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The Photoload Sampling Technique:

Estimating Surface Fuel Loadings From Downward-Looking Photographs of Synthetic Fuelbeds

Robert E. Keane and Laura J. Dickinson

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Abstract

Fire managers need better estimates of fuel loading so they can more accurately predict the potential fire behavior and effects of alternative fuel and ecosystem restoration treatments. This report presents a new fuel sampling method, called the photoload sampling technique, to quickly and accurately estimate loadings for six common surface fuel components (1 hr, 10 hr, 100 hr, and 1000 hr downed dead woody, shrub, and herbaceous fuels). This technique involves visually comparing fuel conditions in the field with photoload sequences to estimate fuel loadings. Photoload sequences are a series of downward-looking and close-up oblique photographs depicting a sequence of graduated fuel loadings of synthetic fuelbeds for each of the six fuel components. This report contains a set of photoload sequences that describe the range of fuel component loadings for common forest conditions in the northern Rocky Mountains of Montana, USA to estimate fuel loading in the field. A companion publication (RMRS-RP-61CD) details the methods used to create the photoload sequences and presents a comprehensive evaluation of the technique.

Keywords: Fuel load loading, fuel sampling, fuelbeds, photographs, wildland fire, and fuels

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Introduction

Comprehensive estimates of fuel loadings in forest and rangeland ecosystems of the United States are critical to accurately predict the fire behavior and effects of alternative fuel and ecosystem restoration treatments to save lives, property, and ecosystems (Laverty and Williams 2000; GAO 2003, 2004). Fuel loadings, along with fuel moisture, are the most important factors that fire managers can control for planning and implementing prescribed burn treatments. Sophisticated fire models such as FOFEM (Reinhardt and Keane 1998; www.frames.gov) and CONSUME (Ottmar and others 1993; www.fs.fed.us/nw/fera/consume.html) require loading estimates so that they can be used to plan, prioritize, design, and implement important fuel treatments for restoring historical fire regimes and reducing hazardous fuels to save lives and property (Mutch 1994; Laverty and Williams 2000).

Measuring surface fuel loadings in the field is difficult because it requires a complex integration of several sampling methods designed for implementation at disparate scales. Downed dead woody fuels are typically sampled using planar intersect techniques (van Wagner 1968; Brown 1970, 1971, 1974) as implemented into many surface fuel inventory sampling systems such as FIREMON (www.fire.org/firemon) (Lutes and others 2006). Planar intersect techniques were only designed for estimating downed woody fuel loadings at the stand level using linear transects that define sampling planes. Dead and live shrub and herbaceous fuels must be either measured using time-consuming destructive methods that involve clipping these fuels within small microplots or using indirect techniques such as allometric regression equations from canopy cover and height estimates. Loadings of duff and litter are often estimated as the product of duff depths and bulk densities measured at various points along the fuel transects or from collecting and weighing a subsample (Brown and others 1982). Many times, the scale and error of surface fuel measurements are incompatible and inconsistent across the fuel components; log loading, for example, often varies at greater spatial scales than fine fuel loading because of log size. These methods are often time-consuming and require extensive training and field expertise. What is needed is an inexpensive, easy, and quick fuel sampling technique that can provide consistent estimates of fuel loadings at the level of accuracy required by the fire behavior and effects models for fuel treatment planning. These fuel loading estimates must be accurate enough to be used as inputs to fire behavior and effects models, and they must also accurately quantify the amount of live and dead carbon on the ground for managing carbon budgets.

This report presents a comprehensive fuel sampling protocol for quickly and accurately estimating surface fuel component loadings using a system called the ***photoload sampling technique*** that involves making visual estimates of loading from a sequence of downward looking photographs depicting graduated fuel loadings by six fuel components. A detailed sampling protocol is presented so that loadings can be estimated at various levels of effort and scale. The photoload sequences in this report were specifically developed to describe the range of fuel loadings for common fuel components in the northern Rocky Mountains of Montana, USA. Also included is a plot form for use in the field.

A companion report by Keane and Dickinson (2007; RMRS-RP-61CD) details the set of methods used to construct the photoload sequences presented here so that photographs can be taken for local fuel types or specialized conditions. The companion report also presents an evaluation of the photoload sampling technique by comparing the photoload estimates made by many participants in a field study with the fuel loadings actually measured on 1 m^2 and 100 m^2 microplots.

Photoload Sampling Background

General Description

The photoload sampling protocol is a fuel sampling technique used to estimate the loading of surface fuels for a number of fire management objectives but primarily for the prediction of fire effects. This technique uses a series of downward- or sideward-looking photographs of synthetic fuelbeds of gradually increasing fuel loadings as reference for visually estimating fuel loadings in the field. You simply match the fuel loading conditions observed on the ground with one of the photoload pictures in the set for that fuel component. You can also adjust for the spatial distribution, diameter, degree of decay, and depth of loading across the sample space. The photoload technique can be used to estimate fuel component loadings at a microplot, macroplot, stand, or landscape scale at various levels of effort depending on your needs, objectives, and available resources (sampling time and funds). This technique can only be used to estimate the loading of surface fuels and does not provide estimates of canopy characteristics. It also isn't designed to estimate loadings of duff and litter layers.

We designed this sampling technique to be used by fire managers, fuel specialists, and researchers to quickly estimate fuel loadings by fuel component. However, it is just one of the many sampling tools available to sample or monitor fuel loadings, such as photo series (for example, see Fischer 1981) or planar intersect methods (see FIREMON, Lutes and others 2006). The photoload technique is not intended to replace the previously developed protocols and methods. Rather, it is intended to be 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. For example, a fire management agency might require the accurate estimation of fuel loads but their field crews have limited experience in planar intersect fuel sampling and there may be little funding available for training, therefore the photoload technique may be a viable option.

Photoload techniques are best used when:

- Fuel sampling experience is low —The photoload technique can be quickly learned and understood. It takes less than a day to become effective with the photoload technique.
- Available sampling time is limited—The photoload technique is a relatively quick and inexpensive method that provides moderately precise and reasonably accurate fuel loadings.

This protocol will eventually be included in the FIREMON sampling system (Lutes and others 2006; www.frames.nbii.gov/firemon) as a separate method. FIREMON (a FIRE MONitoring and inventory system) consists of a set of sampling methods, databases, and plot sheets for sampling fuels, fire behavior, vegetation, and biophysical settings. By becoming a part of the FIREMON system, the photoload sampling protocol can be nested within any number of other sampling methods to obtain a fully integrated sampling scheme designed to fit any application from documenting changes in fuel loadings after treatment to assessing fuel consumption using modeling. For example, the user can quantify fuel loadings with the photoload technique and describe tree density with the FIREMON Tree Data technique at the same sample site and within the same sampling space (a plot for example).

The typical fuelbed is composed of many fuel components with the types and definitions of these components often dictated by the objective of the fuel sampling project. Since most fuel sampling efforts are initiated to quantify fuels for fire behavior and effects prediction, we used the same components in the photoload sampling protocol. Six fuel components are explicitly recognized in the photoload technique:

- 1 hour: <1 cm (0.25 inch) diameter downed, dead, woody fuels
- 10 hour: 1-2.5 cm (0.25-1.0 inch) diameter downed, dead, woody fuels
- 100 hour: 2.5-7 cm (1-3 inch) diameter downed, dead, woody fuels
- 1000 hour (logs): 7+ cm (3+ inch) diameter downed, dead woody fuels
- Shrub: Dead and live shrubby fuels (< 5 cm or 2 inches diameter)
- Herb: Dead and live grass and forb fuels

The loading is visually estimated for each fuel component. We did not include duff and litter layer fuels in this method because their loading is mostly dependent on layer depth which is difficult to estimate from photographs. But, we describe how estimates of litter and duff loadings can be made using the FIREMON methods linked to this photoload sampling protocol.

This report consists of four parts that are integrated together to form the photoload sampling technique. The body of this report presents the background and sampling protocol used for the photoload sampling technique. Appendix A contains the set of photoload sequences for the six surface fuel components integrated into the photoload sampling technique. The photoload sequences consist of a series of photographs of fuelbeds with gradually increasing fuel loadings. They were developed for common fuelbeds that occur in the Northern Rocky Mountains, especially those around western Montana, USA. Photoload sequences for other locally important fuelbeds, such as shrub and herbaceous species not included in Appendix A, must be developed using methods detailed in the companion report (Keane and Dickinson 2007; RMRS-RP-61CD). Appendix B contains a set of tables for computing large branch (100 hour) and log loadings from estimated branch or log lengths as an alternative or companion method to estimating large woody fuel loads within the photoload sampling technique. Last, Appendix C contains possible plot forms and cheat-sheets that can be used for estimating and recording photoload-derived fuel loadings within a sampling area. One plot form allows you to record the details of photoload estimations while the second is used only to record the final loadings. These appendices were designed to be removed from this report using a razor or scissors and then placed in a clipboard for reference in the field. We recommend these pages be laminated so they last longer and are protected against water damage.

The Photoload Sequences

As mentioned, the photoload sequences that we developed for northern Rocky Mountain forests are found in Appendix A. Each fuel component was photographed independently so that an accurate estimate can be obtained without the confusion of including other components in the photos. The photoload sequences are organized in a series of pictures with each picture showing increasing fuel loadings. All pictures for the fine woody fuels (1, 10, 100 hour fuels) were taken from directly overhead looking downward at a 1m x 1m fuel bed (fig. 1a). Shrub and herb fuel components are taken from overhead and from the side at eye level (oblique) (fig. 1b and 1c). Log fuel loadings (1,000 hour woody) are only taken at eye level from the side (oblique) but on 100 m^2 plots (fig. 1d). The loading for the fuel in each picture is shown

a

b

c

d

Figure 1—Examples of pictures in a photoload sequence: a) 1 hour fuels (0.5 kg m^{-2}), b) shrub fuels (ninebark, 0.15 kg m^{-2}), c) herbaeous fuels (pinegrass, 0.8 kg m^{-2}), and d) logs (5.0 kg m^{-2}).

in both English and metric units at the top of the photo (Appendix A). For fine woody fuels, there is a scale in the bottom right corner to help calibrate the user's eye for size. We placed a familiar object next to the side of the oblique picture in the shrub and herb photos to also help calibrate your eye and to provide reference for the average height of the plants in the photos.

The photoload sequences were designed using the metric measuring units of kg m^{-2} for many reasons. First, these units more accurately describe the fuels at the scale of development of the photoload sequences. Second, these units are more appropriate for describing the spatial distribution of the fuels components used in photoloads, especially fine woody, shrub, and herbaceous fuels. Third, it is easier to visualize the weight and area of these units than the conventional units of tons per acre. You can simply multiply metric loading estimates by 4.46 to convert kg m^{-2} to tons $acre^{-1}$ (conversion from kg to lb is 0.454). And last, we felt that a square meter represents the smallest practical scale of evaluation for fine woody, shrub, and herbaceous fuels.

The format we chose for the photographs in Appendix A represents a compromise between convenience and sampling scale. The pictures are large enough to allow sufficient resolution between two similar loadings for most purposes, but small enough to obtain a comprehensive set of loadings for each plant on just one page. Depending on the needs and accuracy of your own study objectives, you may require additional resolution between photos (more photos), or less pages to bring into the field (less photos). You can always create your own photoload sequences using the extensive set of pictures contained on the companion CD (Keane and Dickinson 2007; RMRS-RP-61CD).

Photoload Sampling Protocol

Determining if Photoload Sampling is Right for You

Many sampling methods can be used to estimate fuel loadings and each has advantages and disadvantages. Complex sampling strategies, such as fixed area plot and planar intersect techniques, are accurate and somewhat repeatable, but they can require extensive expertise, time, and funding to implement depending on the fuel component sampled and the objective of the sampling effort (see Keane and Dickinson 2007; RMRS-RP-61CD). These extensive procedures are used when sampling objectives require high quality and accurate data. However, sometimes fuel sampling must be done with minimal funding, limited time, and lack of sampling expertise. In these cases, visual estimates of fuel loadings may be the only alternative.

There are three ocular methods for estimating fuel loadings. The photo series method uses oblique photographs of stand conditions across a variety of habitat types and cover types that occur within the management area (see Fischer 1981 or Ottmar and others 2004 for examples). Many fire managers are using these methods, but recent research has shown resultant ocular estimates may be inaccurate and inconsistent for some fuel components because these same components are not visible in the photo series photographs (Lutes 1999). Another technique is using a fuel model that is identified in the field using various attributes such as vegetation composition, fuelbed characteristics, and expected fire behavior (Anderson and others 1982; Sandberg and others 2001; Lutes and others [in prep]). A fuel model has loadings assigned to each fuel component for use in various mapping and modeling activities. This may be the easiest method but the small number of fuel models used to represent the wide variety of fuel conditions may preclude an accurate estimation of loading. Moreover, there are very few fuel classifications that provide comprehensive keying criteria for consistently identifying the fuel loading conditions. The photoload technique is the third alternative for ocular estimation of fuel loads. It may be desirable because the photos portray graduated fuelbed loadings, the fuels are completely visible, and the estimates are made at the appropriate spatial scale that best matches spatial fuel distribution.

With this in mind, we recommend the following. If there is sufficient time, expertise, and funds to obtain fuel loading estimates, we suggest that the manager use the planar intersect method of fuel sampling to measure these loadings (use protocols detailed in FIREMON). The fixed area technique is also useful and sometimes more accurate, but it can require prohibitively long sampling times and it may be difficult to rectify the sampling intensity with the variability of fuels within in a heterogeneous area. It is more appropriate for research applications. If sampling crews have not been trained for planar intercept, photo series, or fixed area methods, then the photoload technique is a viable alternative and may be better than the photo series method. If sampling crews have experience in photo series fuels estimation, then photo series may be more desirable but not as accurate as photoload techniques. If loadings for locally important fuel components are *not* present in the photoload sequences or photo series photographs, the fuel model method is perhaps the only alternative but there needs to be a fuel model key for your area. We also recommend that you use several methods in a nested strategy to ensure the most accurate estimation of fuels. For example, planar intercept techniques can be used every 10^{th} plot to provide consistent calibration for the photo series and photoload estimations or the photoload technique can be used first, and estimates can then be checked using photo series estimates.

Preparing for Photoload Sampling

We recommend the following equipment be purchased, obtained, or fabricated for use in photoload sampling.

- *Plot frame*—A square meter plot frame with the square meter area measured on the inside dimensions of the frame. You can construct this of wood, PVC pipe, or metal rods.
- *Go-no-go gauge*—A device that has the widths of each woody size class upper diameter range.
- *Clear plastic ruler*—A ruler that can be conveniently stored in a cruiser's vest. This ruler will be used to estimate log diameters and branch lengths. It can also be used to measure duff and litter depths if needed.
- *Cloth tape*—The length of the tape would be dictated by the sampling design. This tape would be used to locate sampling points.
- *Clipboard*—This clipboard should have the ability to allow quick reference to the photoload sequences.
- *Calculator*—This is handy for summing log diameters and lengths.
- *Nails* –Long nails (>20 cm) are handy for anchoring long microplot transect lines either permanently or semi-permanently.
- *Photoload procedures and sequences*—We suggest that the photoload sequences be cut from this document and laminated to waterproof the pages.
- *Digital camera*—We recommend that pictures are taken of the sample site and some microplot conditions for future reference.

Determining the Scale of Sampling for Your Assessment

The first task in photoload sampling is deciding the scale at which to make the loading assessment. The scale of sampling is mostly determined by the sampling objective and the sample unit. The sampling objective defines the accuracy required for the loading estimates and the sampling unit defines the spatial resolution that the loading estimates are intended to describe.

The sampling objective is the purpose of the sampling effort and it dictates the details of any sampling effort. If the fuels sampling project was designed to quantify fuels for input into fire effects models, the accuracy of the fuel loading estimates may not need to be high because of the coarse resolution of fire effects simulation. Conversely, high accuracy is needed when a sampling project is concerned with monitoring fuel loadings after management treatments. If the sampling objective requires accurate estimates of fuel loadings, then, as mentioned above, planar intersect or fixed area techniques are warranted as long as field crews are properly trained.

The sample unit is the finest area where fuel loading values are needed for summary as specified by the objective. For example, the monitoring of the effect of a fuel treatment would probably be done at the stand level (area inside the treatment boundaries), whereas the inventory of fuel loadings on a plot would require the fuel loadings be estimated for the area within plot boundaries. The size of the sampling unit dictates the scale of photoload implementation. Since the photoload technique performs best when the sampling scale is small (about one square meter), it is important that the estimates of fuel loading for larger areas (coarser scales) account for the patchiness of loading across that sampling area.

