for the summer field season using available personnel). And last, the objective must include a *timeline*, both for the project and for the intended use. Many people make the mistakes of (1) using goals instead of defining objectives (not specific); (2) failing to mention what is being sampled (hard to measure); (3) specifying too many tasks (not achievable); (4) including aspects that are unrelated to the sampling effort (irrelevant); and (5) forgetting to add deadlines and scheduling concerns (not time-based). Without doubt, a well-stated objective is the keystone and foundation of a successful project.

Step 2: Determine Fuel Components

This next step involves deciding just exactly what fuel components are needed to satisfy the project objectives to be useful for local photoload sampling efforts. This is done by first identifying the potential uses of the photoload-estimated loadings as specified in the project objectives. If loading estimates are being made to quantify inputs to fire models, such as FOFEM (Reinhardt et al. 1997), FuelCalc (Reinhardt et al. 2006), and CONSUME (Ottmar et al. 1993), then sequences for the input fuel components of those models are needed, such as shrub, herb, litter, and duff. Next, the photoload sequences in the Keane and Dickinson (2007b) report should be evaluated to decide if the species and fuel attributes in that document are appropriate for the new target area and for the project objective(s). The following should also be assessed depending on fuel component.

Fine Woody Debris

The Keane and Dickinson (2007a) photoload sequences for fine woody debris (1, 10, 100 hr downed dead woody) were taken using freshly fallen Douglas-fir downed woody sticks. These sticks had an average particle density of approximately 380 kg m^{-2}, which is commonly found in the field; examples of particle densities found on various northern Rocky Mountain ecosystems can be found in Keane et al. (2012a). If these photos represent stick dimensions and densities for the target area, then they need not be redone. However, if fuelbeds with different stick characteristics and particle densities are present in the target area, such as for broadleaf forests or rangeland conditions, then it is advised to recreate these fine woody fuel categories. In another example, if the photoload series is to be used for assessing slash fuels, then the fine woody sequences may need to be retaken.

Creating fine woody debris sequences can be one of the easiest tasks in this methodology because, unlike plants, sticks can be easily transported into a plot frame to reasonably reconstruct a fuelbed in situ to obtain desired fuel loadings, which can then be photographed. It is always better to photograph undisturbed fuelbeds, but if time and resources are short, we suggest that one flat, representative site be selected and a stash of woody fuel particles be collected for each of the fine woody fuel size classes. Note that studies have shown that the 1, 10, and 100 hr size classes have high uncertainty in their loading estimation because the diameter size class ranges are inconsistent and disparate (table 1) (Keane and Gray 2013; Sikkink and Keane 2008). In some cases, 1.0 cm classes may be a more appropriate measurement to use, unless, of course, the loading data are to be used as inputs to fire models which require the 1, 10, and 100 hr fuels classification method.

Shrub and Herbs

Perhaps the single most important decision in the project is how to represent shrub and herb fuel components. Characteristics of the target area must be assessed to evaluate the number and kinds of shrub and herbaceous fuel components needed to capture the variability in loadings across each life form. Photoload sequences for the shrub species in a montane forest, for example, may require six sequences to represent the six most commonly occurring shrub species for that forest. If the project objectives allow shrub or herb fuels be represented as a life form (i.e., one fuel component for all shrubs and one for all herbs), then the development of the lifeform sequence becomes somewhat easier (only one sequence is needed) but also somewhat problematic (e.g., the wide diversity of shrub or herb species and their corresponding morphologies that can occur within a FAP may be so great that finding representative ranges of fuel loadings may be difficult). Many forest stands, for example, may have over 10 shrub species that have different shapes, sizes, and weights. As a result, we have found that developing photoload sequences at the individual species or guild level may be the most efficient way to partition the large variability within a life form into manageable sampling schemes, and it also allows the sequences to be used for other resource objectives, such as forage and wildlife habitat assessments (Keane and Dickinson 2007a). The downside is that target areas may consist of many shrub and herbaceous species that require many sequences that might overwhelm many projects. If resources are limiting, then grouping species to a genus or plant functional types (Diaz and Cabido 1997; Smith et al. 1993) may be a good way to minimize the large number of photoload sequences needed in highly diverse areas. We have found that these species-level sequences are easier to use, more accurate, and more useful for other purposes, such as ecological abundance measures.

Once shrub and herb components have been decided, then the Keane and Dickinson (2007b) report can be referenced to see if any of the desired species are represented in their photoload sequences. If not, then a sequence must be developed for each of the missing components. Developing shrub and herb component photoload sequences will be the most common use of this method.

Logs

It may be tempting to develop a photoload sequence for 1,000 hr fuels or logs (table 1), especially if a log sequence is important for accomplishing the project objective. However, Keane and Dickinson (2007a) found that creating log loading sequences were fraught with challenges and complications. First, it is difficult to work with logs in the field as they are heavy and unwieldy. For example, it is difficult to measure log weights in situ without subsampling (cutting a cookie for wood density) and taking indirect measurements (log volume), which always introduces additional uncertainty into the weight estimates (Woldendorp et al. 2004). Second, logs in an area are usually in different stages of decay and this creates a wide range of wood densities within and across logs that may confound log weight estimates (Keane et al. 2012a). Next, the spatial distribution of logs is highly variable, ranging from 50 m to over 200 m (Keane et al. 2012a), which makes selecting an appropriate sampling area and plot frame difficult (Step 5). And, most important, the diameters of logs in the representative area are rarely similar within and across forests, and because log weights vary with the square of the diameter, selecting only one diameter to represent all logs in a plot may be an overgeneralization. Therefore, we recommended that log loading be estimated by visually assessing the log lengths and then using tables rather than the photoload sequences (Step 10). We recommend that new tables designed specifically for the local area be created in the right units, the representative wood density, and the appropriate diameter and length classes using Keane and Dickinson (2007a) methods. We have found the table method vastly superior over the photographic method.

If photographic log sequences are desired over the tables, then the sequences in Keane and Dickinson (2007b) should be evaluated to determine if they are sufficient. These sequences are for 6 in and 12 in diameter sound logs. If these diameters are inappropriate, we strongly suggest that all photo series for the target area be evaluated to see if they are useful. Photo series are essentially the same as in situ photoload sequences because they have the same field of view. If there are photo series for the area, then each page can be inspected for log load (1,000 hr) and various pictures that represent the range of log loadings for the target area can be scanned and used to create a photoload sequence. If no photo series are available, then a log photoload series has to be created using this method.

Litter and Duff

Some people may want to augment future photoload sampling efforts to include estimates of loadings for litter and duff to produce a more comprehensive assessment of the total surface fuelbed loadings. As mentioned, assessing duff and litter loadings is difficult using a photographic technique because the thickness of the duff and litter layer, a characteristic that is impossible to assess from a photograph, dictates the amount of biomass (Brown 1981).

However, a more accurate and comprehensive method is available when the bulk densities of the litter and duff layer are multiplied by depths to compute loading. In this method, relatively quick depth measurements for litter and duff can be taken within or directly adjacent to the FAP frame and the average for each layer then multiplied by a layer bulk density value to compute loading (Keane et al. 2012a). This is the most common way to estimate duff and litter loadings (Lutes et al. 2006). However, to use this technique, an accurate estimate of litter or duff bulk density is needed (Keane 2015). Conventional sampling methods often use an overly generalized estimate of bulk density from the literature that isn't entirely representative of the target area (Brown 1981). Therefore, we strongly recommend developing a set of photoload sequences that are also arranged along gradients of bulk density rather than loading for litter and duff. The photos of litter and duff can then be used to select the most appropriate bulk density to use to compute loading.