The first factor to address when designing a photoload sampling project is the desired accuracy of the photoload estimates as specified by the objectives. Since ocular estimates are more accurate if estimated within small plot frames, the most accurate sampling approaches use a random or systematically stratified network of one square meter microplots within the sample unit. However, if the objective implies that only a general description of fuels and their loadings are desired, such as input to computer models for alternative treatment evaluation, then the user can estimate loadings for the entire sampling unit instead of using microplots. The sampling objective will always be tempered by the resources available for sampling. For example, if time and funding are limited, then the time-intensive microplot option is probably not possible and loading estimates might have to be done at the larger sample unit level. Since most fuel sampling projects collect loading measurements to be used as input to fire behavior and effects models, it is important that the sampling intensity reflect the resolution and accuracy required by the models. One must always remember that the quality of model predictions increases with the accuracy of the input parameters. Last, if the sampling objective specifies the need for an estimate of fuel variation, then the microplot sampling at the desired sampling scale is the best alternative.

We feel that the photoload method can be best implemented at one of three scales: the microplot, the macroplot, and the stand scales. These scales can be integrated into a nested sampling design to improve loading estimates. The best way to illustrate this is to describe four common sampling situations. First, say a fire manager must quantify fuels for a 100 acre (40 ha) stand but does not have the expertise for conventional sampling techniques and does not have the time for nested microplot methods. In this case, perhaps the best method for estimating loadings involves traversing the stand and mentally determining an estimate of loading for each fuel component using the photoload technique (stand level photoload estimate). Second, say the fire manager realizes that there may be more time available to get a more accurate answer. The manager might then install four macroplots (large, 0.04 ha or 0.1 ac circular plots) that represent the four common fuel loading conditions observed within the stand and, at each macroplot, the manager estimates fuels within the macroplot boundaries using one loading estimate for each of the six fuel components (macroplot photoload estimate summarized to the stand level). The manager would then need to estimate the proportion of the stand that each plot represents to get a weighted average by area for the entire stand for the loading of each fuel component. Third, the same manager realizes that more accurate and defensible estimates are needed because the project objective includes monitoring and more time is made available. The manager might then install a grid of 25 microplots (1 m^2 square plots on a 5 x 5 grid size) within each of the four macroplots to obtain a better estimate of loading and its variance (microplot photoload estimates summarized to the macroplot level that is then summarized to the stand level). Or, the manager might place one or more microplots in an area or multiple areas of the macroplot that would be representative of the loading for that macroplot subarea (much like the method described above for placing macroplots in stands). Fourth and last, say the manager has sufficient time and wants the best possible estimate using the photoload technique. Here, the manager might install a series of systematic transects within the stand and establish a microplot at fixed intervals along each transect (for example, one microplot every 50 meters) (microplot photoload estimates summarized directly to stand level). The ability of the photoload technique to adapt to various scale and accuracy issues makes it a flexible and robust sampling method. We feel landscape level estimates of fuel loadings (one estimate of loading for each of the six components for the entire landscape) may be inappropriate but possible albeit expensive. The best way to quantify fuel loadings for the entire landscape is to sample loadings for all stands that comprise that landscape.

With all this in mind, we recommend the microplot approach always be used in photoload sampling unless time, funding, and field experience are limited, in which case we recommend that loadings be assessed at the scale that best matches the spatial resolution required by the predictive fire models and the sampling objective. The amount of time and funding available to perform the photoload loading must be determined to try to match the resources available for sampling and the sampling objective to the sampling scale. If accurate answers are required but time and money prevent microplot sampling across large stands, then use microplot sampling on macroplots or macroplot sampling across the stand area. Procedures for sampling at each of the scales are detailed next.

You should first decide on a convention for macroplot and microplot shape and establishment. We suggest that the macroplot be square and the sides oriented in the four cardinal directions, but other strategies may work just as well, such as orienting the sides so they are upslope and cross slope. A grid of microplots can also be established in circular plots to allow more efficient integration into other sampling efforts, such as tree population sampling. We also suggest that the corner of the microplot frame always be established in the southwest corner along a transect so that the microplots are always on the top and along the right hand side of the transect. Be sure to record all methods and the sampling design specifications to ensure that the project can be repeated and analyzed correctly. There is a metadata database in FIREMON to record these sampling specifications, or the user can simply enter these specifications in a notebook for later reference.

Using the microplot approach—The microplot approach involves using plot frames (microplot) to delineate a small sampling area to visually estimate fuel component loadings. In the photoload sampling technique, the size or area of the microplot should be the same as the fuelbeds photographed in the photoload photo sequences; we suggest that the microplot frames be exactly one meter square (1 m by 1 m) to match the dimensions in the photoload pictures. Although other sized plot frames could be used, you must adjust the estimated loadings to account for differences in plot frame area. The microplot frame sides should be one meter long measured on the inside dimensions, not the outside dimensions. We recommend that one corner of the frame remain unattached so that the frame can be opened to include large trees or any other obstruction. We also suggest that the user build several plot frames as they will come in handy if there is more than one person on a field crew or if a frame breaks. We made our plot frames out of plastic PVC pipe and used 90 degree corner pieces to bind the lengths together with glue; however, any material from wood to metal bars will do.

In the microplot approach, the microplots are installed on a grid within the sample unit in a design that fully describes the spatial distribution of fuel loading across the sample unit without preconceived or statistical bias. We recommend randomly establishing a starting point for the first transect, and then establishing a systematic grid that evenly places the microplots across the entire sample unit. The beginning and end of each transect can be marked with an iron pipe, rebar, or large nail that is permanently or temporarily driven into the ground (monitoring applications would require permanent establishment of transects) (see FIREMON for permanent establishment of plots or transects). Ultimately, the user should strive for a 10 percent sample of the sampling area but time and funding will nearly always dictate that a 1 percent sample is more feasible. For example, if the macroplot is 400 m^2 (20 m by 20 m) then a 10 percent sample would be 40 m^2 or 40 microplots. These microplots could be installed on 4 transects that are 5 meters apart and the plot frame would be placed every 2 meters on each transect. In monitoring applications, it is important that a nail be driven in at each microplot location to make sure that future estimates are done on the same piece of ground. We suggest at least two corners be marked with the nails for each microplot. We found that plastic rope in a bright color seems to work well for transects but cloth measuring tapes and string also work equally well. The ropes can be marked at fixed-length intervals to define the placement of the microplot plot frame along the transect. Be sure to assign each microplot a number and record this number, along with the fuel component loadings in the plot form(s) (use the subplot field in Appendix C).

Stand level microplot grids are more difficult to design because stand boundaries are rarely square or rectangular. Moreover, a 10 percent sample in a large stand might result in a prohibitively large number of microplots. For example, a 100 acre (40 ha) stand would require around 40,486 microplots of 1 square meter for a 10 percent sample resulting in an impractical sample target (even the 4,048 microplots required for a 1 percent sample seems excessive). Therefore, the design and implementation of the microplot sampling grid would need to be a compromise between feasibility and statistical validity. We suggest that users match the time available to spend sampling one stand with the time it takes to record loadings for the six components at one microplot (1-5 minutes) and calculate grid sampling density. So, if four stands need to be sampled in one day (eight hour working day), that means that there is roughly 120 minutes (two hours) per stand or 24 microplots per stand assuming a five minute microplot sampling time. This could be put on a grid across the stand that matches the stand shape and size. We found that our photoload evaluators averaged approximately 6.3 minutes per microplot to estimate loadings of all fuel components including the time it took to estimate log loadings at the subplot level. We also found that microplot sampling times ranged from 2.7 minutes for the most experienced evaluators to over 10.1 minutes for novice fuel samplers. These times tended to increase with increasing loadings with the longest times for the slash sites (7.2 minutes) and heavy fuel units (6.3 minutes). Times for most people decreased as more microplots were evaluated, especially for the subplot estimates of log loadings, as people learned how to efficiently use the log loading table (Keane and Dickinson 2007; RMRS-RP-61CD).

Another option for the microplot approach is using double sampling as a general framework for the application of the photoload technique. In double sampling, visual estimates of fuel loadings are obtained on all microplots in the sampling unit, but a subset of these microplots is also destructively sampled (fuel is collected, sorted, dried, and weighted) just after the visual estimates are made. Regression techniques can then be used to develop calibration relationships to adjust the visual estimates using the destructively sampled data. A large subset should be obtained that spans the entire range of loading values for each fuel component.

Using the macroplot approach—This approach will probably be the most common one used in fire management. Here the user traverses the macroplot and estimates a loading that best represents the macroplot as a whole. Again, a macroplot is usually about 0.1 acres in size and is often circular or square. The user must account for the spatial distribution of fuel in the plot and adjust the estimate accordingly. We recommend the following procedure:

1. Visually divide the macroplot into areas where there are obvious differences in fuels.
2. Estimate the proportion of those divisions to the entire macroplot area.
3. Estimate the loading of each fuel component for each of the divisions.
4. Calculate a weighted average by area of the loadings.
5. Record the loading on the plot sheet.

Novices of the photoload method will probably need to write down the proportional areas and related loadings to accurately calculate the weighted average loading, but more experienced field people will find that they can actually perform many of the calculations in their head. Remember, the resolution of the photoload estimates is quite low so the proportional areas and weighted average calculations need not have three or four decimal places. For example, we recommend the proportional areas be in classes of 10 percent and loading estimate never have more than two decimal points (0.02 for example).

Sampling times for the macroplot approach will vary by evaluator and site conditions, but we found that it took about 5.1 to over 10 minutes to estimate loadings of all six surface fuel components for a macroplot. This estimate will decrease with increasing sampling experience and decreasing fuel loadings.

Using the stand approach—Although fire managers might think that this is the most desirable scale at which to estimate fuel loadings, we suggest that stands be divided into homogenous areas of fuel loadings to more accurately estimate a loading for the entire stand. Most stands are quite large and it may take time to properly traverse the entire area, which makes it difficult to remember or visualize the distribution of fuel conditions across the sub-areas. Therefore, we suggest the user install a grid of either microplots or macroplots to systematically sample the stand. The number of plots in the grid would be dictated by a number of factors, most notably the time available to sample the stand. Follow the guidance presented in the previous two approaches for the proper methods for micro- or macroplot sampling.

If a gridded sampling strategy is impossible and the user has time for only one estimate, we recommend using the same procedures for the stand as for the macroplot. The following procedures should be followed:

1. Visually divide the stand into areas that reflect obvious differences in fuel loadings.
2. Record these divisions on a stand map.
3. Estimate the proportion of those divisions to the entire stand area.
4. Estimate the loading of a fuel component for each of the divisions.
5. Calculate a weighted average by area of the loadings.
6. Record the loading on the plot sheet.

The detail and resolution of the stand divisions will probably be dictated by the sampling objective. If a quick estimate of fuel loadings is needed to compute a fire effect, then the divisions should only reflect *major* loading differences (low and high loadings, for example). However, if the fuels are needed to develop a fire prescription, then all fuel complexes should be described and accounted for in the final estimate.

Last, we strongly recommend that the area proportions and assigned loadings for each sub-stand be recorded for later use. This is important for the accurate calculation of fire effects. Models such as FOFEM and CONSUME are point models that predict fire effects for a point on the landscape. The user of these models must take the point predictions and summarize them to the spatial scale of application. To do this for a stand, we recommend that the fuel loadings for each of the stand divisions be used to simulate fire effects with the predicted effects then summarized to the stand level by the area weighted average.

Making the Photoload Fuel Loading Estimates

Estimating fuel loading with the photoload technique involves matching the conditions observed on the ground within the sampling unit with the conditions in the set of photographs of loadings provided in the photoload sequences (Appendix A). The conditions are matched *only* on visual assessment of loading characteristics; no other factors such as fuelbed appearance, color, or wetness should be considered. The user should try to match loadings between the photos in the photoload sequences with the loadings observed on the ground. However, estimating fuel loadings using only ocular guesses is not as simple as it appears. Many factors must be accounted for in the ocular estimate to obtain the most accurate fuel loadings. The four most important factors are spatial distribution, degree of decay, branch diameter, and fuel depth.

The photoload sampling technique was designed to estimate loadings for the fuel components that are above the litter layer and plainly visible and identifiable. Some parts of twigs and branches are buried in the litter and duff. Do not include the buried material in the loading estimate. Anything buried below the litter layer is considered duff or litter and should be sampled using another technique (we suggest the FIREMON Fuel Loading methods). This is also true for logs. The central axis along the longitudinal length of the log needs to be above the litter layer to be considered 1000 hour woody fuels. Rotten logs are the most difficult to identify for sampling because they are broken and it is difficult to identify the central axis. The planar intersect method (Brown 1971) detailed in FIREMON recommends visually reconstructing the original log size for rotten logs that have fallen apart.

We found through extensive testing that the order that loadings are estimated by fuel components is important for many people. 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 suggest that the user first enter zero for each fuel component not evident within the sample unit. Then, enter the loadings for those components with minimal loadings, such as shrubs and herbs. This usually leaves only one or two components left and the loadings for these are easily estimated because all other fuels have been eliminated. We suggest that log loadings always be estimated last because they are usually done at a 100 m^2 scale.

Adjusting visual estimates—Any estimate of fuel loading must be adjusted to account for the variability and properties of the fuel within the sampling unit. The loading of any fuel component is rarely evenly and uniformly distributed across a sampling unit, and this is especially true for woody fuels. Fuels are normally clustered in piles called "jackpots" because the origins of most fuels are usually from trees, and trees are usually clustered and clumped within a stand. Therefore, the user of the photoload technique should always account for the spatial distribution in the visual loading estimates. This is done by matching photoload pictures with all levels of fuel loading within the sample unit and then performing a weighed average of these loadings with the estimated aerial proportions of the fuel loading levels within the sampling unit. As an example, say we have a 1,000 m^2 plot and, by matching photoload sequence pictures, found that the ocular estimates for fuel loadings were 0.1 kg m^{-2} for 10 percent of the plot, and 1.1 kg m^{-2} for 50 percent of the plot, and 2.0 kg m^{-2} for 40 percent of the plot; then, the final loading would be 1.36 kg m^{-2} (0.1x10+1.1x50+2x40 divided by 100). This concept can be used to adjust loadings at any scale, most often within a microplot, macroplot or stand. Many people may find that it is easier and quicker to perform this weighted average in their heads while others, especially novices, need to write the information on the plot sheet (see the first plot form in Appendix C). Some of the evaluators of the photoload method found it useful to visualize what the fuel in the sampling unit would look like if each component was evenly distributed on the ground and this visualization was compared with photoload pictures. In the photoload sampling technique evaluation, we found that many evaluators had trouble making the mathematical calculations and writing the subsequent answer correctly onto the plot form. We recommend that novice photoload users record all proportion and scale estimates onto the plot form and perform the calculations after the visual estimates are completed.

The depth of the fuelbed must also be accounted for in the estimate of loading using the photoload technique, especially shrub and herb components. Fortunately, woody fuels on most fuelbeds have virtually no depth under natural conditions. However, shrub and herb fuelbeds have depth (measured as average plant height) and this dimension must be included in the photoload process to adjust for the ocular estimate. The photoload technique assumes that changes in fuel depth are proportional to the loadings. This assumption may be an oversimplification of reality, but there is little research to support any other approach. Each of the pictures for shrub and herb fuelbeds in Appendix A contains a height of the plant material. This is the height that we measured as we constructed the fuelbeds to be photographed. We suggest that once the photoload picture is matched to the fuel conditions in the field and the loading has been determined, the loading estimate should be adjusted for differences in observed and pictured plant height. This is done by multiplying the estimated loading by the proportional change in height from the picture to the observed fuelbed. For example, if the photoload shrub height is 1 meter and the matched loading is 2.0 kg m^{-2} but the observed height of the shrubs in the field is 2 meters, then the actual loading would be twice the estimated loading computed as 4.0 kg m^{-2} (2.0 kg m^{-2} x 2 meters / 1 meter) because the height in the field is twice the height in the photoload picture.

If the litter surface is not visible for downed dead woody material, as in slash and activity fuelbeds, then the same procedure should be done to compute that loading except the depth of the photoload picture fuelbed is assumed to be the highest diameter of the woody size class. Use the picture for the fine woody fuel load that best portrays the top of the fuelbed and then adjust that loading by fuel depth. So a slash bed composed of a 10 hour woody fuelbed that is 10 cm deep might be matched with the photoload picture of 5 kg m^{-2} but the actual loading would be the product of the photoload estimated loading (5.0 kg m^{-2}) and the depth of the fuelbed (0.1 meters) divided by the largest diameter of the 10 hour class (this fuel class goes from 0.6 cm (0.25 inches) to 2.5 cm (1 inch) so the largest diameter is 0.025 meters) so the final loading estimate would be 20 kg m^{-2} (5.0 kg m^{-2} x 0.1 m depth / 0.025 m diameter).