Either of these approaches would involve sampling the photographed fuelbeds for litter and duff bulk density and loading. Measurements of bulk density and loading attributes could be added to each photo in the photoload sequence to provide a means of estimating litter and duff loading using photoload visual techniques (Keane et al. 2012a) or to use in the supplemental sampling of depths. Because sampling for loading and for bulk density are essentially identical, we strongly suggest both are done at each sample site. Methods for measuring litter and duff loading and bulk density attributes are detailed in Step 7 to 9. Methods for using these attributes to estimate loading in the field are detailed in Step 12.

Step 3: Find Representative Locations

This next step involves extensive reconnaissance across the entire target area to find the best candidate representative locations in which to photograph loading sequences. It is sometimes highly efficient and timely to conduct the entire photoload sequence project in a small area that is generally representative of the larger target area, but this may not be possible because of the high variability in loading across the target area or if sequences for more than one fuel component are being developed. Therefore, care must be taken to ensure that the entire gamut of fuel loading conditions are captured for the target area. There may be more than one representative location for a fuel component within the target area.

The best candidate sites for sampling are those that are relatively free of other fuel components and feature the particular fuel component for the photos. Other fuel components can be plainly visible in the photo but they should not dominate the photograph. Sagebrush representative areas, for example, should be dominated visually by sagebrush with minimal evidence of other shrub species within the photo. Once representative locations are selected, the entire vicinity should be inspected to determine the range of fuel loadings present within the area and the appropriate points at which to take the photographs to represent each of the loading conditions within this range (sample sites).

It is possible that more than one fuel component can be measured within the FAP frame. A photoload photo for the 1 hr fuel loading, for example, can be the same photo that depicts a loading for a shrub or herb species. In fact, if time and resources are limited, then sampling multiple fuel components at one sample site may be warranted.

Step 4: Decide Sampling Frame

Fine Woody Debris, Shrub, Herb

Now that you are familiar with all of the possible fuel loading conditions within the representative locations of the target area from the reconnaissance, an appropriate sampling frame must be decided to clearly delineate a spatial boundary in the photographs of fine fuels. The original Keane and Dickinson (2007b) method used a 1 m x 1 m (1 m^2) square sampling frame to bound fine woody, shrub, and herbaceous fuel conditions (fig. 7). This size is optimal for capturing fuel conditions within the FAP because (1) fuel particles are plainly visible when the photo viewpoint is close enough to the ground; (2) loading assessments are always in the right units (per m^2); and (3) spatial variabilities of fine fuel component loadings are adequately represented (Keane et al. 2012b). The estimate of the amount of fuel on the plot can be easily converted to the proper units because the plot frame is 1 m^2 (e.g., a visual estimate of the amount of fuel is 0.5 kg inside the plot frame, so the loading is 0.5 kg m-2). And most importantly, Keane et al. (2012a) found that the finer woody, shrub, and herbaceous fuels vary across space at scales from 1 to 5 m. We feel that this 1 m^2 photo frame is suitable for most fine woody, shrub, and herbaceous fuel components for these reasons.

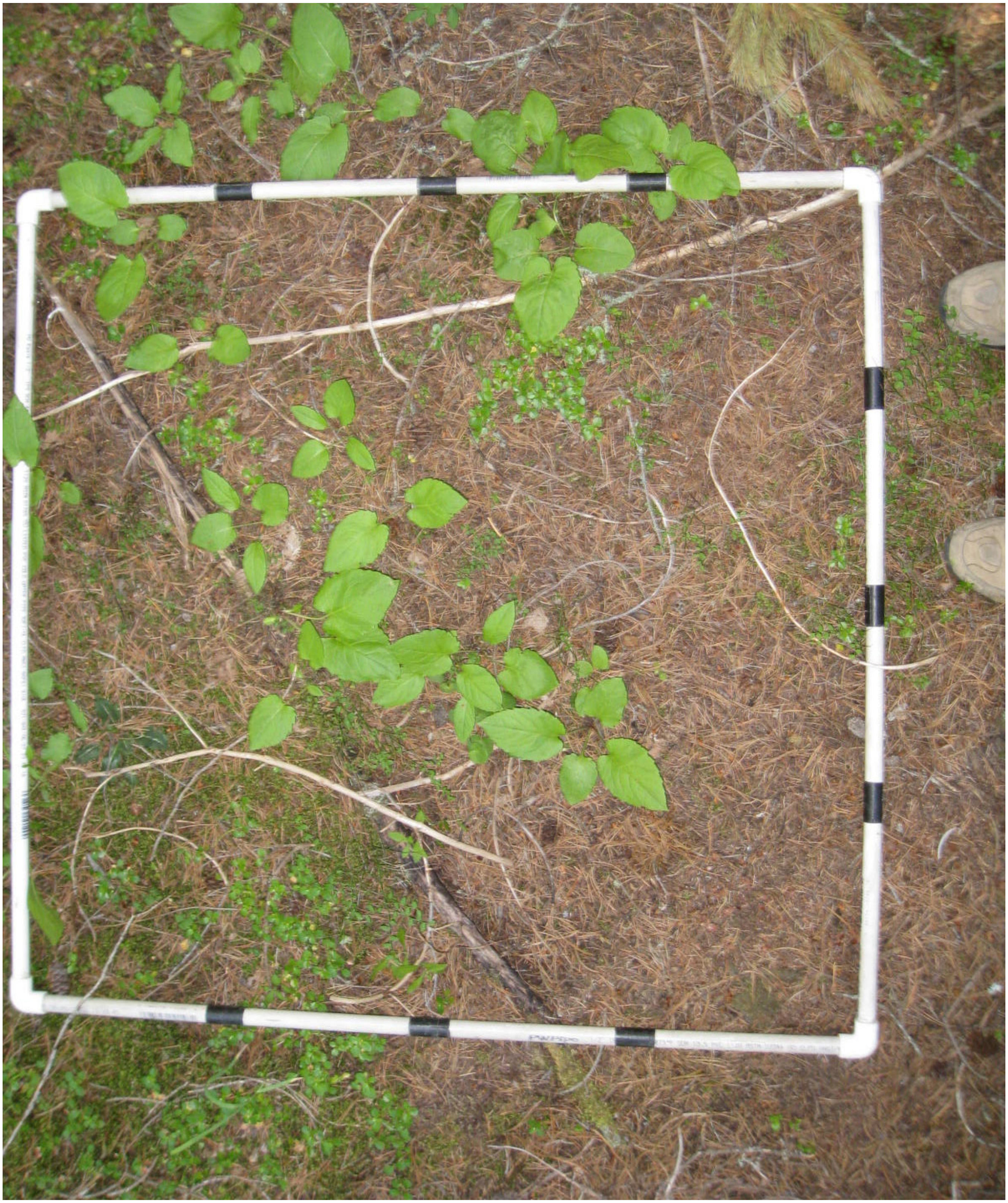


Figure 7—A 1 m x 1 m square plot sampling frame to be used to outline the photo to emphasize fuel conditions and set the spatial boundary of fuel estimates. Note the frame is made of 2.5 cm (1 in) diameter white PVC pipe and black tape is used to identify half and quarter portions within the frame to aid in visual estimation. The inside of the frame delineates the 1 m^2 area.

There are times, however, when a 1 m^2 FAP is inappropriate. If shrub or herbaceous components are taller than 1.5 m (5 ft), then a 2 m x 2 m plot frame may be more ecologically and statistically viable. Also, since 100 hr and 1,000 hr downed dead woody fuels vary at scales greater than 5 m (Keane et al. 2012b), a larger plot frame may be needed. Keane and Dickinson (2007a) used a 100 m^2 sampling frame for 1,000 hr downed dead woody fuels in the original method but found that visual estimates at that scale are extremely difficult and highly variable (Sikkink and Keane 2008).

Once the FAP size has been decided, then it is time to build the frame so it is plainly visible in the photographs (inset 2). We recommend that the plot frame be built from heavy-duty white PVC round piping with a 1 cm to 2.5 cm (0.5 to 1 inch) diameter (fig. 7). If the representative site is somewhat dark, then the PVC pipe could be painted a highly visible color, such as neon orange or yellow. We also suggest that black tape be used to mark the halfway mark on all sides and the quarter distances on two sides (fig. 7). This will allow quick and easy estimates of percent cover and can also indicate sampling spots if litter and duff depths are being taken (Lutes et al. 2006; Lutes et al. 2009).

Inset 2 (a-c)

The PVC plot frame is built from heavy duty, round white PVC piping with 1 cm to 2.5 cm (0.5–1 inch) diameter. Pipes are fit together at the corners with PVC joints to create the 1 m2 plot frame. Black tape can be used to mark the half and quarter distances to aid in quick and easy estimates of percent cover and to indicate sampling spots for litter and duff depths. A meter is measured from inside the plot frame.

Logs

If photoload sequences are needed for logs, instead of using the table method (see Step 2), then the plot frame will need to be much larger than the one used for the fine fuels. Log loadings are highly variable in the field because they are patchily distributed across the landscape (Keane 2016). Dense forest stands often have many logs that can be evenly distributed at scales from 50 m^2 to 150 m^2, while open, park-like stands have widely dispersed logs that vary at scales above 150 m^2. We have found that a 100 m^2 sampling frame is acceptable for most forested stands with natural fuels (Keane et al. 2012b; Keane 2015; Keane 2016). However, this area can be increased if inadequate for the target area (i.e., log loading is low and more logs need to be in the picture). Instead of a fixed plot frame, we suggest using highly visible (yellow) ropes that are staked to the ground to define the plot area.

The shape of the plot frame for photoload sequences may become an issue due to the physics of the camera lens and oblique point of view. As mentioned, Keane and Dickinson (2007a) used a unique plot shape to define the boundaries of the original photoload sequences for logs (fig. 5). This has also worked well for in situ photosequence creations, except for forests with scarce logs, in which case the shape was simply enlarged to go to 200 m^2.

Step 5: Find Sample Sites

A major decision that now must be made is how many photos to take to fully represent the range of fuel conditions for the target area. This number may dictate the number of sample sites needed, but it shouldn't be used to limit sample site selection. The desired number of sample sites depends on many factors, but three criteria have proven to be most important: (1) the resolution needed to quantify fuel loading for that component; (2) the range of fuel loading conditions evident on the representative location or for the entire target area; and (3) the people that will be using the photoload sequences. If experienced fuel specialists are using the sequence for a relatively simple fuel component, such as sagebrush, than perhaps only a small number of photographs are needed. A general rule of thumb is no more than 15 and no less than 5 photos in a sequence. And, when in doubt, always add another site and take photos and sample the site for loading if there are time and resources. In fact, we suggest that, if time permits, a large number of sample sites be selected to ensure a good range of loading conditions. Remember, it really doesn't matter how many representative sites are photographed and sampled because selection of whether the photograph should be included in the photoload sequence is decided later in Step 10.

Selecting sample sites involves finding an area 1–4 m^2 in size within the representative location to represent one fuel loading condition along the gradient of fuel loading conditions evident in the target area. Canopy cover or plant volume is often useful as a surrogate for biomass amount to determine a loading (Keane 2015). Once a site has been identified, it can be flagged to be measured later or it can be measured immediately by dropping the plot frame onto the ground to bound loading conditions.

Step 6: Take Photograph

Fine Woody Debris, Shrub, Herb

Now it is time to take the photograph to capture the specific fuel loading conditions for the desired fuel component at the sample site (inset 3). This should be one of the easiest tasks in the entire process. First, the plot frame should be placed on the representative site to fittingly capture the fuel loading conditions of the desired fuel component. The plot frame should lie directly on the ground and be positioned such that it illustrates and highlights the spatial domain of the photograph. Fuels in the photographed frame should not be trampled or modified in any way, especially if shrub and herbaceous fuels are being photographed.

Inset 3 (a-f)

The plot frame should be placed on the representative site to fittingly capture the fuel loading conditions of the desired fuel component. The plot frame should lie directly on the ground and positioned such that it illustrates and highlights the spatial domain of the photograph. Fuels in the photographed frame should not be trampled or modified in any way, especially if shrub and herbaceous fuels are present. All photos should be taken at eyelevel or around 1.75 m (5.5 ft) above the ground. The picture should represent conditions inside the plot frame and on two or more sides of the frame. Profile pictures are useful for showing the fuelbed and general conditions of the photographed area.

Next, the photograph depicting fuel loading conditions for the photoload sequence is taken with a camera. Any camera can be used to take the photograph, including cellphone cameras. However, high resolution photographs are always best, especially for depicting fine fuels. All photos should be taken at eye-level or around 1.75 m (5.5 ft) above the ground. The photo should be taken focused directly down at the fuelbed or from the side. A tripod is not needed. Again, the photo should be taken to capture the conditions inside the plot frame. We suggest at least two photos be taken at each sample site on two or more of the sides of the plot frame. Each photo should be checked in the field to ensure high quality and picture objectives were filled.

It is also suggested that photos showing the fuelbed from the side (profile) and the general conditions of the photographed local area around the representative site be taken to capture a greater scale illustration of site conditions (inset 3), much like the photos taken in photo series (Maxwell 1976; Ottmar and Vihnanek 2000). Digital Photo Series is a web-based project that provides a compilation of natural fuels photo series. These extra photos can be integrated into the photoload sequence as a way to provide additional context to each individual photo (Step 10).

All photos should include an object or measurement device for scale (inset 4). There are several ways to do this including pasting a cloth tape to the plot frame; putting a ruler or yardstick in the photo; or adding an object of known dimensions in the photo such as an aluminum can, dollar bill, helmet, or pencil. In log photos, people and range poles are often used. These objects will help in estimating loading.

Logs

Photos of the log loadings are oblique and designed to emphasize the log distribution, size, and number. There is no suggested way to take this photo. The field of view of the camera should be maximized to show only the plot frame such as the one in figure 3. It may be beneficial to review various photo series to get an idea of how to take the picture.

Litter and Duff

If litter and duff sequences are needed to augment field sampling efforts, we suggest that a photo that emphasizes the litter layer also be taken (inset 4). This photo can be taken closer to the ground (e.g., 3 ft or closer) or at another point of view and it can be added to a sequence to help with visual loading estimates. Perhaps two or more photos are needed to fully capture the conditions within the FAP. Moreover, it is highly recommended that the photo of the litter and duff profile be taken after the material is excavated for bulk density measurements (Step 8).