The degree of decay for downed woody fuels can also influence the accuracy of fuel load estimates and adjustments should be made to correct for the amount of rot. The photoload sampling technique assumes all downed dead woody fuel is sound. So, any observed decay will reduce the loading estimates. We suggest that the following factors be used to adjust sound fuel loadings to account for degree of decay using the decay classes as implemented in FIREMON.

- Decay class 1—No need to adjust for decay
- Decay class 2—No need to adjust for decay
- Decay class 3—Multiply loadings by a factor of 0.90
- Decay class 4—Multiply loadings by a factor of 0.75
- Decay class 5—Multiply loadings by a factor of 0.50

These values were computed from values taken from Brown (1970) and Busse (1994).

Another adjustment is for woody particle diameter in the large woody fuels (100 hr and 1000 hr logs). There is a pronounced diameter bias when estimating loading for woody size classes greater than 1 inch (2.5 cm) in diameter. The range of diameters in large woody fuels is so large that photographs depicting a loading for the fuels with diameters at the small end of the size class may underestimate loadings by a factor of nine for 100 hr fuels because loading increases by the square of the diameter. It is important that the user make sure that the diameters observed in the photoload sequences are the same as those observed in the sampling unit. If not, then the user should use the tables provided in Appendix B to adjust the photoload loadings or approximate loadings directly. Follow the instructions presented for each table in Appendix B and estimate loadings accordingly.

The photoload technique allows the user the flexibility to pick a loading that may be between two consecutive pictures in a photoload sequence. For example, say the user found that the conditions observed on the ground for 1 hr woody fuels did not exactly match any one picture but the loading was definitely greater than the 1.0 kg m^{-2} picture but less than the 1.2 kg m^{-2} picture (see Appendix A). Therefore, the user has the ability to visually extrapolate between pictures and decide on a more appropriate loading. For example, the loading would be estimated at 1.1 kg m^{-2} if the observed loadings appear to be exactly halfway between the two photos. If the conditions were just a bit more than the 1.0 kg m^{-2} photo, then the user might record 1.01 kg m^{-2} as the estimate. Users actually have the ability to assign any fuel loading and they are not confined to using only the loadings printed on the top of the photoload sequence photographs.

In summary, we suggest that each visual estimate of fuel loadings follow these guidelines:

1. Select two photoload pictures that bound the observed loading on the sample unit.
2. Compute a loading estimate by extrapolating between pictures.
3. Adjust that loading for fuelbed depth for that component.
4. Adjust that loading to account for degree of decay.
5. Adjust that loading for the spatial distribution of fuels within the sample frame.
6. Adjust loading for differences in diameter for large woody fuels.

It may be that the target accuracy defined by the sampling objective does not require this six-tiered process of ocular estimation, but we believe that every photoload estimate should be done according to this procedure and users will find that it will become second nature after a while. The loading in the photoload sequences is provided in both English and metric units. It is important that the user select the appropriate units for assessment and be consistent when completing the plot sheet.

Calibrating your eye for estimating loadings—We found that the ability of users to consistently and accurately estimate woody fuels is mostly dependent on their level of expertise. Because of this, it is important that users of the photoload technique calibrate their eye so that they can consistently and accurately estimate loadings. This calibration can be done by repeating the methods that we used for measuring the reference fuel loading conditions in the evaluation of the photoload technique (see Keane and Dickinson 2007; RMRS-RP-61). We suggest that the user build 1x1 meter square plot frames and go to the field and estimate loadings within the plot frame using the photoload sequences and protocol. Then, the user should collect, dry, and weigh by fuel component, and compare the measured loadings with the ocular estimates. We also suggest that the users take photos of the 1x1 meter frames before sampling so that they can compare their measured loadings with the photoload pictures to calibrate their eye in future field seasons or to teach the photoload technique to others.

Another method to calibrate photoload woody fuel estimates is to define a plot of known area and install a number of transects to measure woody fuel using the planar intersect technique (FIREMON, Lutes and others 2006). We suggest that at least 20-30 transects be established and measured within the defined area to get the most accurate woody fuel loadings. The computed woody fuel loadings by size class can be compared to photoload estimates for the defined area. Again, pictures should be taken of the plot and fuel conditions to document the fuelbed conditions for use in training future crews.

Estimating fine woody fuel loading—The most important guidance for estimating loadings of fine woody components is to first correctly identify the right fuel components. Three questions must be answered for the observed fuels to be sampled—are the fuels: 1) *down*,

2) *dead*, and 3) *woody*. The fine fuel particles must be unattached from their parent stems and be below the 6 foot (2 meter) surface fuel height to be considered down; down fuels are those fuel components that are not attached to live or upright dead plants and are entirely on the ground or below 6 feet (2 meters). Larger fuels, such as logs and large 100 hr branches or boles, may look like snags and may not seem down but this is a gray area and we suggest you follow the rule that all woody fuel originating from a tree bole is considered down woody if it leans at an angle greater than 45 degrees from the zenith angle (less than 45 degrees from the horizontal ground). If it is at an angle greater than 45 degrees above horizontal, it can only be considered down if it is a broken bole or branch from a tree where at least one end of the bole is touching the ground (not supported by its own vegetation or other branches). The most confusing situation in the field is dead branches that are attached to a live or dead upright tree but are below the 6 foot (2 meter) sampling height. They might even touch the ground. These are not considered down fuels because they are not detached as yet.

"Dead" fuels are fuels that have no live foliage or branchwood material. Fresh slash and newly broken branches with green foliage are still considered dead even though they are technically alive because we assume they will eventually be dead. Dormant does not mean dead. Dormant plants with no live foliage do not count as dead fuel. Examples include shrubs that have lost their leaves in the autumn and winter. Many people are confused by woody fuel identification and tend to put stalks of annual plants, for example, into the woody category when in fact the stalks are dead herbaceous. Remember needles, detached grass blades, pine cones, and pieces of bark on the ground are considered litter. Since litter loading is not assessed in photoload, be sure not to confuse litter fuels with fine woody fuel.

When sampling fine woody loading with the photoload technique, the user should assess the conditions within the sampling unit (microplot, macroplot, stand) concentrating on loading characteristics and select a photo from the photoload sequences presented in Appendix A that best matches the fuel loading conditions that correlates with the fuel on the ground. If loading seems to fall between two of the photos, choose the appropriate loading between the two loading values in Appendix A, and record it on your data sheet. Be sure to use a "go-no-go" gauge (see FIREMON methods) to measure the diameters of woody fuels to more accurately estimate loadings.

It is sometimes helpful to visually line up the fuel in the photoload photograph, and estimate the distance along one side of the square that the fuel occupies. Then, compare this length with that observed in the sample unit (microplot). Our evaluators found it helpful to concentrate on fuel length to visually compare photoload pictures (they visually added up the length of fuel in the photo with the length of fuel observed on the ground). Pay special attention to the range of diameters in both the photo series and in your sampling unit. Some of the images in Appendix A may not have the range of diameters observed within the sampling unit area. Therefore, the estimate of loading may need to be increased or decreased depending on the differences between diameter distributions.

The most difficult task to perform in the photoload visual approximations is to distinguish between the fine woody fuel size classes with only your eye. Many twigs have tapered diameters that start as 10 hour fuels (diameters greater than 0.25 inches) and then become 1 hour fuels (diameters less than 0.25 inches) somewhere up the stem. This is another major source of error in photoload estimates. Many people find it confusing to visually separate 1 hr from 10 hr fuels and 10 hr from 100 hr fuels. It takes practice but eventually most people become quite accomplished at visually identifying the three fine fuel size classes. We suggest users of the photoload technique take a "go-no-go" gauge or a clear plastic ruler into the field to quickly identify portions of wood into the appropriate size classes. Tips on the use of these two items are detailed in FIREMON (Lutes and others 2006).

Estimating log fuel (1000 hr) loading—Log loadings are estimated at a different scale than the other fuel components in photoload. Logs, because of their large size, are estimated at a subplot level and we highly recommend these subplots be 100 m^2 (10 meters by 10 meters) to match the photoload pictures and tables. If the subplots are not 100 m^2 then you can't use the tables in Appendix B.

Log loadings are especially difficult to estimate using the photoload technique because the pictures do not adequately capture the diameter distribution of the logs in the sample plot. Since log loadings increase by the square of the diameter, small changes in diameter can result in large changes in log loading. Moreover, log rot can also influence loading. As a result, the user must pay special attention to the distribution of log diameters and log lengths on the sample unit. The loading estimated with the photoload picture must be adjusted to account for the difference in diameters between logs in the pictures and logs observed in the field.

The easiest method is to estimate the average diameter on the sample unit and adjust the loadings accordingly. However, the calculation of the average diameter of the logs to estimate loading is also problematic. Since loading is calculated by volume, and volume is calculated from log cross-sectional area and length, and the cross sectional area is calculated by the log diameter squared, then loading is related to the square of the diameter. So, the average diameter should be a quadratic mean rather than an arithmetic mean to accurately calculate volume. This means that larger diameter logs should be given more weight than small diameter logs. So, the calculation of the most accurate average diameter must be done using the square root of the average of the sum of the diameters squared (called the quadratic mean diameter or QMD). There are tables in Appendix B to help with this calculation.

We recommend that the photoload user use the log loading tables in Appendix B to calibrate, adjust, and refine the ocular measurements obtained by the photoload sequences in Appendix A. This alternative method can be used in two ways. First it can be used as a tool to check the loading estimate you made using the photoload sequences described above. Second, it can be used alone without consulting the photo series. To use these tables, the user simply estimates the average diameter of the logs within a 100 m^2 fixed area (we suggest 10 by 10 meters so that it corresponds to the area in the photoload log pictures) and the length of log in the area. These estimates are then referenced in the tables to get the loading. The user can measure log diameters and length with a ruler or tape to get more accurate loading estimates. A more accurate but slower method is to group logs into diameter classes and find lengths by diameter class and use the mid-point of the diameter class and the length in the class to find the loading, and then sum up all loadings by class for a final loading estimate. The most accurate but time intensive method is to measure the log length and diameters of each end of the log to find the loading for each log, then sum up loadings across all logs. The integration of this tabular technique with the photoload technique should provide consistent estimates of loadings, especially when the loadings are high. We also suggest that this same process be used to adjust 100 hour woody fuel loading since loadings can vary greatly across that diameter class width (1 to 3 inches or 2.5 to 7.5 cm).

Here are some guidelines that will help with the photoload estimates of log loadings. First, be sure that logs that have their central axis lying above the duff and litter layer; logs below duff layer are considered duff. Second, be sure that only log fuels are measured; eliminate the parts of the log that are less than 3 inches (7.5 cm) in diameter. Be sure to record the average rot class of the logs on the sample area. This may be important for adjusting the final loading values. And last, adjust all estimates to account for differences in observed and photoload diameters.

In summary, we suggest you follow these steps to accurately and consistently estimate log loadings using the photoload technique. To find a loading using the 6 inch and 10 inch photo sequences follow these steps:

1. Estimate the quadratic mean diameter (QMD) for logs within the sample area (square root of the average of the diameters squared). Record the QMD in the Observed QMD of the photoload plot form (first plot form in Appendix C).
2. Choose the photoload sequence of imitation logs (6 inch or 10 inch) that most closely matches the average QMD of the logs in your sample area. Record which series you are using, by writing a "6" or a "10" in photoload QMD field.
3. Determine the photo from the selected log series that most resembles the loading conditions in the sample unit you are evaluating. Remember to evaluate logs on a 100 m^2 area. Record this loading on the plot form.
4. Find the diameter conversion factor in Table 1 of Appendix B using the observed QMD and photoload QMD and write the conversion factor in the plot form. Record this on the plot form.
5. Calculate the final loading by adjusting the ocular photoload estimate (step 2 and Column A on plot form) for diameter differences by multiplying by the conversion factor. Record this final estimate in the appropriate box on the plot form.
6. Refine the estimate of loading using the second method that uses the tables in Appendix B. This is done only if there is time.
7. Adjust the loading using the rot class multipliers mentioned previously.

The user should record all estimates on the plot form and all intermediate calculations should also be written directly on the plot form. There is plenty of room for calculations and summary statistics.

Estimating shrub and herbaceous loading—The first step in estimating shrub and herb loadings with the photoload technique is to identify the plant species within the sample unit. The user must estimate loading by matching the group of species occurring in the sample area with one or more of the photoload sequences in Appendix A. However, the photoload sequences in Appendix A do not contain all undergrowth plant species in the northern Rocky Mountains, only those that were common in the western Montana study area (Keane and Dickinson 2007; RMRS-RP-61CD). Only seven shrub species, two grass species, and two forb species are found in Appendix A. Therefore, it is necessary to match the morphology of the species observed in the field with the species presented in the photoload sequences (Appendix A). If there are several species of vegetation on your plot, you may choose to use several photo series, one for each species, and then sum the individual loadings to make a final loading estimate of shrub or herbaceous components. Or, you can rate the loading as a collection of species using the most similar photoload sequence.

Finding the appropriate picture in the photoload sequences is a bit more difficult for shrub and herbs because these fuels have depth (plant height), species differences, and heterogeneous distributions. Therefore, we have provided a side view along with a top view to help in estimating loadings. For shrubs and herbs, the user should try to match the pictures with field conditions based on three characteristics: species (previously discussed), cover and density. Once a picture is chosen, then the corresponding loading must be adjusted for differences between height in the picture and height in the sample area. The average height of each plant photo series is indicated at the top of each page in the photoload sequences of Appendix A. Adjust shrub and herbaceous loading only when the average plant height in the photos is different from the average height of plants on your plot.

We recommend that the user follow these steps to determine an adjusted loading:

1. Choose a shrub or herb photoload sequence that best represents the vegetation on your sample area. Match to the closest species, genus, or morphology.
2. Visually estimate the loading using standard photoload procedures. Write this loading on the photoload plot form in Appendix C.
3. Estimate the height of the shrub or herb present within the sample unit. This is estimated as an integrated average across the entire sampling area. A hint is to visually drape a sheet over the shrub or fuel component and estimate the average height across the entire sheet. Write this height in the top of the division on the plot form.
4. Write the photoload height for the sequence that is being used on the plot form. This height should be at the top of each page in the shrub or herb sequence.
5. Calculate the height ratio (divide observed height by photoload height) and multiply the ratio by the loading estimate to calculate the final height. Write in the appropriate field of the plot form.
6. Estimate final loading by multiplying the visual estimate of loading by the height ratio.

This process can be repeated several times and the sum of the final loadings can be entered into the final field if more than one photo series of plants are used.

We recommend that shrub and herbaceous loadings be estimated when the plants are still green and at the peak of their growth (end of the growing season). However, this may be impossible for many sampling efforts. Users should avoid sampling too early in the year before new growth and too late when some plants have been eaten or deteriorated. If early or late sampling is the only option, be sure to only rate the fuels that are observed at that time—do not try to recreate optimum growth—unless the sampling objective requires that you adjust for phenology.

Estimating litter and duff loadings—We do not present any methods for estimating duff and litter loads in the photoload technique. However, we strongly recommend that loadings for these fuel components be estimated using the methods presented in FIREMON (Lutes and others 2006) and linked to the methods presented in this study. We recommend that duff plus litter depth and percent of that depth that is litter be measured in two opposing corners of each microplot used to estimate loadings. Duff and litter measurements can be written on the FIREMON plot form or the Photoload plot form.