Step 7: Measure Attributes

Once the pictures are taken, it is then time to measure various in situ attributes of the fuel component that will be tagged to each photo in the developed photoload sequence (inset 5). These measurements must be done prior to clipping or destructively sampling the FAP. These measurements are important in using the photoload sequences to accurately estimate loadings, especially for shrub and herb species, and they can also be used to provide additional information to the photo. No extra measurements are needed for fine woody fuels.

Inset 4 (a-f)

All photos should include an object or measurement device for scale. At the plot frame level, a ruler, soda can, or any object of known dimension is acceptable. For log photos, people are often used. These objects help in estimating loading. Litter and duff sequences should emphasize the litter layer and capture conditions within the FAP. Litter and duff photos should be taken after material has been excavated.

Shrub and Herbs

If the fuel component is a shrub or herbaceous species or group, then the average height of the plants for the component needs to be measured or estimated for the entire sampling frame to adjust visual loadings to account for the differences in height between the photo and field conditions when using the developed sequence (Keane and Dickinson 2007b). This can be done in any number of ways. In an intensive approach, a carpenter's tape can be used to take height measurements at 1–10 points within the plot frame to calculate an average (e.g., take height measurements at the 9 points along the plot frame). Or, the average height can be approximated by visually determining a point within the plot that is representative of average height and measuring the height at that point (inset 5). Some sampling techniques suggest envisioning a cloth sheet draped onto the fuel component and estimating the average height from the envisioned surface (Lutes et al. 2006). Or the average height can be approximated by viewing the fuel component from the side (profile) using a tape or yardstick as reference. Finally, a photo of the plot profile can also be taken to estimate height in the lab on the computer using software (inset 5).

We also recommend a number of other measurements be taken for the shrub or herb component. First, a visual estimate of projected canopy cover can be recorded to aid fuel estimation and to support other possible uses of the photo (inset 5). Next, we suggest that the sampling crew make some preliminary estimates of the loading to practice the photoload technique, and it may be beneficial to integrate the sampling with the training presented later in the *Discussion* section.

Logs

Log biomass will probably not be collected for most sequence development projects for obvious reasons. Therefore, to approximate log weight, a volume based approach is often used. Log volume can be approximated from the length of the log (m) and the diameters of the large and small end of the log measured up to 7.62 cm (see Step 10). We also suggest that a decay class be used to estimate the wood density of the log (table 3). These four measurements (length, large and small diameters, and decay) should be repeated for all logs above 10 cm in diameter (inset 5). The methods detailed in FIREMON (Lutes et al. 2006) or FFI (Lutes et al. 2009) may be useful for this effort.

Duff and Litter

If the project has identified litter and duff as two components that need sequences, we also suggest that the depths of the litter and duff be taken within the northwest quarter of the FAP. The suggested collection procedure is similar to that used by Keane et al. (2012a) where duff and litter depths are taken at five points in the northeast quarter of the frame (each corner and halfway between each corner) (fig. 8). This is done using a plastic clear ruler and a trowel; the trowel is used to excavate a small area at a sampling point down to mineral soil and the zero end of the ruler is placed on the mineral soil so that the depths of the litter and duff can be read directly off the ruler (inset 5). Since the transition from litter to duff is often difficult to detect, there is rarely an obvious measurement point between the two layers and a "best guess" is often needed. We have found the most repeatable means to distinguish between litter and duff is that the duff begins when the fuel particles can no longer be differentiated (the original fuel particle cannot be identified [Keane 2015]).

Inset 5

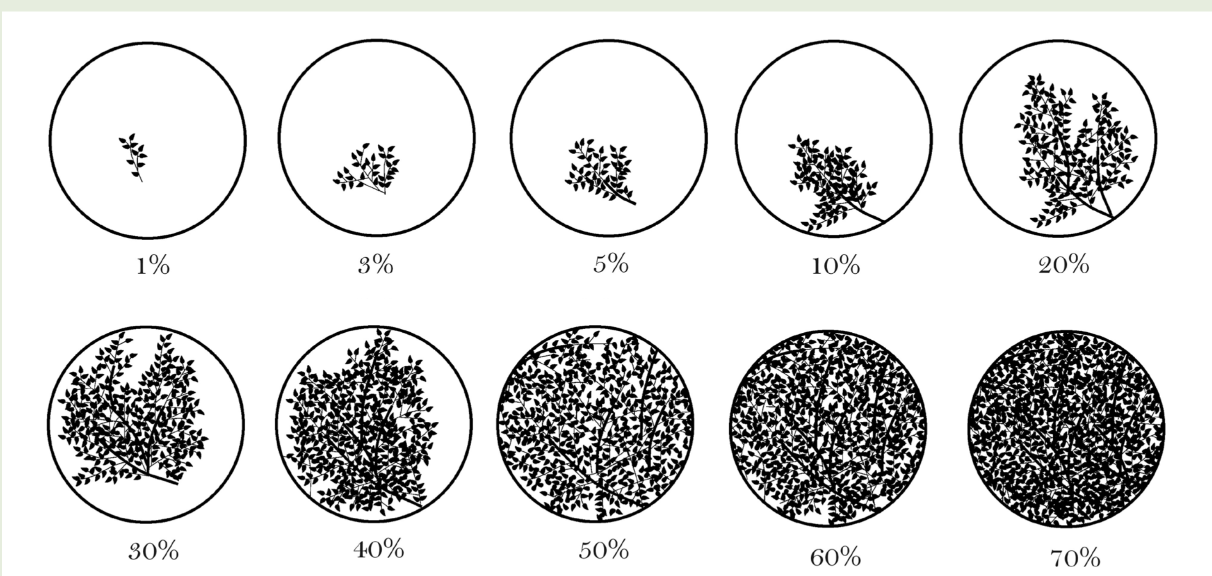
Prior to destructive sampling, it is necessary to measure various in situ attributes in order to accurately estimate loadings, especially for the shrub and herb fuel components. No extra measurements are needed for fine woody fuels.

Measure Attributes

Shrub or Herbaceous Species or Groups

Average height of the plants must be measured or estimated for the entire sampling frame so that loadings can be adjusted for height differences between the photo and field conditions. Average height can be approximated a number of ways, such as by determining a point within the plot that is representative of average height and measuring the height at that point; a photo of the plot profile can also be taken to estimate height in the lab on the computer using software.

A recommended measurement for the shrub or herb component is a visual estimate of the projected canopy cover to aid fuel estimation and to support other possible uses of the photo. The following figure taken from FIREMON (Lutes et al. 2006) details the visual estimation of cover for multiple entities using a pictorial representation; the cover of multiple entities makes the estimation task more difficult because you have to mentally separate each entity. It is easiest to first make an estimate of the total vertically projected cover on the sampling area, and then estimate cover of the entities from greatest cover to least cover.



Logs

Volume is approximated using log length, diameter at the large and small ends, and decay class as shown in FIREMON (Lutes et al. 2006).

Duff and Litter

Duff and litter depths are measured with a trowel used to excavate a small area at a sampling point by digging down to mineral soil; placing the zero end of a clear plastic ruler on the mineral soil provides a direct measure duff and litter depths.