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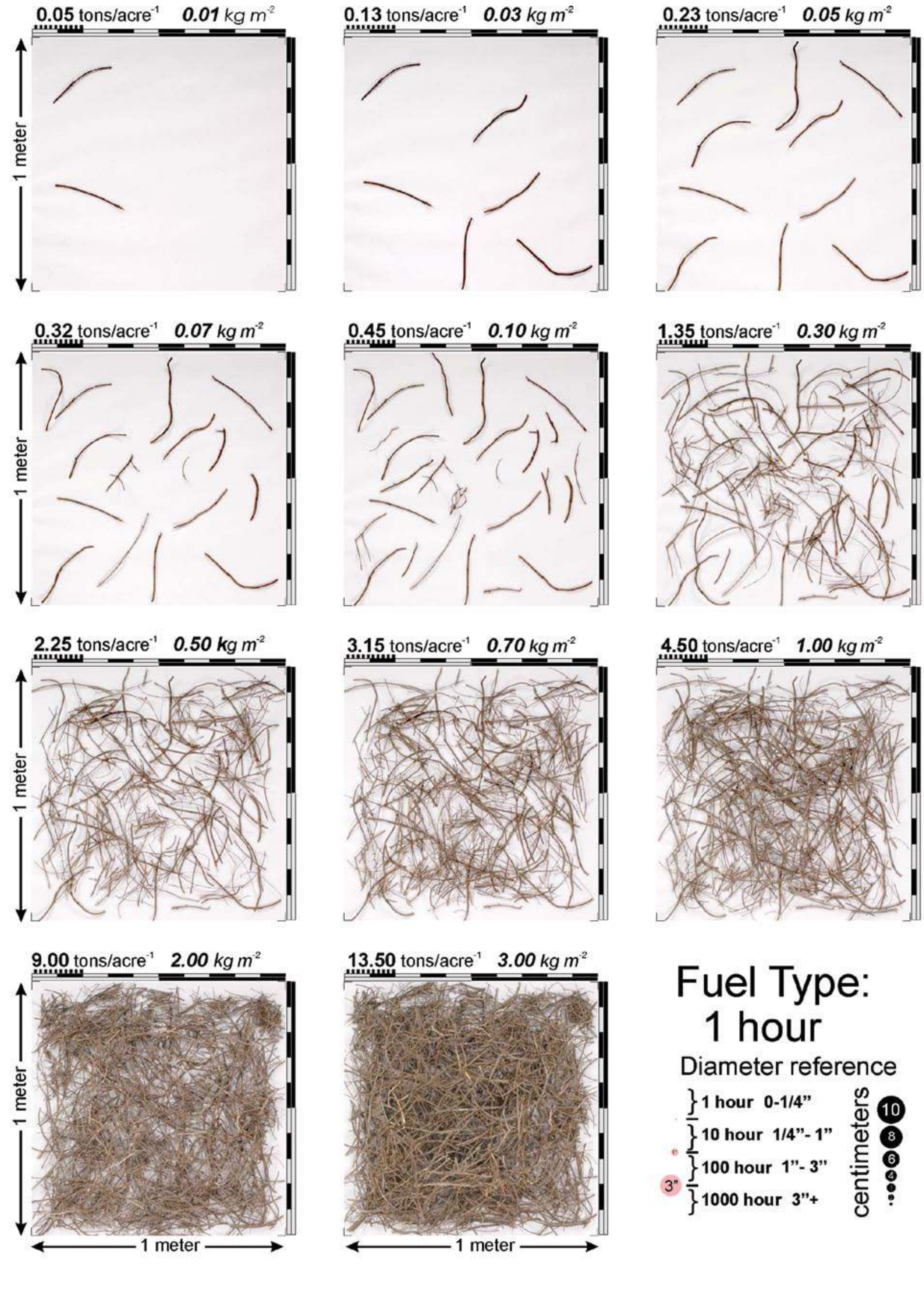
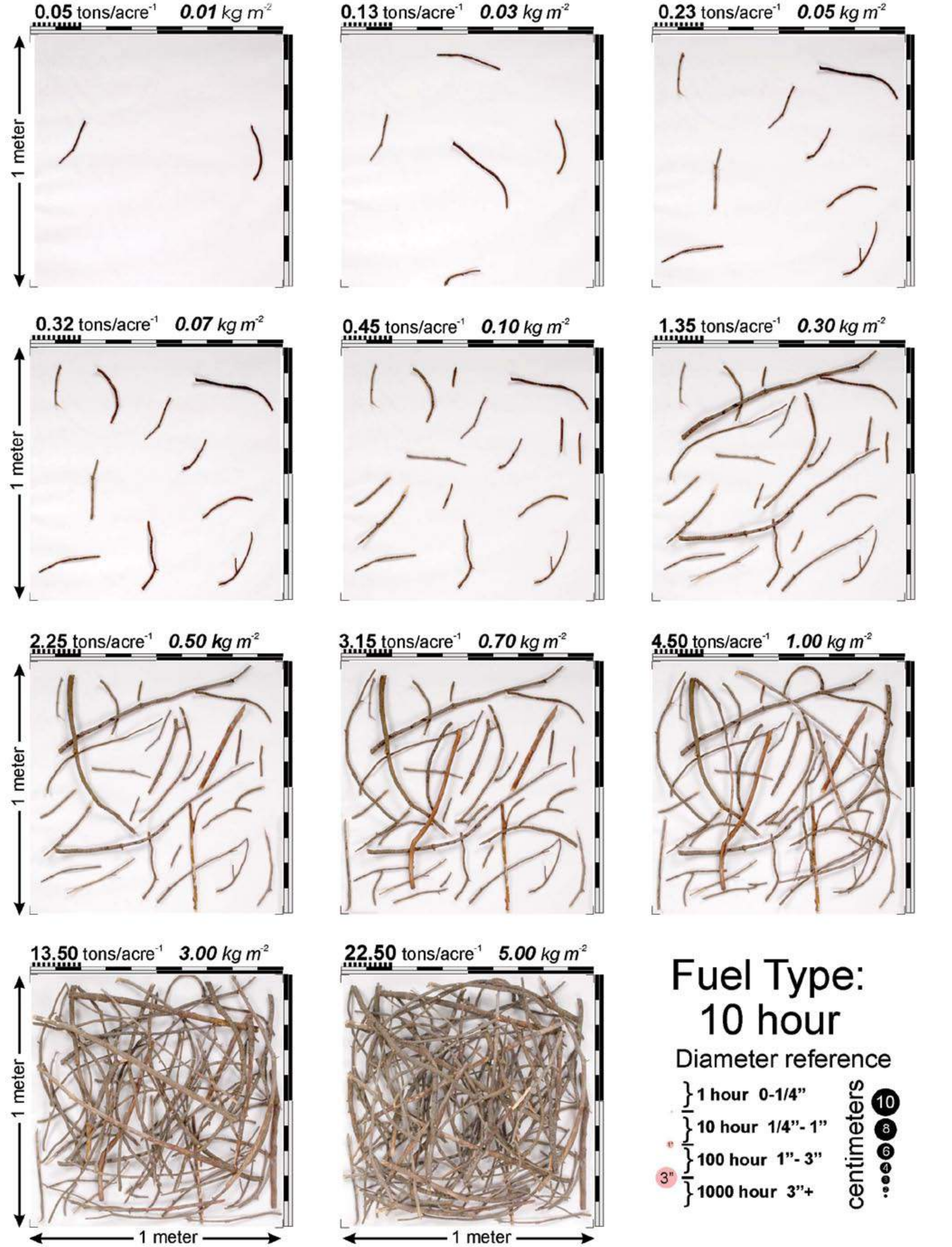
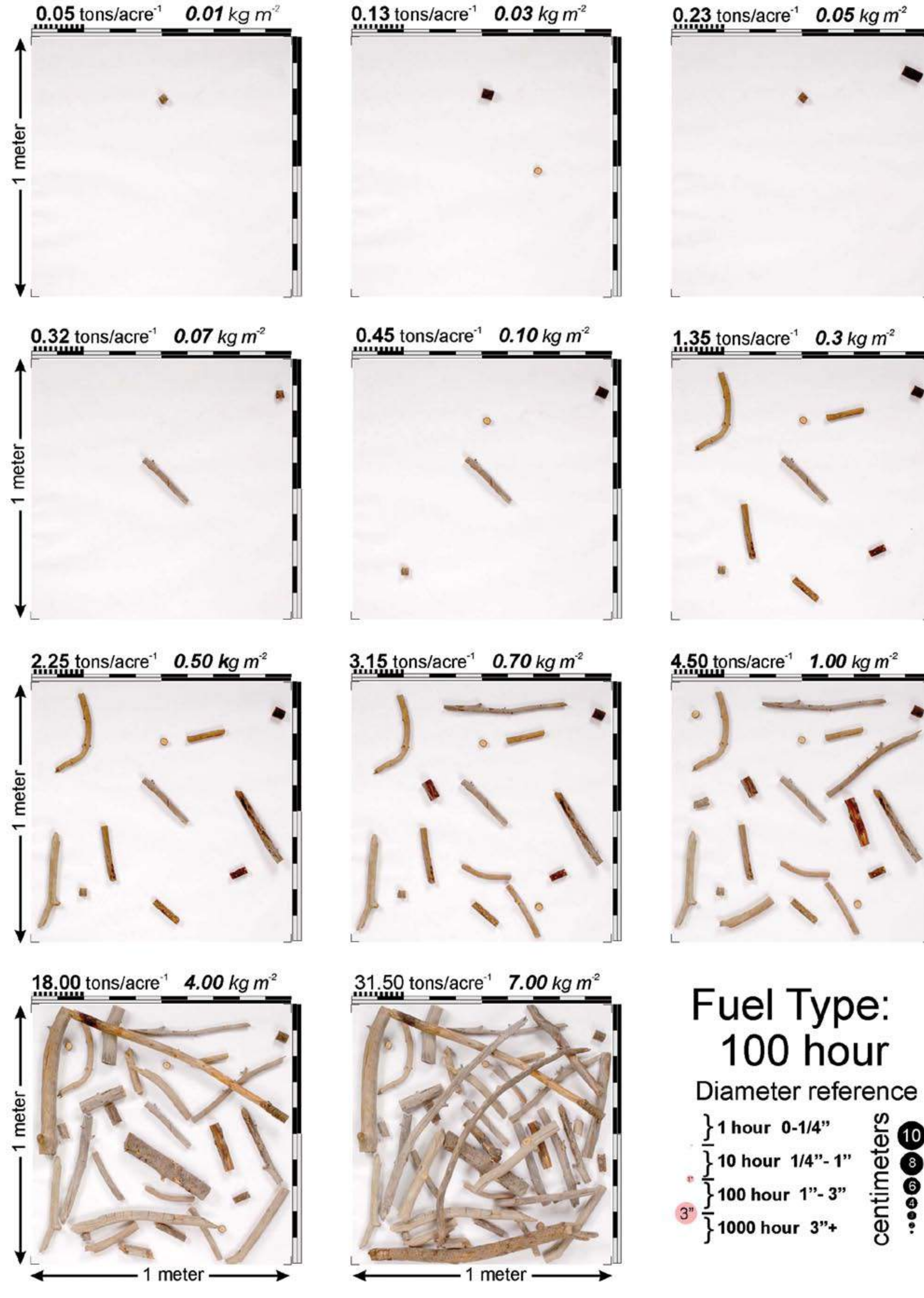
Appendix A—Photoload Sequences for Northern Rocky Mountain Fuelbeds



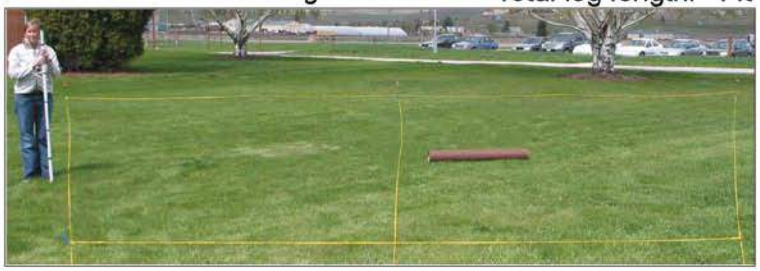

0.05 tons/acre-1 0.01 kg m-2
0.13 tons/acre-1 0.03 kg m-2
0.23 tons/acre-1 0.05 kg m-2
0.32 tons/acre-1 0.07 kg m-2
0.45 tons/acre-1 0.10 kg m-2
1.35 tons/acre-1 0.30 kg m-2
2.25 tons/acre-1 0.50 kg m-2
3.15 tons/acre-1 0.70 kg m-2
4.50 tons/acre-1 1.00 kg m-2
13.50 tons/acre-1 3.00 kg m-2
22.50 tons/acre-1 5.00 kg m-2
1 meter
Fuel Type:
10 hour
Diameter reference
1 hour 0-1/4"
10 hour 1/4"- 1"
100 hour 1"- 3"
1000 hour 3"+
3"
centimeters
10
8
6
4


0.05 tons/acre-1 0.01 kg m-2
0.13 tons/acre-1 0.03 kg m-2
0.23 tons/acre-1 0.05 kg m-2
0.32 tons/acre-1 0.07 kg m-2
0.45 tons/acre-1 0.10 kg m-2
1.35 tons/acre-1 0.3 kg m-2
2.25 tons/acre-1 0.50 kg m-2
3.15 tons/acre-1 0.70 kg m-2
4.50 tons/acre-1 1.00 kg m-2
18.00 tons/acre-1 4.00 kg m-2
31.50 tons/acre-1 7.00 kg m-2
1 meter
1 meter
Fuel Type:
100 hour
Diameter reference
1 hour 0-1/4"
10 hour 1/4"- 1"
100 hour 1"- 3"
1000 hour 3"+
3"
centimeters
10
8
6
4

Fuel Type: 1000 Hour

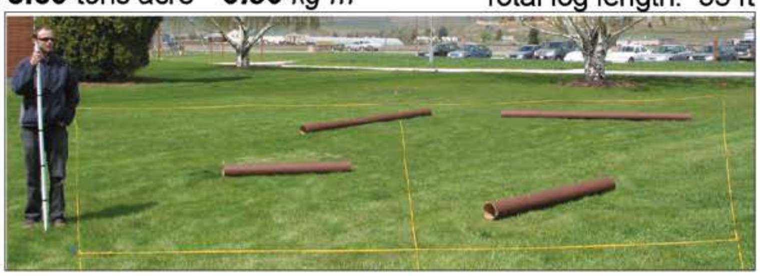
Species: ***Psuedotsuga menziesii*** **(Douglas-fir) imitation Diameter: 6.00 in (15.20 cm)**

0.45 tons acre^{-1} ***0.10*** *kg m*$^{-2}$ Total log length: 4 ft

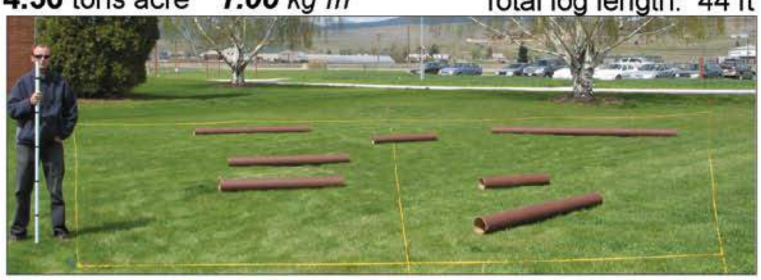


1.80 tons acre^{-1} ***0.40*** *kg m*$^{-2}$ Total log length: 18 feet

3.60 tons acre^{-1} ***0.80*** *kg m*$^{-2}$ Total log length: 35 ft



4.50 tons acre^{-1} ***1.00*** *kg m*$^{-2}$ Total log length: 44 ft



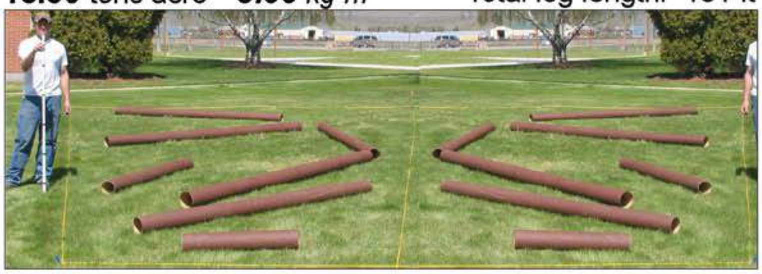
6.75 tons acre^{-1} ***1.50*** *kg m*$^{-2}$ Total log length: 66 ft

Fuel Type: 1000 Hour

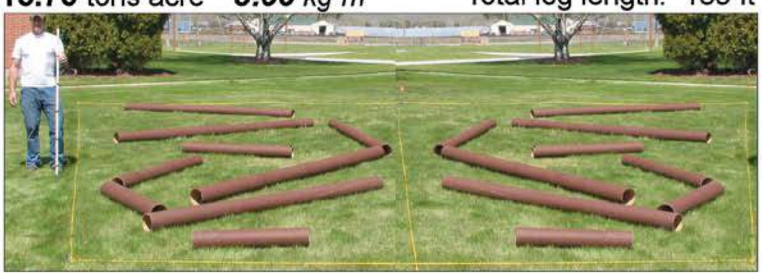
Species: *Psuedotsuga menziesii* (Douglas-fir) imitation   Diameter: 6.00 in (15.24 cm)

11.25 tons acre^{-1} ***2.50** kg m^{-2}*   Total log length: 110 ft

13.50 tons acre^{-1} ***3.00** kg m^{-2}*   Total log length: 131 ft

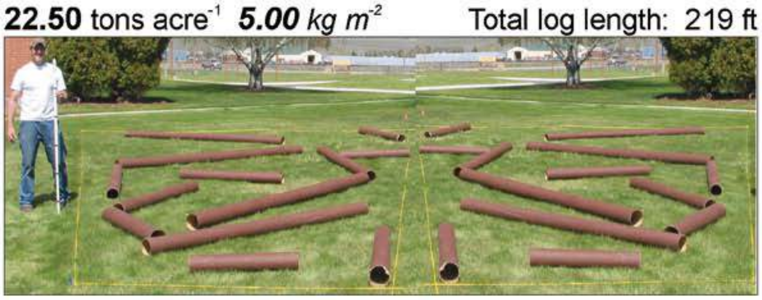


15.75 tons acre^{-1} ***3.50** kg m^{-2}*   Total log length: 153 ft



18.00 tons acre^{-1} ***4.00** kg m^{-2}*   Total log length: 175 ft

22.50 tons acre^{-1} ***5.00** kg m^{-2}*   Total log length: 219 ft



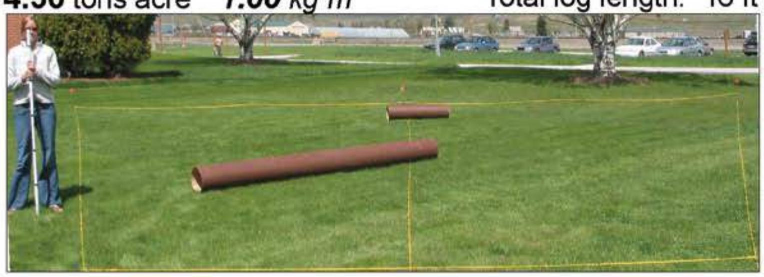
Fuel Type: 1000 Hour

Species: *Psuedotsuga menziesii* (Douglas-fir) imitation   Diameter: 10.00 in (25.40 cm)

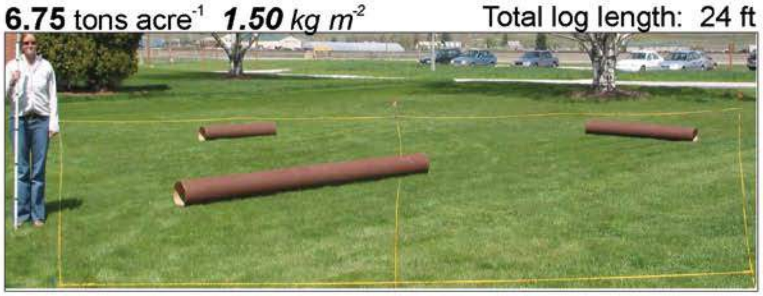
0.45 tons acre^{-1} ***0.10*** *kg m^{-2}*   Total log length: 2 ft

1.80 tons acre^{-1} ***0.40*** *kg m^{-2}*   Total log length: 6 ft

4.50 tons acre^{-1} ***1.00*** *kg m^{-2}*   Total log length: 16 ft



6.75 tons acre^{-1} ***1.50*** *kg m^{-2}*   Total log length: 24 ft



9.00 tons acre^{-1} ***2.00*** *kg m^{-2}*   Total log length: 32 ft

Fuel Type: 1000 Hour

Species: ***Psuedotsuga menziesii* (Douglas-fir) imitation Diameter: 10.00 in (25.40 cm)**

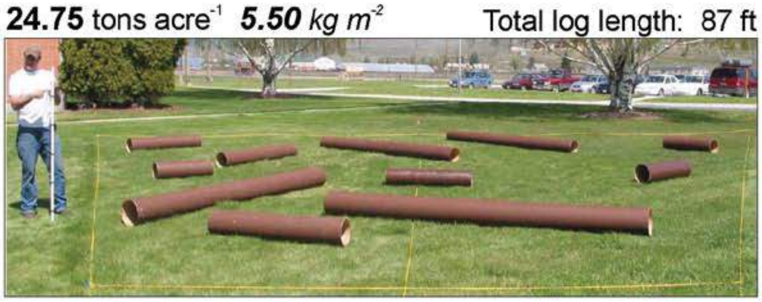
11.25 tons acre^{-1} ***2.50*** *kg m^{-2}* Total log length: 40 ft

13.50 tons acre^{-1} ***3.00*** *kg m^{-2}* Total log length: 47 feet

15.75 tons acre^{-1} ***3.50*** *kg m^{-2}* Total log length: 55 ft

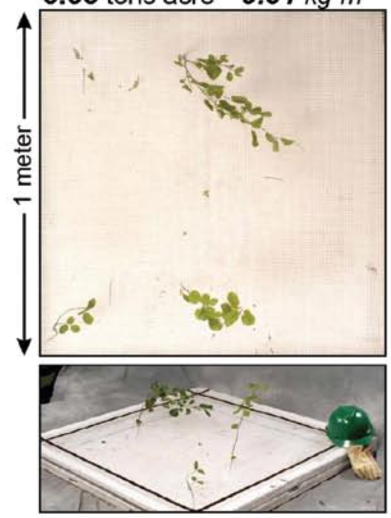
20.25 tons acre^{-1} ***4.50*** *kg m^{-2}* Total log length: 71 ft

24.75 tons acre^{-1} ***5.50*** *kg m^{-2}* Total log length: 87 ft



Fuel Type: Live Shrub
Species: *Amelanchier alnifolia* (Serviceberry) Ht: 14.00 in (35.56 cm)

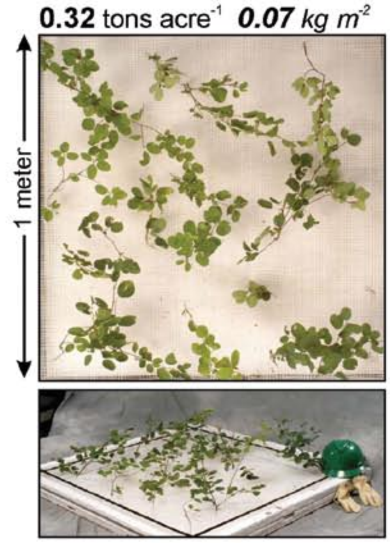
0.05 tons acre^{-1} ***0.01** kg m^{-2}*



0.13 tons acre^{-1} ***0.03** kg m^{-2}*

0.23 tons acre^{-1} ***0.05** kg m^{-2}*

0.32 tons acre^{-1} ***0.07** kg m^{-2}*



0.41 tons acre^{-1} ***0.09** kg m^{-2}*

0.54 tons acre^{-1} ***0.12** kg m^{-2}*

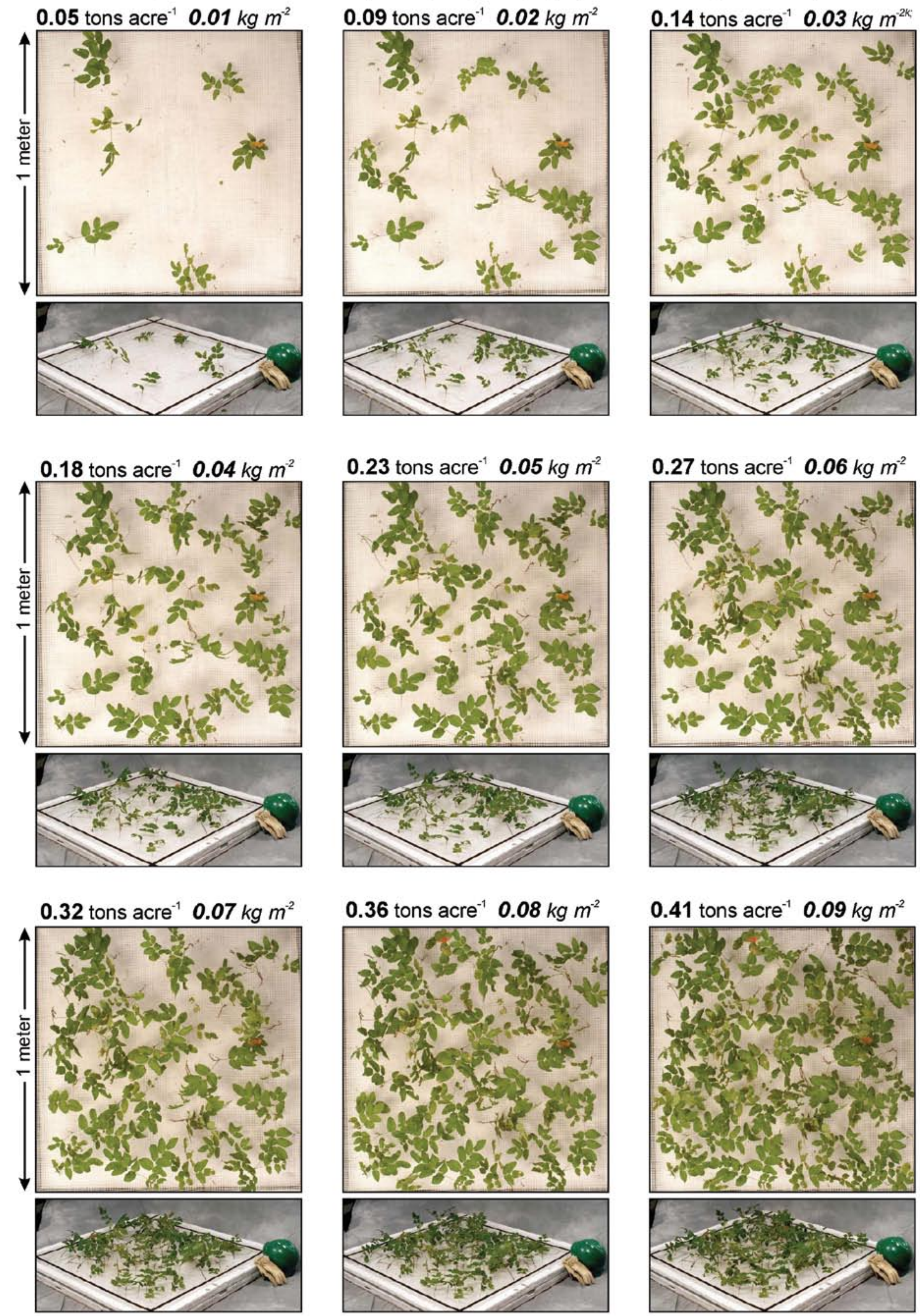
0.68 tons acre^{-1} ***0.15** kg m^{-2}*

0.81 tons acre^{-1} ***0.18** kg m^{-2}*

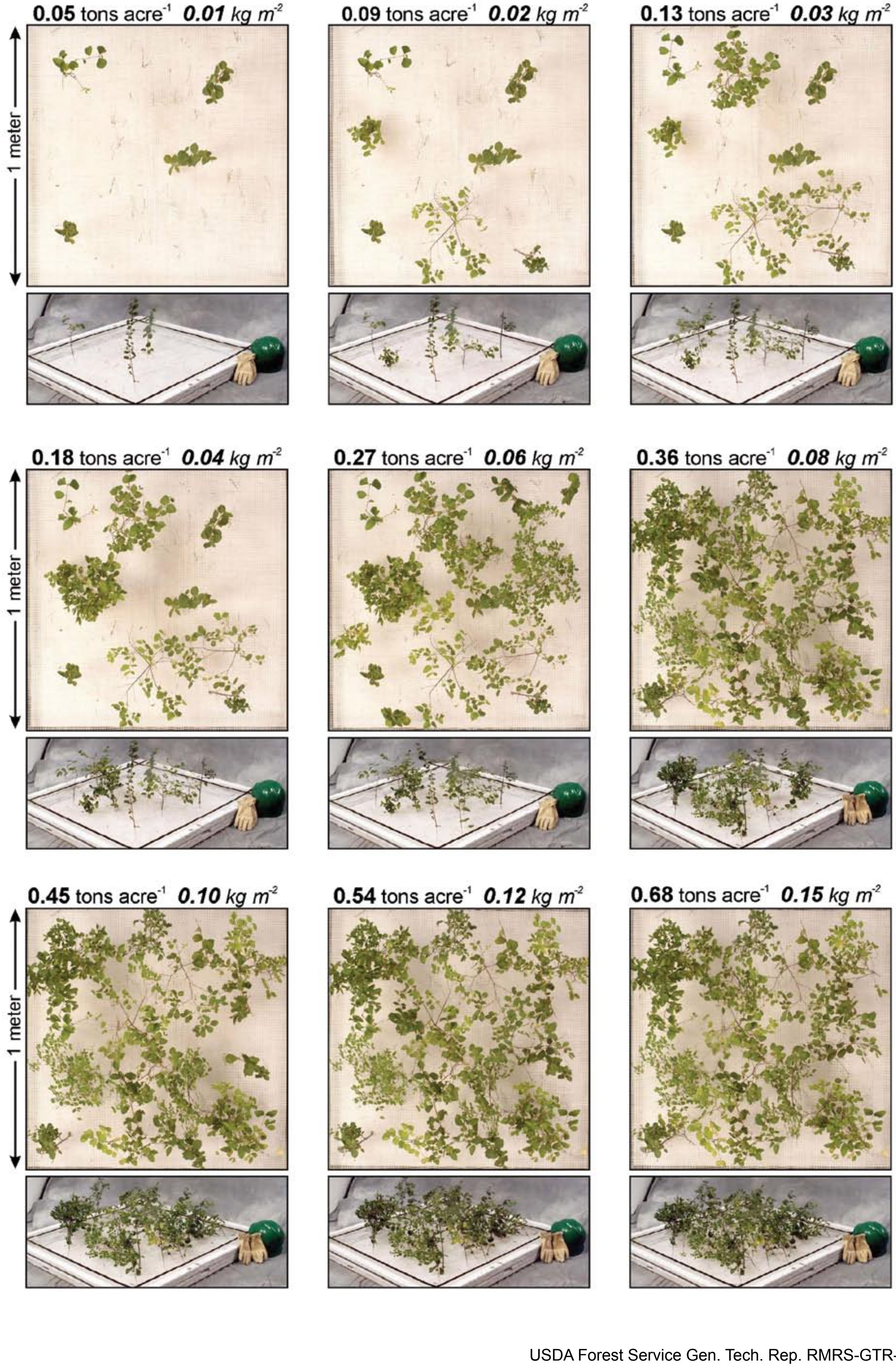
1.13 tons acre^{-1} ***0.25** kg m^{-2}*

Fuel Type: Live Shrub

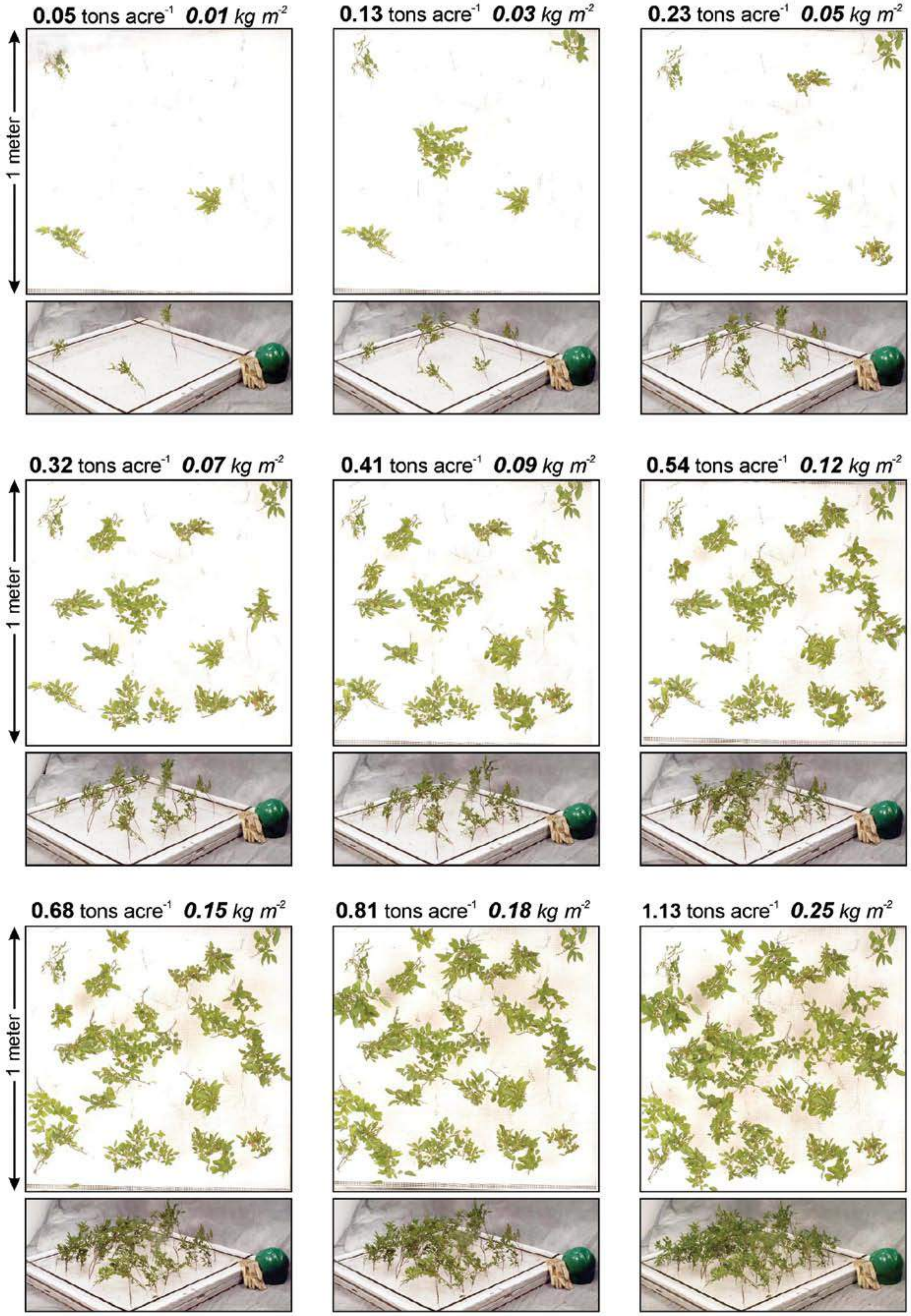
Species: *Berberis repens* (Oregon grape) Ht: 4.00 in (10.16 cm)