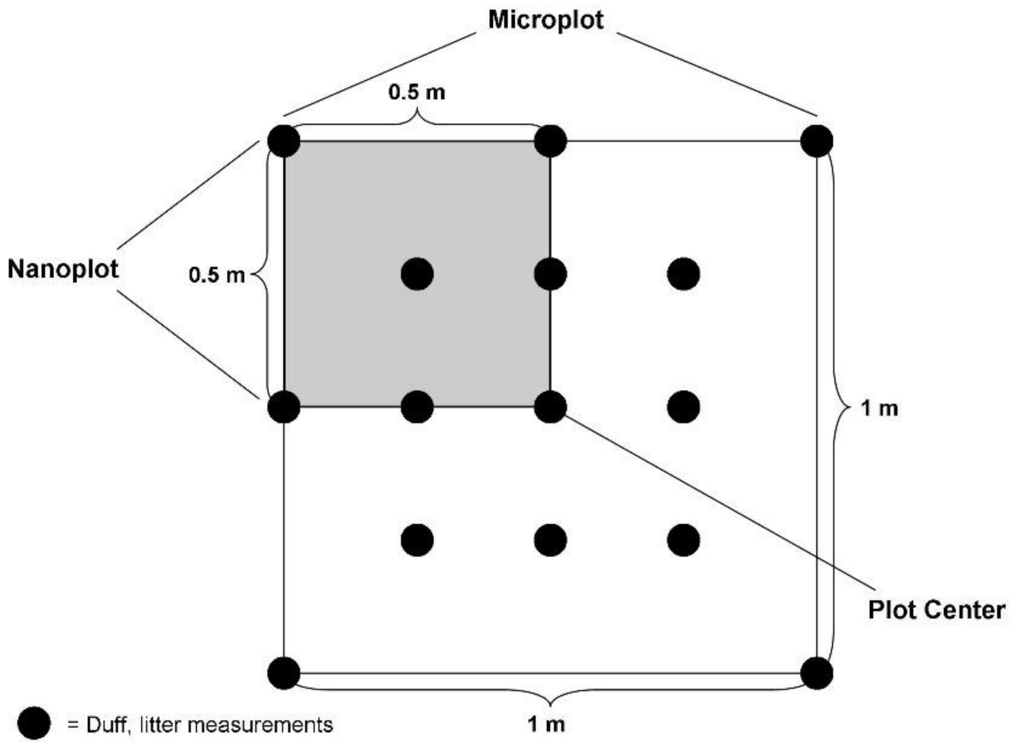


Figure 8—Litter and duff depth sampling places on the Northwest (NW) quadrant of the FAP. The gray area is the portion of the FAP in which duff and litter samples are taken and the dots show the location of each depth measurement site. The other dots in the figure show a possible pattern to measure duff and litter depths in a sampling effort.

Step 8: Collect Material

It's now time to collect all the biomass for each component in the FAP once all measurements are recorded. This is done using destructive sampling techniques involving clipping and gathering the target fuel component particles. It is important that only the target fuel components be gathered and that they are collected independently of each other. This means that if a shrub species is the target component, then only material, live or dead, for that species be collected and stored; do not mix fuel components. This may be confusing as the dead particles of shrub or herbaceous species often mingle making it difficult to determine to which species a particle belongs. If time and resources permit, we recommend that the biomass for fuel components (other than the featured fuel component) be collected as well for a wide variety of reasons. First, the photo may provide a dual purpose in serving as part of a sequence of another fuel component and as a training photo. Moreover, it could be that the loading for the ancillary fuel component may provide a critical loading in the sequence gradient that was unanticipated.

Fine Woody Debris

Downed dead woody material is sometimes difficult to sample because it often extends beyond the dimensions of the plot frame and it is often integrated into the duff and litter. Only woody fuel particles that are visible or above the litter should be collected; do not collect any woody material that was below the litter and duff but was revealed during the collection process. Clip all woody fuel particles that extend beyond the plot frame boundary. Place the woody material from the interior of the FAP in paper bags and label as appropriate. Long and unwieldy woody fuel particles can be snipped so that they neatly fit into the bags (inset 6).

Inset 6

Once all measurements are recorded, biomass for each component can be collected. Only the target fuel components should be gathered; so, if a shrub species is the target, then only live or dead material for that species should be collected and stored. Fuel components should not be mixed, and collection bags should be clearly marked with identifying information.

Fine Woody Debris

Downed woody material that extends beyond the dimensions of the plot frame should be clipped at the plot boundary; only the woody fuels that lie above the litter within the plot frame should be collected. Unwieldy woody fuel particles can be snipped to fit into the bags.

Shrub and Herbs

Shrub and herbaceous material should be clipped at ground level, above the litter. Do not include roots, stems, and leaves that are integrated into the litter. Shrubs may require a heavier clipper than standard garden snips. Place material in clearly labeled bags. Any material that crosses the plot frame boundaries should be clipped at the boundary and only the fuels from inside the plot frame should be included in the bag.

Litter and Duff

If developing litter and duff sequences, then a subsample of the FAP must be collected. Rather than collecting duff and litter from the entire plot frame boundary, we suggest collecting only the material from the northwest quarter of the FAP (refer also to fig. 8) for measurement and analysis.

Shrub and Herbs

Shrub and herbaceous material should be clipped at ground level, just above the litter (inset 6). Do not include roots, stems, and leaves that are fully integrated into the litter. Shrub fuels may require a heavier clipper than the standard garden snips if branch diameters are large (> 2 cm). This clipped material should be placed in a paper bag and the bag labeled with permanent marker as to the date and representative site name or number. If any shrub or herbaceous material crosses to the outside of the plot frame, then that material must be clipped and not included in the fuel sample; only material within the plot frame boundaries should be included in the paper bag.

Logs

Obviously, collecting all logs within the photoload picture is difficult so log weight must be estimated from log volume multiplied by wood density. To obtain an accurate estimate of wood density, it is important to sample it at the sample site; however, most projects will use standard densities from the literature such as the synthesis of coarse woody debris developed by Harmon and others (Harmon et al. 2008). But if higher accuracies are needed, then a cookie must be sawn from one or more logs. This is best done with a chainsaw, but it can also be done with a bow saw or cross-cut saw. The dry weight and volume of the cookie can then be used to compute density, with or without bark (Williamson and Wiemann 2010).

Litter and Duff

If litter and duff photoload sequences are desired, then a subsample of the FAP area must be collected. Here, we suggest that duff and litter material from the northwest quarter of the FAP be collected for measurement and analysis, and not the entire 1 m^2 (fig. 8). The black tape marks on the plot frame can be used as reference. After excavation, the depths at the four corners of the hole where the excavated material was taken are measured for both litter and duff similar to Step 7, inset 5.

There are many ways to remove the litter and duff. We have used a flat-nosed shovel with nose dimensions that match the subframe dimensions (50 cm). Others have used trowels, their hands, and spatulas to perform this task. It is important to avoid getting mineral soil in the duff and litter sample. The sample can be placed in a paper bag and the duff and litter can be separated in the lab before drying.

Step 9: Dry and Weigh Material

Fine Woody Debris, Shrub, Herb

All collected and sorted fine fuel material should be placed in a drying oven at 90 °C for 2–3 days to dry to less than 1 percent moisture content. Once dried, the fuels should then be placed on a scale to obtain a weight. That weight will be the loading (kg m-2) if a 1 m^2 FAP was used, or convert to loading by dividing by the size of the FAP. Be sure the units match. Record this number in a spreadsheet, along with the fuel component, sample site number, date, and any other notes. The user can convert to tons per acre by multiplying by 4.46.