Fuel Type: Live Shrub
Species: *Symphoricarpos albus* (Snowberry) Ht: 14.00 in (35.56 cm)

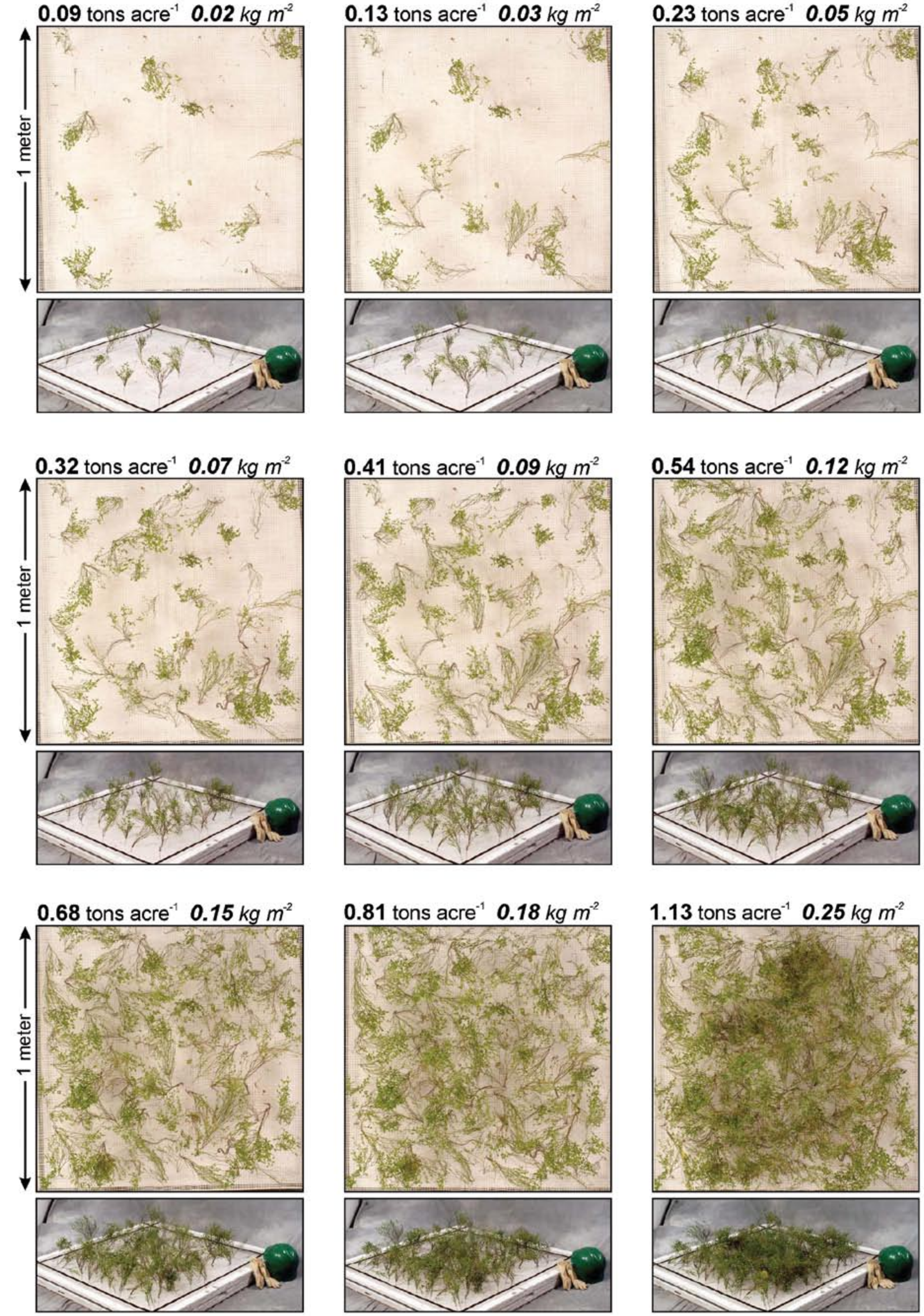


Fuel Type: Live Shrub
Species: Vaccinium globulare (Huckleberry) Ht: 14 in (35.6 cm)



Fuel Type: Live Shrub

Species: *Vaccinium scoparium* (grouse whortleberry) Ht: 7.00 in (17.78 cm)

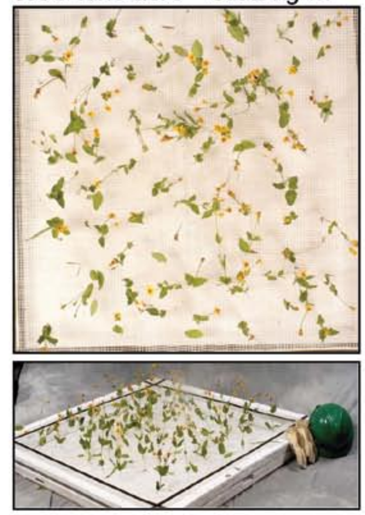


Fuel Type: Live Forb
Species: *Arnica latifolia* (arnica) Ht: 12.00 in (30.48 cm)

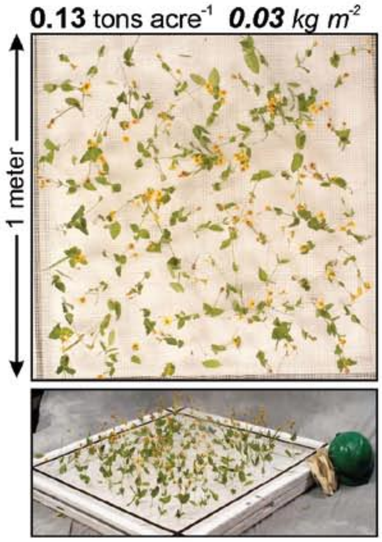
0.02 tons acre^{-1} ***0.005*** *kg m*$^{-2}$

0.05 tons acre^{-1} ***0.01*** *kg m*$^{-2}$

0.09 tons acre^{-1} ***0.02*** *kg m*$^{-2}$



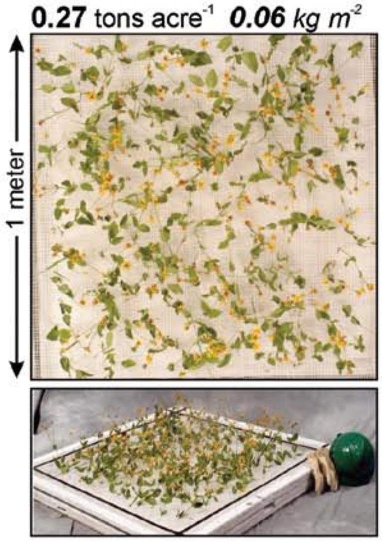
0.13 tons acre^{-1} ***0.03*** *kg m*$^{-2}$



0.18 tons acre^{-1} ***0.04*** *kg m*$^{-2}$

0.23 tons acre^{-1} ***0.05*** *kg m*$^{-2}$

0.27 tons acre^{-1} ***0.06*** *kg m*$^{-2}$

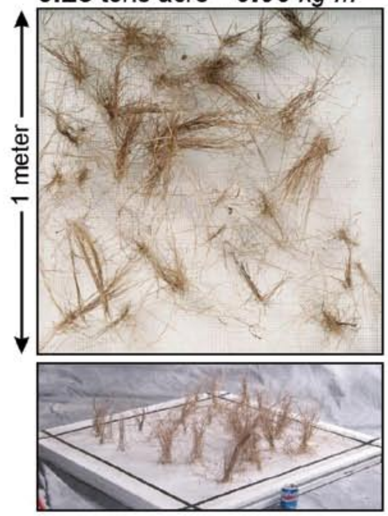


0.32 tons acre^{-1} ***0.07*** *kg m*$^{-2}$

0.36 tons acre^{-1} ***0.08*** *kg m*$^{-2}$

Fuel Type: Dead Herbaceous
Species: *Calamagrostis rubescens* (Pinegrass) Ht: 8.00 in (20.30 cm)

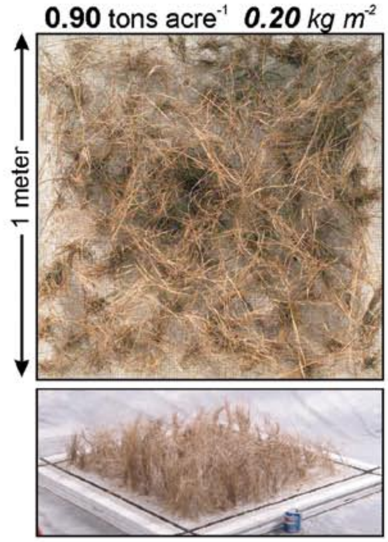
0.23 tons acre^{-1} ***0.05*** *kg m^{-2}*



0.45 tons acre^{-1} ***0.10*** *kg m^{-2}*

0.68 tons acre^{-1} ***0.15*** *kg m^{-2}*

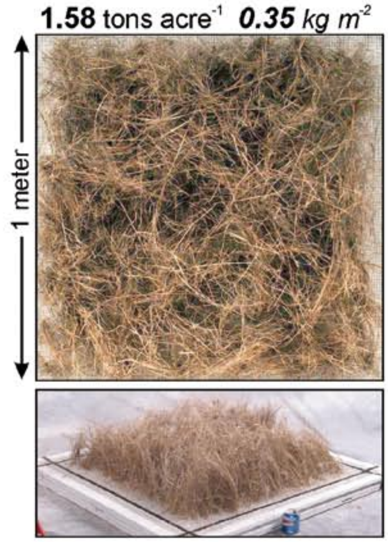
0.90 tons acre^{-1} ***0.20*** *kg m^{-2}*



1.13 tons acre^{-1} ***0.25*** *kg m^{-2}*

1.35 tons acre^{-1} ***0.30*** *kg m^{-2}*

1.58 tons acre^{-1} ***0.35*** *kg m^{-2}*



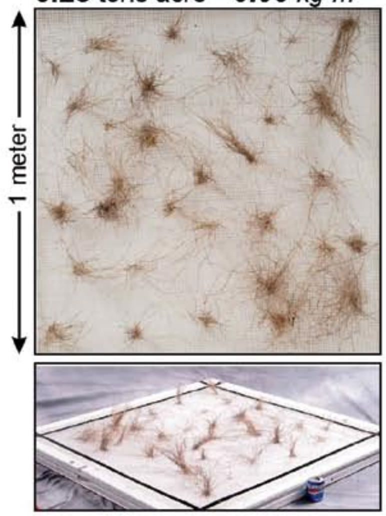
1.80 tons acre^{-1} ***0.40*** *kg m^{-2}*

2.03 tons acre^{-1} ***0.45*** *kg m^{-2}*

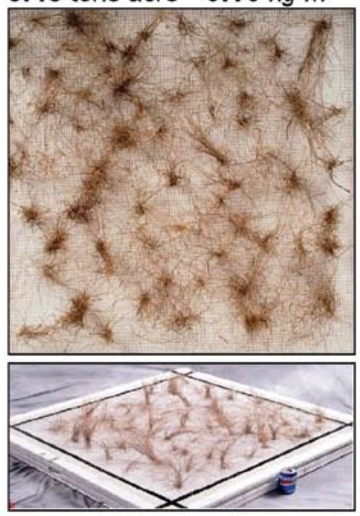
Fuel Type: Dead Herbaceous

Species: *Festuca scabrella* (Rough Fescue) Ht: 1 ft (30.5 cm)

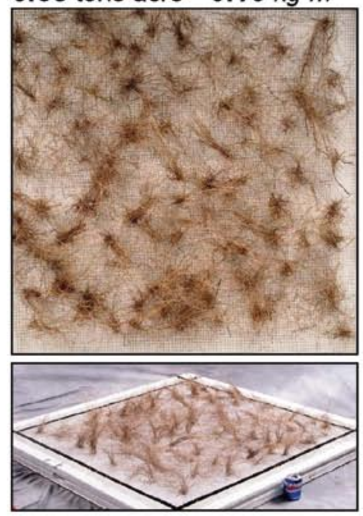
0.23 tons acre^{-1} ***0.05*** *kg m^{-2}*



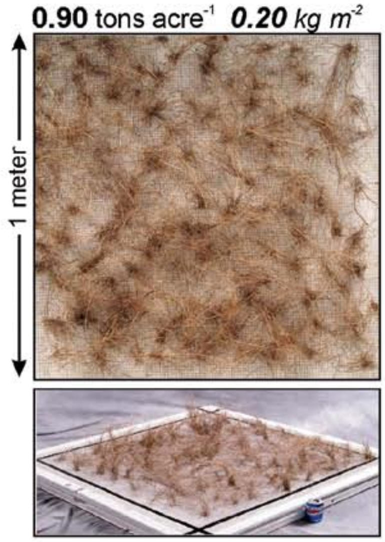
0.45 tons acre^{-1} ***0.10*** *kg m^{-2}*



0.68 tons acre^{-1} ***0.15*** *kg m^{-2}*



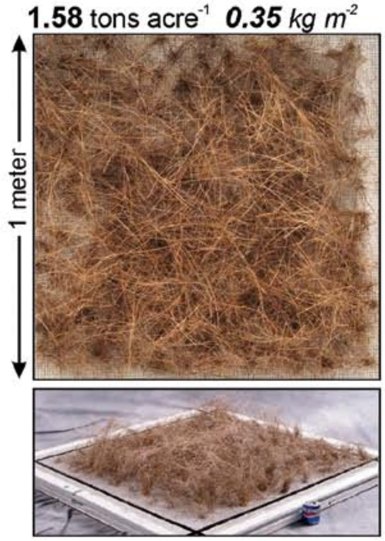
0.90 tons acre^{-1} ***0.20*** *kg m^{-2}*



1.13 tons acre^{-1} ***0.25*** *kg m^{-2}*

1.35 tons acre^{-1} ***0.30*** *kg m^{-2}*

1.58 tons acre^{-1} ***0.35*** *kg m^{-2}*

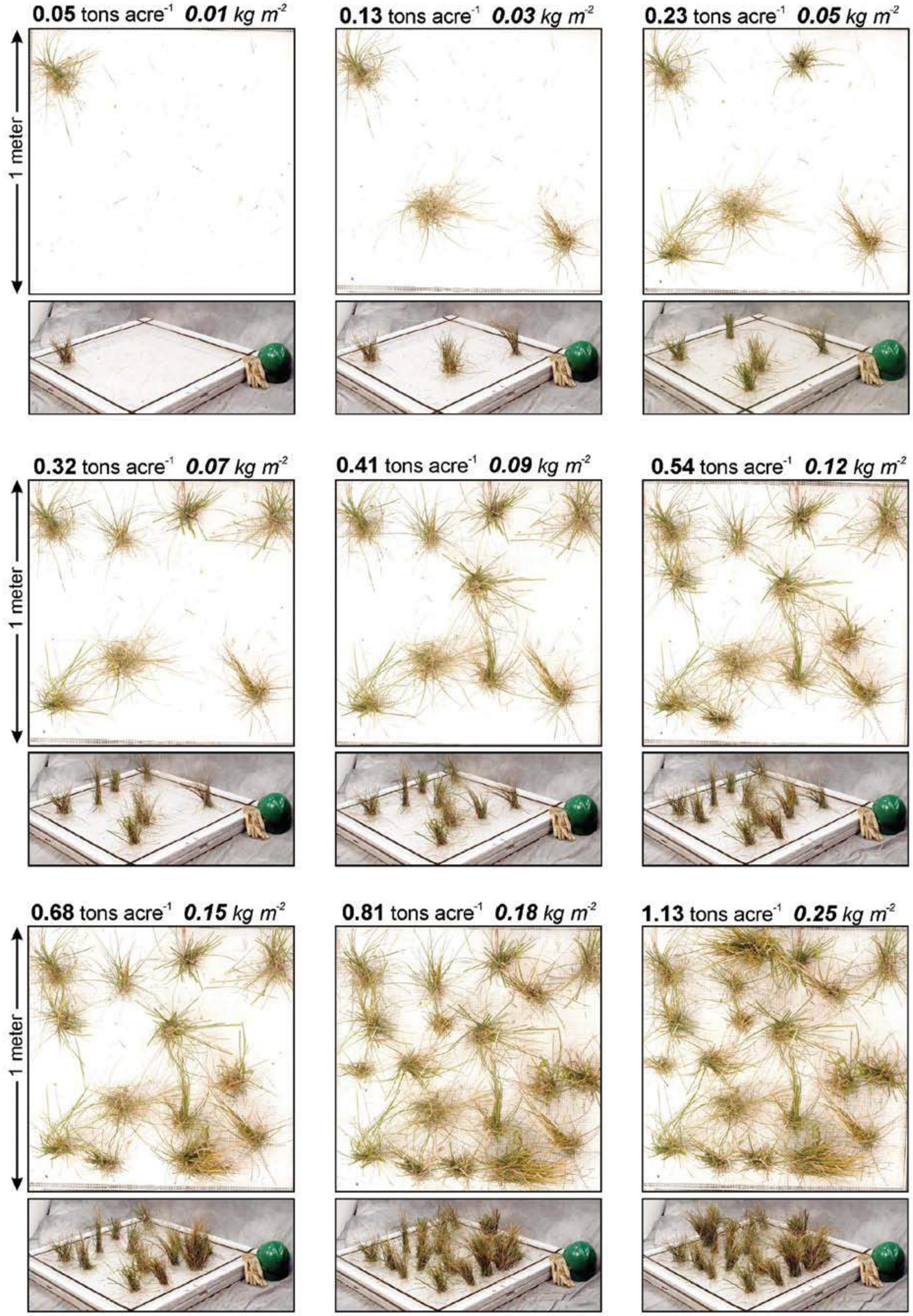


1.80 tons acre^{-1} ***0.40*** *kg m^{-2}*

2.03 tons acre^{-1} ***0.45*** *kg m^{-2}*

Fuel Type: Live Forb

Species: *Xerophyllum tenax* (Bear Grass) Ht: 10.00 in (25.40 cm)



Appendix B—Tables of Log and Branch Loading by Diameter and Length

Photoload log diameter conversion table—This table is used to adjust photoload estimated log loadings for the difference in log diameters between the photoload photo sets and the log diameters observed in the field.

Observed average log diameter		Photoload log picture diameter set	
(in)	*(cm)*	*6 inch*	*10 inch*
3	7.62	0.25	0.09
4	10.16	0.44	0.16
5	12.7	0.69	0.25
6	15.24	1.00	0.36
7	17.78	1.36	0.49
8	20.32	1.78	0.64
9	22.86	2.25	0.81
10	25.40	2.78	1.00
11	27.94	3.36	1.21
12	30.48	4.00	1.44
13	33.02	4.69	1.69
14	35.56	5.44	1.96
15	38.10	6.25	2.25
16	40.64	7.11	2.56
17	43.18	8.03	2.89
18	45.72	9.00	3.24

To adjust photoload loading for log diameters in the field, use the following steps:

1. Select either the 6 inch or 10 inch photoload photo set based on the similarity of log diameters found in the sample area.
2. Determine the photo in that set that most resembles loadings in the area you are evaluating.
3. Determine the average diameter of 1000 hour fuel in the area you are evaluating and find that diameter in column one or two of the table above. Remember, the quadratic mean diameter is a better estimate of average log diameter. The formula for quadratic mean diameter (QMD) is:

$$QMD = \sqrt{\frac{\sum d^2}{n}}$$

where d is log diameter and n is the number of logs.

4. Find the conversion factor in column three or four, depending on which photo series you used in step 2, and determine the conversion factor.
5. Multiply the conversion factor by the loading you estimated from step 2. The product is the final loading of 1000 hour fuel of your sample area.

The following set of tables represents an alternative method of determining woody fuel loading of branches and logs using an average diameter and length. The tables were constructed so that once users determine the average diameter of the woody fuel component and the total length of that component, they can reference the table to determine loading. The conversion to loading assumed a log density that is 400 kg m^{-3}, which is typical for sound northern Rocky Mountain tree species as an aggregate. However, you can proportionally adjust the values in the tables to reflect wood density of rotten logs. The tables are arranged first by downed dead woody fuel component—100 hour (branches) and 1000 hour (logs). Then, the tables are arranged by the units used to estimate diameter and length observations. There are four tables for each fuel component. The first table is used if the diameters and lengths were measured in inches and feet, respectively, and the loading is desired in tons per acre. The second table has inches and feet for diameter and length, but loading is in kg per square meter (a unit that is more easily visualized). The third and fourth tables have diameter and length in centimeters and meters but the loading is kg m^{-2} for one table and tons per acre for the other.

One important reminder on estimating loading using this technique. The loading of 100 hr fuels are estimated for a sampling area of one square meter. The loading of 1000 hr fuels (logs) are estimated on 100 m^2 area (10 meters by 10 meters). All the tables are constructed using these plot dimensions.

The following steps are used to estimate loading using these tables:

1. Measure the length of all woody fuel particles in the fuel component (100 hr or 1000 hr) within the sample area (1 or 100 m^2). This can be visually estimated or actually measured using a cloth tape.
2. Estimate the average diameter across all logs within the sample area. The best estimates of average diameter are done using the quadratic mean square estimate where the sum of the squares of all woody fuel particles are estimated and then divided by the number of particles and then the square root is taken.
3. Find the table that matches the appropriate woody fuel component and the units desired.
4. Find the loading by cross referencing the length and diameter.
5. Use linear extrapolation across rows or columns if the diameter or lengths do not match the categories listed in the table.
6. Record the final loading on the plot sheet.

Branch 100 hour wood fuels (1-3 inches dia)—Estimated on a 1 m^2 plot—English units for diameters (in) and lengths (ft)—**English units for loadings (tons $acre^{-1}$)**

Branch 100 hr loadings in tons $acre^{-1}$

LENGTH (ft)	DIAMETER (inches) 1	1.5	2	2.5	3	LENGTH (ft)
1	0.33	0.74	1.32	2.07	2.98	1
2	0.66	1.49	2.65	4.13	5.95	2
3	0.99	2.23	3.97	6.20	8.93	3
4	1.32	2.98	5.29	8.27	11.90	4
5	1.65	3.72	6.61	10.33	14.88	5
6	1.98	4.46	7.94	12.40	17.85	6
7	2.31	5.21	9.26	14.47	20.83	7
8	2.65	5.95	10.58	16.53	23.81	8
9	2.98	6.70	11.90	18.60	26.78	9
10	3.31	7.44	13.23	20.66	29.76	10
11	3.64	8.18	14.55	22.73	32.73	11
12	3.97	8.93	15.87	24.80	35.71	12
13	4.30	9.67	17.19	26.86	38.68	13
14	4.63	10.41	18.52	28.93	41.66	14
15	4.96	11.16	19.84	31.00	44.64	15
16	5.29	11.90	21.16	33.06	47.61	16
17	5.62	12.65	22.48	35.13	50.59	17
18	5.95	13.39	23.81	37.20	53.56	18
19	6.28	14.13	25.13	39.26	56.54	19
20	6.61	14.88	26.45	41.33	59.51	20
	1	1.5	2	2.5	3	
	DIAMETER (inches)					

Branch 100 hour wood fuels (1-3 inches dia)—Estimated on a 1 m^2 plot—English units for diameters (in) and lengths (ft)—**Metric units for loadings (kg m^{-2})**

Branch 100 hr loadings in kg m^{-2}

LENGTH (ft) \ DIAMETER (in)	1	1.5	2	2.5	3	LENGTH (ft)
1	0.07	0.17	0.30	0.46	0.67	1
2	0.15	0.33	0.59	0.93	1.33	2
3	0.22	0.50	0.89	1.39	2.00	3
4	0.30	0.67	1.19	1.85	2.67	4
5	0.37	0.83	1.48	2.32	3.34	5
6	0.44	1.00	1.78	2.78	4.00	6
7	0.52	1.17	2.08	3.24	4.67	7
8	0.59	1.33	2.37	3.71	5.34	8
9	0.67	1.50	2.67	4.17	6.00	9
10	0.74	1.67	2.97	4.63	6.67	10
11	0.82	1.83	3.26	5.10	7.34	11
12	0.89	2.00	3.56	5.56	8.01	12
13	0.96	2.17	3.85	6.02	8.67	13
14	1.04	2.34	4.15	6.49	9.34	14
15	1.11	2.50	4.45	6.95	10.01	15
16	1.19	2.67	4.74	7.41	10.68	16
17	1.26	2.84	5.04	7.88	11.34	17
18	1.33	3.00	5.34	8.34	12.01	18
19	1.41	3.17	5.63	8.80	12.68	19
20	1.48	3.34	5.93	9.27	13.34	20
	1	1.5	2	2.5	3	
	DIAMETER (in)					

Branch 100 hour wood fuels (2-8 cm dia)—Estimated on a 1 m^2 plot—Metric units for diameters (cm) and lengths (m)—**English units for loadings (tons acre^{-1})**

Branch 100 hr loadings in tons acre^{-1}

LENGTH (m) \ DIAMETER (cm)	1	2	3	4	5	6	7	8	9	10	LENGTH (m)
1	0.17	0.67	1.51	2.69	4.20	6.05	8.24	10.76	13.62	16.81	1
2	0.34	1.35	3.03	5.38	8.41	12.11	16.48	21.52	27.24	33.63	2
3	0.50	2.02	4.54	8.07	12.61	18.16	24.72	32.28	40.86	50.44	3
4	0.67	2.69	6.05	10.76	16.81	24.21	32.96	43.04	54.48	67.26	4
5	0.84	3.36	7.57	13.45	21.02	30.26	41.19	53.80	68.10	84.07	5
6	1.01	4.04	9.08	16.14	25.22	36.32	49.43	64.56	81.72	100.88	6
7	1.18	4.71	10.59	18.83	29.42	42.37	57.67	75.33	95.33	117.70	7
8	1.35	5.38	12.11	21.52	33.63	48.42	65.91	86.09	108.95	134.51	8
9	1.51	6.05	13.62	24.21	37.83	54.48	74.15	96.85	122.57	151.32	9
10	1.68	6.73	15.13	26.90	42.03	60.53	82.39	107.61	136.19	168.14	10
	1	2	3	4	5	6	7	8	9	10	

DIAMETER (cm)

Branch 100 hour wood fuels (2-8 cm dia)—Estimated on a 1 m^2 plot—Metric units for diameters (cm) and lengths (m)—**Metric units for loadings (kg m^{-2})**

Branch 100 hr loadings in kg m^{-2}

LENGTH (m)	DIAMETER (cm) 1	2	3	4	5	6	7	8	9	10	LENGTH (m)
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
	1	2	3	4	5	6	7	8	9	10	

DIAMETER (cm)

Log 1000 hour wood fuels (3+ inches dia)—Estimated on a 100 m^2 plot—English units for diameters (in) and lengths (ft)—**English units for loadings (tons $acre^{-1}$)**

Log 1000 hr loadings in tons $acre^{-1}$

LENGTH (ft)	DIAMETER (in) 3	4	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	LENGTH (ft)
1	0.03	0.05	0.08	0.12	0.16	0.21	0.27	0.33	0.48	0.65	0.85	1.07	1.32	1.60	1.90	2.24	2.59	2.98	1
2	0.06	0.11	0.17	0.24	0.32	0.42	0.54	0.66	0.95	1.30	1.69	2.14	2.65	3.20	3.81	4.47	5.18	5.95	2
3	0.09	0.16	0.25	0.36	0.49	0.63	0.80	0.99	1.43	1.94	2.54	3.21	3.97	4.80	5.71	6.71	7.78	8.93	3
4	0.12	0.21	0.33	0.48	0.65	0.85	1.07	1.32	1.90	2.59	3.39	4.29	5.29	6.40	7.62	8.94	10.37	11.90	4
5	0.15	0.26	0.41	0.60	0.81	1.06	1.34	1.65	2.38	3.24	4.23	5.36	6.61	8.00	9.52	11.18	12.96	14.88	5
6	0.18	0.32	0.50	0.71	0.97	1.27	1.61	1.98	2.86	3.89	5.08	6.43	7.94	9.60	11.43	13.41	15.55	17.85	6
7	0.21	0.37	0.58	0.83	1.13	1.48	1.87	2.31	3.33	4.54	5.92	7.50	9.26	11.20	13.33	15.65	18.15	20.83	7
8	0.24	0.42	0.66	0.95	1.30	1.69	2.14	2.65	3.81	5.18	6.77	8.57	10.58	12.80	15.24	17.88	20.74	23.81	8
9	0.27	0.48	0.74	1.07	1.46	1.90	2.41	2.98	4.29	5.83	7.62	9.64	11.90	14.40	17.14	20.12	23.33	26.78	9
10	0.30	0.53	0.83	1.19	1.62	2.12	2.68	3.31	4.76	6.48	8.46	10.71	13.23	16.00	19.04	22.35	25.92	29.76	10
15	0.45	0.79	1.24	1.79	2.43	3.17	4.02	4.96	7.14	9.72	12.70	16.07	19.84	24.00	28.57	33.53	38.88	44.64	15
20	0.60	1.06	1.65	2.38	3.24	4.23	5.36	6.61	9.52	12.96	16.93	21.43	26.45	32.01	38.09	44.70	51.84	59.51	20
25	0.74	1.32	2.07	2.98	4.05	5.29	6.70	8.27	11.90	16.20	21.16	26.78	33.06	40.01	47.61	55.88	64.80	74.39	25
30	0.89	1.59	2.48	3.57	4.86	6.35	8.03	9.92	14.28	19.44	25.39	32.14	39.68	48.01	57.13	67.05	77.77	89.27	30
35	1.04	1.85	2.89	4.17	5.67	7.41	9.37	11.57	16.66	22.68	29.62	37.49	46.29	56.01	66.66	78.23	90.73	104.15	35
40	1.19	2.12	3.31	4.76	6.48	8.46	10.71	13.23	19.04	25.92	33.86	42.85	52.90	64.01	76.18	89.40	103.69	119.03	40
45	1.34	2.38	3.72	5.36	7.29	9.52	12.05	14.88	21.43	29.16	38.09	48.21	59.51	72.01	85.70	100.58	116.65	133.91	45
50	1.49	2.65	4.13	5.95	8.10	10.58	13.39	16.53	23.81	32.40	42.32	53.56	66.13	80.01	95.22	111.75	129.61	148.79	50
	3	4	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	

DIAMETER (in)

Log 1000 hour wood fuels (3+ inches dia)—Estimated on a 100 m^2 plot—Metric units for diameters (cm) and lengths (m)—**Metric units for loadings (kg m^{-2})**

Log 1000 hr loadings in kg m^{-2}

LENGTH (ft) \ DIAMETER (in)	3	4	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	LENGTH (ft)
1	0.03	0.05	0.08	0.12	0.16	0.21	0.27	0.33	0.48	0.65	0.85	1.07	1.32	1.60	1.90	2.24	2.59	2.98	1
2	0.06	0.11	0.17	0.24	0.32	0.42	0.54	0.66	0.95	1.30	1.69	2.14	2.65	3.20	3.81	4.47	5.18	5.95	2
3	0.09	0.16	0.25	0.36	0.49	0.63	0.80	0.99	1.43	1.94	2.54	3.21	3.97	4.80	5.71	6.71	7.78	8.93	3
4	0.12	0.21	0.33	0.48	0.65	0.85	1.07	1.32	1.90	2.59	3.39	4.29	5.29	6.40	7.62	8.94	10.37	11.90	4
5	0.15	0.26	0.41	0.60	0.81	1.06	1.34	1.65	2.38	3.24	4.23	5.36	6.61	8.00	9.52	11.18	12.96	14.88	5
6	0.18	0.32	0.50	0.71	0.97	1.27	1.61	1.98	2.86	3.89	5.08	6.43	7.94	9.60	11.43	13.41	15.55	17.85	6
7	0.21	0.37	0.58	0.83	1.13	1.48	1.87	2.31	3.33	4.54	5.92	7.50	9.26	11.20	13.33	15.65	18.15	20.83	7
8	0.24	0.42	0.66	0.95	1.30	1.69	2.14	2.65	3.81	5.18	6.77	8.57	10.58	12.80	15.24	17.88	20.74	23.81	8
9	0.27	0.48	0.74	1.07	1.46	1.90	2.41	2.98	4.29	5.83	7.62	9.64	11.90	14.40	17.14	20.12	23.33	26.78	9
10	0.30	0.53	0.83	1.19	1.62	2.12	2.68	3.31	4.76	6.48	8.46	10.71	13.23	16.00	19.04	22.35	25.92	29.76	10
15	0.45	0.79	1.24	1.79	2.43	3.17	4.02	4.96	7.14	9.72	12.70	16.07	19.84	24.00	28.57	33.53	38.88	44.64	15
20	0.60	1.06	1.65	2.38	3.24	4.23	5.36	6.61	9.52	12.96	16.93	21.43	26.45	32.01	38.09	44.70	51.84	59.51	20
25	0.74	1.32	2.07	2.98	4.05	5.29	6.70	8.27	11.90	16.20	21.16	26.78	33.06	40.01	47.61	55.88	64.80	74.39	25
30	0.89	1.59	2.48	3.57	4.86	6.35	8.03	9.92	14.28	19.44	25.39	32.14	39.68	48.01	57.13	67.05	77.77	89.27	30
35	1.04	1.85	2.89	4.17	5.67	7.41	9.37	11.57	16.66	22.68	29.62	37.49	46.29	56.01	66.66	78.23	90.73	104.15	35
40	1.19	2.12	3.31	4.76	6.48	8.46	10.71	13.23	19.04	25.92	33.86	42.85	52.90	64.01	76.18	89.40	103.69	119.03	40
45	1.34	2.38	3.72	5.36	7.29	9.52	12.05	14.88	21.43	29.16	38.09	48.21	59.51	72.01	85.70	100.58	116.65	133.91	45
50	1.49	2.65	4.13	5.95	8.10	10.58	13.39	16.53	23.81	32.40	42.32	53.56	66.13	80.01	95.22	111.75	129.61	148.79	50
DIAMETER (in)	3	4	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	