It may be that so much material was collected for a given fuel component that it was impossible to fit all the biomass into a drying oven(s) in the time allotted. If this is anticipated, then another procedure may be more appropriate but less accurate. The collected material is weighed in the field to obtain a wet weight. Then, a small portion of the weighed material is also weighed in the field and placed in a labeled paper bag. This material should then be transported back to the lab to be dried in the oven. After 2 to 3 days at 90 °C, the material should be weighed and the moisture content of that portion should be estimated from the pre- and post-dry weights. That moisture content, as a proportion, can then be used to adjust the wet weight of the collected fuel component to a dry weight.

Logs

If photoload sequences were taken for the log fuel components, then the log measurements must be used to compute log volume that is then used to estimate log weight. Biomass of individual logs (kg) is calculated by multiplying log volume by the measured wood density (D, kg m^{-3}) using the following equation:

$$M = VD \tag{1}$$

where V is the volume of the particle (m3), and D is the wood density (kg m-3) quantified from laboratory analysis of the collected woody cookie. Volume (V) is calculated using the following equation:

$$V = \frac{l}{3}\left[(a_s + a_l) + \sqrt{(a_s a_l)}\right] \tag{2}$$

where a_s and a_l are the areas (m^2) of the small and large end of the fuel particle (a = ϖd2/4, where d is the log diameter at the small and large ends of the log), respectively, and l is the length of the particle (m). This assumes that the log shape approximates a truncated frustum. As mentioned, wood density (kg m-3) is either taken from the literature (Harmon et al. 2008) or calculated from samples taken onsite. To determine densities, the total dry mass of the collected cookie is divided by the total volume of the cookie. The volume of the cookie is estimated using a water displacement method—see Keane et al. (2012b).

Litter and Duff

If duff and litter material were collected, and the entire profile was stored as a whole, then we strongly recommend that the litter and duff be separated and then dried and weighed separately. It is important to remember that this sample is from a fraction of the photographed plot, so it is important to convert to the right units based on the size of the duff and litter collected sample; if a quarter of the plot was taken, for example, then the measured dry weight is multiplied by 4 to calculate a loading (kg m-2) if it was a meter square plot frame. Litter and duff photoload-based sampling require a bulk density as well.

The duff bulk density is easily calculated as the weight of the duff sample divided by the product of the average of the four duff depths taken at the corners of the excavated sample converted to meters and the area of the excavated sample in meters (units for bulk density are kg m-3). The same approach is used to calculate litter bulk density.

The duff loading and bulk density values can be used for the two separate methods of estimating duff and litter loadings for photoload sampling mentioned in Step 2. First, if time is pressing and sampling experience is low, then it may be that the calculated loading for the different photoload sequence pictures can be used as a loading for photoload sampled areas in the future. A much better method would be to measure the duff and litter depths on the photoload sampled areas (at least four measurements), calculate an average and convert from cm to m, and then multiply by the bulk density to calculate loading. In our opinion, this second approach is far superior to any other indirect approach, such as allometric regression equations from cover and height estimates (Keane 2015; Lutes et al. 2006) in the literature.

Step 10: Create Photoload Sequence

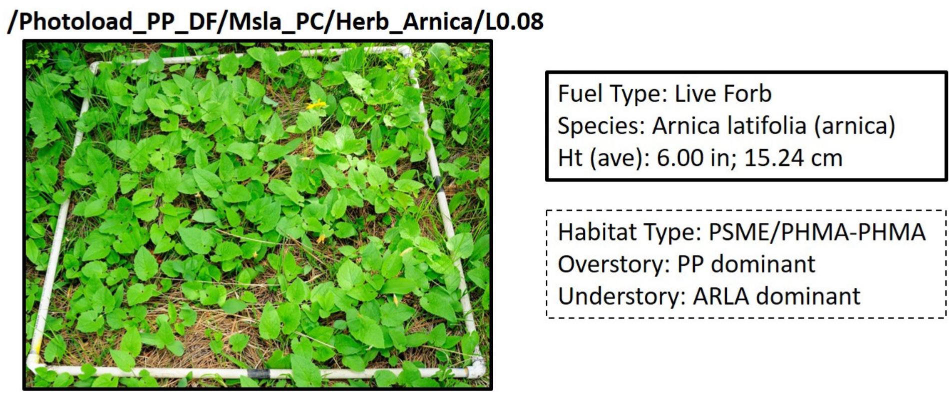
In this step, all photoload sequences for the entire target area for all loadings and fuel components are downloaded to a computer system into an efficient directory structure to facilitate rapid creation of photoload sequences using computer software. A possible directory structure would be: **/Project_Name/Target_Area/Fuel_Component/Loading_ Sequence_Number,**

where **Fuel_Component** is the short name for a selected component (e.g., ninebark, PHMA, or shrub) and **Loading_Sequence_Number** is the loading value for that fuel component (e.g., L0.5 is 0.5 kg m-2). All photos taken for a target loading, including those that portray stand conditions, duff and litter profiles, and fuel conditions, are downloaded into each appropriate directory. Next, the spreadsheet of loadings by fuel component by target area is opened to reference the measured values. Then, a graphics package to develop the photoload sequences must be selected. Any graphics package will do, but most people will probably use Microsoft Word, PowerPoint, or Adobe Acrobat. It is helpful if the developer is familiar with the selected graphics package and it is best if the user has done graphics layouts before. If not, a private contractor may be needed to create high quality products.

The overall design of the photoload sequence field sampling sheet is created next (fig. 1). Remember, this sheet will be used by people in the field to quickly estimate fuel component loadings, so it is critical that the photos are high quality and of sufficient size, loading estimates are clearly attached to each photo in the desired units, and the sheet is designed so the gradient of fuel loading is easy to understand. We strongly suggest one sheet per fuel component, one picture per fuel loading, and at least 5 and at the most 12 pictures per sheet. At a minimum, the sheet should contain the loading photo and measured loading pair. In addition, other information can be attached to each photo including duff and litter loading, duff and litter bulk density, and, for shrub and herbs, the average height of the fuel component (inset 7). The back of the sheet can be used to display the other photos taken at each loading representative site and any other types of information that may be useful (vegetation type, potential vegetation type, UTMs). Example photoload sequence sheets can be found in Keane and Dickinson (2007b) (fig. 1).

Inset 7

(7_1) Photos for a target area are downloaded to a computer system with a directory structure that will facilitate rapid creation of photoload sequences. Loading estimates associated with the photo should be clearly attached to each photo along with other information deemed necessary by the user, such as average height of the fuel component (shrubs and herbs). The back of the sheet can be used to display other photos and other information such as potential vegetation type.



(7_2) The following picture displays an incomplete sequence to highlight the process of creating a photo sequence. The page below was created by selecting a photo of the target component in which a photo series for an herb component (*Arnica*) is developed. Beginning with the photo depicting the least loading, dragging the photo into the software and placing it in the first position along with the measured loading (and height for shrubs and herbs). This procedure is repeated for the photo with the next lowest loading and so on until the photoload sheet is complete. Here, an incomplete sheet displays the highest loading in the series in the lower right corner. Blank boxes are provided to contain the next two lower loadings if those photos are available. The upper three photos depict decreasing loadings from right to left and all the photos are labeled with measured loading and heights since they are herbaceous components.