Log 1000 hour wood fuels (8+ cm dia)—Estimated on a 100 m^2 plot—Metric units for diameters (cm) and lengths (m)—**English units for loadings (tons acre^{-1})**

Log 1000 hr loadings in tons acre^{-1}

LENGTH (m) \ DIAMETER (cm)	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	
1	0.04	0.17	0.38	0.67	1.05	1.51	2.06	2.69	3.40	4.20	5.09	6.05	7.10	8.24	9.46	10.76	12.15	13.62	15.17	16.81	1
2	0.08	0.34	0.76	1.35	2.10	3.03	4.12	5.38	6.81	8.41	10.17	12.11	14.21	16.48	18.92	21.52	24.30	27.24	30.35	33.63	2
3	0.13	0.50	1.13	2.02	3.15	4.54	6.18	8.07	10.21	12.61	15.26	18.16	21.31	24.72	28.37	32.28	36.44	40.86	45.52	50.44	3
4	0.17	0.67	1.51	2.69	4.20	6.05	8.24	10.76	13.62	16.81	20.34	24.21	28.42	32.96	37.83	43.04	48.59	54.48	60.70	67.26	4
5	0.21	0.84	1.89	3.36	5.25	7.57	10.30	13.45	17.02	21.02	25.43	30.26	35.52	41.19	47.29	53.80	60.74	68.10	75.87	84.07	5
6	0.25	1.01	2.27	4.04	6.31	9.08	12.36	16.14	20.43	25.22	30.52	36.32	42.62	49.43	56.75	64.56	72.89	81.72	91.05	100.88	6
7	0.29	1.18	2.65	4.71	7.36	10.59	14.42	18.83	23.83	29.42	35.60	42.37	49.73	57.67	66.20	75.33	85.04	95.33	106.22	117.70	7
8	0.34	1.35	3.03	5.38	8.41	12.11	16.48	21.52	27.24	33.63	40.69	48.42	56.83	65.91	75.66	86.09	97.18	108.95	121.40	134.51	8
9	0.38	1.51	3.40	6.05	9.46	13.62	18.54	24.21	30.64	37.83	45.78	54.48	63.93	74.15	85.12	96.85	109.33	122.57	136.57	151.32	9
10	0.42	1.68	3.78	6.73	10.51	15.13	20.60	26.90	34.05	42.03	50.86	60.53	71.04	82.39	94.58	107.61	121.48	136.19	151.74	168.14	10
11	0.46	1.85	4.16	7.40	11.56	16.65	22.66	29.59	37.45	46.24	55.95	66.58	78.14	90.63	104.04	118.37	133.63	149.81	166.92	184.95	11
12	0.50	2.02	4.54	8.07	12.61	18.16	24.72	32.28	40.86	50.44	61.03	72.64	85.25	98.87	113.49	129.13	145.78	163.43	182.09	201.77	12
13	0.55	2.19	4.92	8.74	13.66	19.67	26.78	34.97	44.26	54.64	66.12	78.69	92.35	107.10	122.95	139.89	157.92	177.05	197.27	218.58	13
14	0.59	2.35	5.30	9.42	14.71	21.19	28.84	37.66	47.67	58.85	71.21	84.74	99.45	115.34	132.41	150.65	170.07	190.67	212.44	235.39	14
15	0.63	2.52	5.67	10.09	15.76	22.70	30.90	40.35	51.07	63.05	76.29	90.79	106.56	123.58	141.87	161.41	182.22	204.29	227.62	252.21	15
16	0.67	2.69	6.05	10.76	16.81	24.21	32.96	43.04	54.48	67.26	81.38	96.85	113.66	131.82	151.32	172.17	194.37	217.91	242.79	269.02	16
17	0.71	2.86	6.43	11.43	17.86	25.73	35.01	45.73	57.88	71.46	86.46	102.90	120.77	140.06	160.78	182.93	206.52	231.53	257.97	285.83	17
18	0.76	3.03	6.81	12.11	18.92	27.24	37.07	48.42	61.29	75.66	91.55	108.95	127.87	148.30	170.24	193.69	218.66	245.15	273.14	302.65	18
19	0.80	3.19	7.19	12.78	19.97	28.75	39.13	51.11	64.69	79.87	96.64	115.01	134.97	156.54	179.70	204.46	230.81	258.76	288.31	319.46	19
20	0.84	3.36	7.57	13.45	21.02	30.26	41.19	53.80	68.10	84.07	101.72	121.06	142.08	164.78	189.16	215.22	242.96	272.38	303.49	336.28	20
	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	

DIAMETER (cm)

Log 1000 hour wood fuels (8+ cm dia)—Estimated on a 100 m^2 plot—English units for diameters (in) and lengths (ft)—**Metric units for loadings (kg m^{-2})**

Log 1000 hr loadings in kg m^{-2}

LENGTH (ft) \ DIAMETER (cm)	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	LENGTH (ft)
1	0.01	0.04	0.08	0.15	0.24	0.34	0.46	0.60	0.76	0.94	1.14	1.36	1.59	1.85	2.12	2.41	2.72	3.05	3.40	3.77	1
2	0.02	0.08	0.17	0.30	0.47	0.68	0.92	1.21	1.53	1.88	2.28	2.71	3.19	3.69	4.24	4.83	5.45	6.11	6.80	7.54	2
3	0.03	0.11	0.25	0.45	0.71	1.02	1.39	1.81	2.29	2.83	3.42	4.07	4.78	5.54	6.36	7.24	8.17	9.16	10.21	11.31	3
4	0.04	0.15	0.34	0.60	0.94	1.36	1.85	2.41	3.05	3.77	4.56	5.43	6.37	7.39	8.48	9.65	10.90	12.21	13.61	15.08	4
5	0.05	0.19	0.42	0.75	1.18	1.70	2.31	3.02	3.82	4.71	5.70	6.79	7.96	9.24	10.60	12.06	13.62	15.27	17.01	18.85	5
6	0.06	0.23	0.51	0.90	1.41	2.04	2.77	3.62	4.58	5.65	6.84	8.14	9.56	11.08	12.72	14.48	16.34	18.32	20.41	22.62	6
7	0.07	0.26	0.59	1.06	1.65	2.38	3.23	4.22	5.34	6.60	7.98	9.50	11.15	12.93	14.84	16.89	19.07	21.38	23.82	26.39	7
8	0.08	0.30	0.68	1.21	1.88	2.71	3.69	4.83	6.11	7.54	9.12	10.86	12.74	14.78	16.96	19.30	21.79	24.43	27.22	30.16	8
9	0.08	0.34	0.76	1.36	2.12	3.05	4.16	5.43	6.87	8.48	10.26	12.21	14.34	16.63	19.09	21.71	24.51	27.48	30.62	33.93	9
10	0.09	0.38	0.85	1.51	2.36	3.39	4.62	6.03	7.63	9.42	11.40	13.57	15.93	18.47	21.21	24.13	27.24	30.54	34.02	37.70	10
11	0.10	0.41	0.93	1.66	2.59	3.73	5.08	6.64	8.40	10.37	12.54	14.93	17.52	20.32	23.33	26.54	29.96	33.59	37.43	41.47	11
12	0.11	0.45	1.02	1.81	2.83	4.07	5.54	7.24	9.16	11.31	13.68	16.29	19.11	22.17	25.45	28.95	32.69	36.64	40.83	45.24	12
13	0.12	0.49	1.10	1.96	3.06	4.41	6.00	7.84	9.92	12.25	14.83	17.64	20.71	24.01	27.57	31.37	35.41	39.70	44.23	49.01	13
14	0.13	0.53	1.19	2.11	3.30	4.75	6.47	8.44	10.69	13.19	15.97	19.00	22.30	25.86	29.69	33.78	38.13	42.75	47.63	52.78	14
15	0.14	0.57	1.27	2.26	3.53	5.09	6.93	9.05	11.45	14.14	17.11	20.36	23.89	27.71	31.81	36.19	40.86	45.80	51.04	56.55	15
16	0.15	0.60	1.36	2.41	3.77	5.43	7.39	9.65	12.21	15.08	18.25	21.71	25.48	29.56	33.93	38.60	43.58	48.86	54.44	60.32	16
17	0.16	0.64	1.44	2.56	4.01	5.77	7.85	10.25	12.98	16.02	19.39	23.07	27.08	31.40	36.05	41.02	46.30	51.91	57.84	64.09	17
18	0.17	0.68	1.53	2.71	4.24	6.11	8.31	10.86	13.74	16.96	20.53	24.43	28.67	33.25	38.17	43.43	49.03	54.97	61.24	67.86	18
19	0.18	0.72	1.61	2.87	4.48	6.45	8.77	11.46	14.50	17.91	21.67	25.79	30.26	35.10	40.29	45.84	51.75	58.02	64.64	71.63	19
20	0.19	0.75	1.70	3.02	4.71	6.79	9.24	12.06	15.27	18.85	22.81	27.14	31.86	36.95	42.41	48.25	54.48	61.07	68.05	75.40	20
DIAMETER (cm)	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	

Appendix C—Photoload Plot Form and Cheat Sheet

Plot ID: ______________________ **FIREMON Plot ID:** ____________________ **Date:** ____________________

Examiner: ____________________ **Stand ID:** ________________

Subplot: _______________

Fuel Component	Adjustments									Calculations	Final Load
	Rot Adj Factor	Height			Diameter			Spatial Distribution			
		Obs Ht	Photo Ht	Adj Factor	Obs QMD	Photo QMD	Adj Factor	Weighted Average	Loading		
1 hr											
10 hr											
100 hr											
1000 hr											
Shrub											
Herb											
Other											

Subplot: _______________

Fuel Component	Adjustments									Calculations	Final Load
	Rot Adj Factor	Height			Diameter			Spatial Distribution			
		Obs Ht	Photo Ht	Adj Factor	Obs QMD	Photo QMD	Adj Factor	Weighted Average	Loading		
1 hr											
10 hr											
100 hr											
1000 hr											
Shrub											
Herb											
Other											

Diameter reduction table—Find diameter observed in field in first column, then go to log picture diameter set used to estimate loading and find the reduction factor.

Observed average log diameter		Photoload log picture diameter set	
(in)	*(cm)*	*6 inch*	*10 inch*
3	7.62	0.25	0.09
4	10.16	0.44	0.16
5	12.7	0.69	0.25
6	15.24	1.00	0.36
7	17.78	1.36	0.49
8	20.32	1.78	0.64
9	22.86	2.25	0.81
10	25.40	2.78	1.00
11	27.94	3.36	1.21
12	30.48	4.00	1.44
13	33.02	4.69	1.69
14	35.56	5.44	1.96
15	38.10	6.25	2.25
16	40.64	7.11	2.56
17	43.18	8.03	2.89
18	45.72	9.00	3.24

Date: Examiner:

Sample Unit			Photoload Loadings (kg m^{-2} or T $acre^{-1}$)						
Stand	Plot	Subplot	1hr	10hr	100hr	1000hr	Shrub	Herb	Other

<u>Photoload</u>

Cheat Sheet

Using the Plot Sheet

You don't have to complete all fields on the plot sheet. For most applications you might only complete the Final Load field.

Header Information: Complete this information for your records. Use the PlotID as an identifier in a data file. Use the FIREMON plotID if you are linking photoloads with other FIREMON techniques. Use date and examiner to help document sampling details. Record StandID if this plot is sampling a stand.

Subplot field is used if there are more than one photoload estimate per plot such as on a transect. Subplots can be used as plots if only one estimate per plot is desired.

Adjustments

Rot Adjustment: Enter an adjustment factor for down wood rot (if unknown, the adjustment factors for FIREMON decay classes – 1=1.0, 2=1.0, 3=0.9, 4=0.75, 5=0.5)

Height Adjustment: First enter observed height of component (obs ht) then enter the photoload height (photo Ht). Calculate adjustment factor by dividing the observed height by photoload height (example: 1.2 feet measured on plot and 0.8 feet on photoload sequence calculates to a 1.5 = 1.2/0.8).

Diameter Adjustment: Record the quadratic mean diameter (QMD) observed on plot in Obs QMD and record the QMD of log photoload sequence used (either 6 or 10 in). Look up conversion in Log Conversion table and record in Adj factor.

Spatial Distribution: Traverse plot or stand and match a loading with a proportion of plot and do this for entire plot. Calculate a weighted average by proportion area of loading and enter in Loading field. For example, say 10% of plot had 1.0 kg m^{-2}, 50% had 2.0 kg m^{-2}, and 40% had 3.0 kg m^{-2}, then the weighted average would be (10x1.0+50x2.0+40x3.0)/100=2.3 kg m^{-2}

Calculations: Multiply the height, diameter, and rot adjustment factors by the Loading field in the Spatial Distribution set of fields to calcluate the Final Load.

Notes: the height adjustment is only needed for down woody fuels if the litter layer is not visible through the woody fuels (slash, for example). Diameter adjustments are only needed for 100 hr and 1000 hr fuels, but can be used for 1 hr and 10 hr fuels if desired. The weighted average for spatial distribution is only needed if it is important in sampling objective.

Important Sampling Concepts

- 1, 10, 100, and 1000 Hour fuels must be woody, down, and dead, to be counted. Needles, grass blades, pine cones, and bark pieces are all considered litter, not down, dead, woody fuel.
  - "Woody" refers to a plant with stems, branches or twigs that persist from year to year.

  - “Down” includes all fuel in the sampling plane that is 45 degrees or less above horizontal. If it is at an angle greater than 45 degrees above horizontal it should only be considered down if it is the broken bole of a dead tree where at least one end of the bole is touching the ground (not supported by its own branches or other live vegetation).
  - “Dead” has no live foliage. Fresh slash and newly broken branches with green foliage are exceptions because they are technically dead even though they may have green foliage. Dead branches on live trees that enter the sampling plane should not be counted. Don’t confuse dead with dormant.

- When sampling logs, do not count logs that have their central axis lying in or below the duff layer. These logs burn more like duff and should not be sampled as logs.

- When sampling logs, you will measure a small and large end of the log. Remember, a log must be greater than 3 inches in diameter. If the log tapers into a 100 hour fuel, only count the part of the fuel that is 3 inches and greater. Your small end will never be less than 3 inches.

- The Log photos in your manual are of 6 inch and 10 inch logs. When you estimate your log loading it is imperative to adjust for the mean log diameter (quadratic mean diameter is best) in your subplot and to record this on your plot sheet.

- One stick can consist of 1, 10, and 100 hour fuel. Record a loading for each fuel component even if it is one branch or stick.

- Only sample fuels inside the sample frame. If a stick crosses over or under the frame, only count the part inside the frame. Ignore the portion outside of the frame.

- Before you start recording loadings on your plot sheet, eliminate fuel components without loadings first. Put zeros in the final loading box and then begin determining the loadings for other fuel components. Please do not put a dash through the final loading box, as this will be interpreted as not being sampled rather than not being present.

- When assessing herbaceous and shrub loadings, remember to adjust for the mean height of the foliage in your physical subplot and to record this on your plot sheet.

- Always remember to adjust estimated fuel loadings for four factors: spatial distribution, diameter, decay, and depth.

NOTES

RMRS
ROCKY MOUNTAIN RESEARCH STATION

The Rocky Mountain Research Station develops scientific information and technology to improve management, protection, and use of the forests and rangelands. Research is designed to meet the needs of National Forest managers, Federal and State agencies, public and private organizations, academic institutions, industry, and individuals.

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