The sequences are created by finding the photo with the least loading for a component, dragging the photo into the software, and placing it in the first position (upper left, for example) (fig. 1) (inset 7). Then, the loading measured for that photo is entered near the photo in the software along with the correct units. For shrub and herbaceous components, height is also entered near the loading. Last, any ancillary measurements can be entered near the loading, such as canopy cover, date of sampling, and any other important reference data. This procedure is then repeated for the photo with the next lowest loading and so on. Keep in mind that the next loading photo may not be visually different from the previous photo, so be sure that the difference in loadings is clearly portrayed in the two photos. This is done until the entire range of loadings is represented in the sequence. It is important to keep the photos on one page for ease of use in the field; therefore, the photos should be large enough for ease of differentiation between photos with the print font large enough to be easily seen.

All developed in situ photoload sequences will be used in the field, so it is important that the printed sheets can hold together in adverse weather conditions such as rain and snow. We suggest printing on a high-quality paper and then laminating the sheet in such a way that it easily fits on a clipboard, tatum, or loose-leaf notebook (Step 11). We also suggest that at least three copies of each sheet be created in anticipation of field mishaps; the sheets are easily forgotten at the sample site.

Logs

As mentioned, creating log photoload sequences for logs is a demanding task that takes considerable amounts of time and resources because log volume must be measured, log weight calculated and summed, and then converted to a loading. However, an in situ log photoload sequence can be extremely valuable in ecosystems with a small range of log diameters, such as lodgepole pine forests. To create the log sequence, follow the same procedure as above but also provide important log data such as average diameter, average decay class, and total length next to the photo.

Litter and Duff

Photoload sequences of litter and duff can be constructed in two ways—along gradients of loadings and along gradients of bulk density. There may be few differences between photos in a duff or litter loading sequence to make confident estimates of loading because of the lack of evidence in the photo for depth of each layer. For this reason, duff and litter loading should be estimated from depths actually measured in the field and bulk densities assessed using the photoload method.

Step 11: Create Photoload Sampling Book

It is rare that fuel loading sampling projects use photoload sequences developed for only one fuel component. Field measurements for multiple components are more common, such as a set of each of the three fine woody (1, 10, 100 hr) components, a set for each shrub (one sequence for each major shrub species), and a set for each selected herb (one sequence for each major herb species). This involves at least 5 and perhaps as many as 20–30 sequences.

Therefore, considerable thought should be given on how these sequences will be transported and used in the field. Each sequence can be put on one sheet and each sheet can be put inside a tatum or within a notebook or folder. We suggest that each sequence be placed in a loose-leaf notebook and a tag should be attached to the sequence noting the fuel component. Next, the fuel components should be ordered in the notebook from most common to least common or in such a way as to facilitate ease of sampling.

Step 12: Start Estimating Loadings Using the Photoload Technique

Now you are ready to bring the sampling book into the field and start estimating fuel component loadings using your eyes and the photoload technique. There are a few things that are important to recognize when using these new photoload sequences instead of the original Keane and Dickinson (2007b) sequences:

1. Other fuel components are plainly visible in the photos (fig. 7). In the original sequences, we constructed fuelbeds showing only one component in the studio. However, in situ photoload sequences may have litter, shrubs, and herbaceous fuels within the photos. This means that you must visually focus on the target fuel component and ignore all other biomass sources. Many find this difficult because the other components can be distracting and the species are not the same when compared across photos or in the field. If this becomes a problem, we suggest a series of training sessions and fuel sampling efforts to calibrate user visual estimations (see *Discussion*).
2. Estimating intermediate loadings across two photos can be difficult. The photoload technique allows you to visually approximate the difference in loading between two photos when field loadings don't match the photos (Keane and Dickinson 2007b). However, when developing in situ photoload sequences, the developer does not have full control of the amount of biomass in the FAP, especially for shrub and herbaceous fuel components. Therefore, the differences in loadings across the photos in a sequence are not consistent or the same; difference in loadings for sagebrush shrubs in one photo pair, for example, may be half of the difference in another photo pair. This makes extrapolation difficult. As a result, a field calculator should be taken in the field to help with the extrapolation math.
3. Starting and ending photos in the sequence may not be adequate. It could be that the first photo in the sequence starts with such a high loading that it is difficult to estimate loadings for a field condition with less biomass. More difficult, however, may be when the last photo in the sequence fails to capture the highest biomass conditions. You have two options: update the sequence to include a higher or lower loading or try to estimate loading the best they can.

All of the plot forms and ancillary material provided in Keane and Dickinson (2007b) can be used with the new sequences to estimate loadings, and the same photoload estimation procedure can be used. Moreover, the sequences in that report can be used in concert with the newly developed in situ sequences.

Litter and Duff

If actual loading sequences were made of the litter and duff, then use the photoload methods in Keane and Dickinson (2007b) to estimate loading, but beware that the estimates will have a high degree of uncertainty. This may be acceptable in many projects.

However, more accurate and repeatable loading estimates for litter and duff can be calculated from the measurement of their depths and assessment of the bulk density sequences. We suggest taking anywhere from 4–10 depth measurements along the FAP frame and the average can be entered in the field sheet. Then, the bulk density from the photoload sequence is visually assessed using conditions in the sequence. This keyed bulk density value is then multiplied by the average depth to determine loading. This is perhaps one of the most accurate ways to measure duff and litter loadings because the sequence has been adjusted for local conditions and the bulk density values are arranged from highest to lowest in the photos in the sequences. Conventional methods to assess litter and duff loadings use measured depths, but multiply the depths by a bulk density value from the literature (Harmon et al. 2008) and not by a value that has been computed for the target area. The only major problem with this method is that there may be little difference between photos in the sequence that allow consistent identification of the right bulk density value. If it is difficult to differentiate between photos in the sequence, we suggest using the average bulk density values across all photos.

DISCUSSION

The methodology presented in this report can be implemented to create a quick, inexpensive, and useful set of photoload sequences for field sampling of fuel component loadings. In anticipation that more sequences will be needed as this technique is used throughout the target area, it is strongly suggested that a comprehensive field notebook be created to document in detail each of the steps mentioned in the previous section for development of each photoload sequence. It also helps to photo-document the methods and details of the sequence development for others to reference when creating sequences in the future. Many have found it necessary to create a document such as this report for creating sequences for local applications. Lastly, it is important to document any challenges and barriers encountered during sequence development and detail how they were solved.

Challenges

Perhaps the single greatest challenge in both developing the in situ photoload sequences and using them in the field is phenological timing. It is important that the photoload sequences are developed for shrub and herb fuel components to match the timing of the subsequent photoload sampling; phenological conditions should be the same in photos and field. If the phenologies in the sequences do not match the observed phenology, substantial errors in visual estimates are possible. However, shrub or herb plants often have incomplete development in either the sequences or in field sampling efforts, resulting in overestimation or underestimation of loadings. We feel the best time to sample or develop sequences may be at the start of the field season when all plants are fully developed or the end of the field season when many have cured. In any case, the phenology of the sequences must be recognized during field sampling campaigns.

Another related challenge is how to deal with shrub or herbaceous fuel components that are in different phenological stages. A grass species, for example, may have both dead and live biomass clearly evident in the plot frame. Or, a shrub plant may have dead leaves on a live branch. Or one fuel component may be green while another, such as grass, may be fully cured. Or the photos may show green plants while the plants are cured in the field. The manner in which mixed phenology is managed in field sampling efforts depends on how the photoload sequences were created. If live and dead material were included in the clipped material, then live and dead should be combined in the visual estimates of loading. Sometimes, the dead foliage is on the ground, such as last year's grass blades. In general, all the branch and foliar material that is in contact with the ground should be considered litter and included in the litter for evaluation, not the shrub or herb components. In the end, it is at the discretion of the user and developer as to how to deal with mixed phenology.

Another challenge in photoload sequence development and subsequent sampling is how to handle tree regeneration in surface fuelbeds. Some forested stands may have dense tree regeneration that facilitates rapid fire spread and contributes to increasing fireline intensities, so it is important that this seedling and sapling biomass be included in fuel assessments (Keane 2015). The problem is that saplings often extend above the 2 m surface fuel height limit, making it difficult to evaluate biomass loadings below 2 m. Some people count the number, height, and species of seedlings and saplings within the photoload plot frame to create a tree list that is used to model tree biomass as a separate fuel component. Others may create photoload sequences for each tree species or for all tree species. And still others include the tree biomass in the shrub fuel component.

The last challenge is quantifying litter and duff loading within the photoload construct. This report has detailed at least two ways to integrate duff and litter sampling in the photoload technique. But, be aware that there may be great differences in the depths and bulk densities of litter and duff throughout the target area.

Training

Perhaps the most controllable source of error in using the newly developed photoload sequences is the level of training accomplished prior to application of the photoload method. Keane and Dickinson (2007a) and Sikkink and Keane (2008) found that the accuracy of the visual loading estimations increases with an individual's experience using the photoload technique and with users' experience in sampling fuels. To address this uncertainty, the Holley and Keane (2010) training guide was developed to calibrate the user's estimation before going into the field. We suggest that this guide also be used as a tool for training individuals who will use the new photoload sequences.

In addition, there are some other ways to improve visual photoload estimates when time and resources are available. First, 1- or 2-day training sessions in the use of the new sequences can be conducted with field-going personnel. In these training sessions, field people can estimate loadings on FAPs using the plot frame, and then they can clip and weigh the material to see if their estimates were accurate and to develop a means to estimate more accurately. Also, developers of the new photoload sequences can take all the unused photos and data and create their own field guide similar to Holley and Keane (2010). Or, they can specifically take additional photos and sample additional sites during Steps 6–9 to create the field guide. Last, training session organizers can construct their own fuelbed loadings for fine woody components using collected material so that field people can see a gradient of loadings and calibrate their eye for this entire range. Training is a critical phase in photoload estimation and it should never be ignored.

Improvements

Some projects might demand a high accuracy of photoload fuel loading estimation for successful completion of the project objectives. Research applications, for example, often require a high resolution and accuracy for photoload visual estimates to control unexplained uncertainty due to user error (McColl-Gausden and Penman 2017; Tinkham et al. 2016; Volkova et al. 2016). Some monitoring projects evaluating changes in fuel loading after treatments cannot use destructive techniques, so accurate photoload estimates are important. In these cases, we strongly suggest conducting additional sampling using what Catchpole and Wheeler (1992) called a "double sampling" method when a subset of the photoload visual estimate sampling sites are destructively sampled to determine actual fuel loadings. Then, the visual estimates from the destructively sampled sites are regressed with the actual loadings to determine the accuracy of the photoload sampling (R^2, standard error) and also to determine if the visual estimates are being underestimated or overestimated (slope of regression line: < 1.0 = underestimation). More importantly, the slope of the regression line can be used as a correction factor for those visual estimates that were not destructively sampled (fig. 9). Keane et al. (2012a) used double sampling to calculate correction factors to adjust photoload visual estimations to evaluate the spatial variability of wildland fuels in the U.S. northern Rocky Mountains. In our projects that used double sampling, we've found that many people underestimate fuel loadings with the photoload method, and this underestimation increases with the amount of biomass (Keane and Gray 2013).

Most visual estimation techniques demand constant calibration to ensure consistency and accuracy (Lutes et al. 2006; Lutes et al. 2009), and the photoload technique is no exception. You should constantly check your estimations, especially at the beginning of the field season and after a long period of no sampling, against destructively estimated loadings to ensure consistency. We have found that bringing several experienced field personnel together for a few hours to talk over visual estimations in the field is often helpful. Usually, the average visual assessment across a number of assessors is the "best" estimate, so it is important to discuss visual estimates with others before and during field sampling efforts.

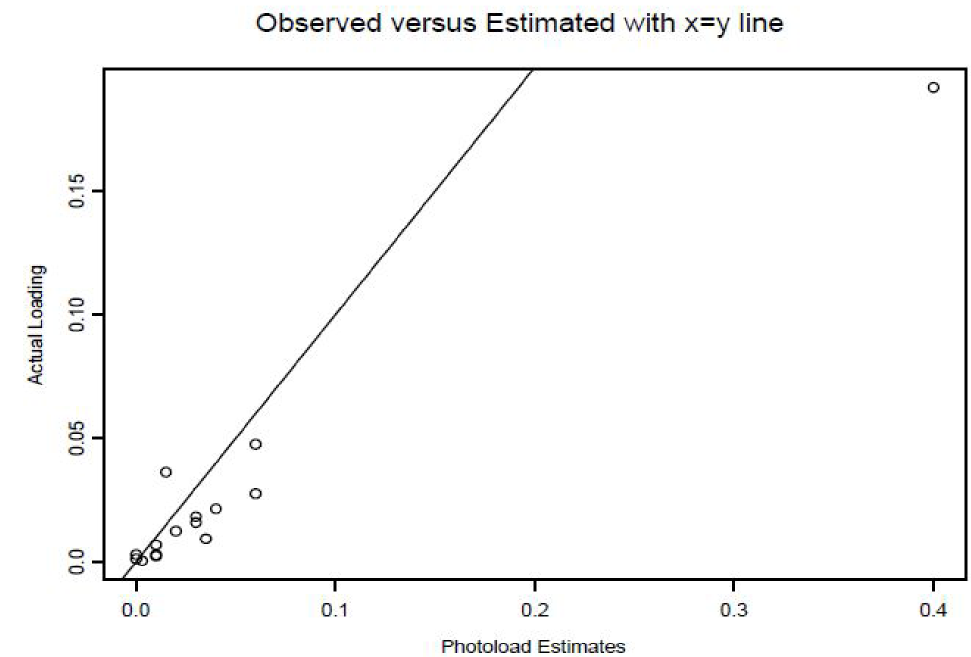


Figure 9—Example of the regression analysis of photoload visual estimates (X axis) and the destructively sampled actual fuel loadings (Y axis).

SUMMARY

The photoload technique provides a relatively cheap, fast, and accurate method to estimate loadings of major fuel components. However, the original photoload publication lacked sufficient photoload sequences to implement the technique worldwide. Because creating new photoload sequences using photographed fuelbeds in the studio is logistically impractical for most applications, an alternative method is needed to quickly create photoload sequences for local applications by local specialists. This report details a comprehensive method to create photoload sequences from field sampled fuelbeds. To help the wildland fuel science community, we suggest that any new photoload sequences be emailed to the authors to be placed on a website for others to use.

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