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Estimating masticated and cone fuel loads using the Photoload method

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Abstract

Background Recognizing the complexity and varied nature of forest fuelbeds is crucial in understanding fire behavior and effects on the landscape. While current modeling efforts often consider fine and coarse woody debris surface fuel loads, those options do not always provide the most complete description of the fuelbeds. Both masticated fuels and cones can be a significant part of the fuelbed, with the potential to influence fire behavior and effects, but they are not currently captured in planar intersect methods or Photoload fuel sampling methodology. Cones are prevalent in most forested conifer stands, while mastication is a type of fuel treatment used to compact fuelbeds by shredding or chipping small trees, shrubs, and down woody debris. The treatment creates nonuniform particle sizes that violate assumptions of the planar intersect method to estimate dead surface fuel loads. The Photoload method of fuel load estimation allows visual estimates of fuel loads by particle type and the flexibility to develop photosequences of new fuel types.

Results We created Photoload mastication sequences for estimating loading of masticated fuels, as well as cone loading sequences. Our mastication photosequences were developed from *Pinus ponderosa-Pseudotsuga menziesii* forests in Montana, USA, but could be used to provide a relative estimate of load for any masticated material. The cones used for developing photosequences were gathered from several forest types in the Northern Rockies, USA. We created two masticated fuel photosequences—fine particles < 7.62 cm and coarse particles ≥ 7.62 cm in width and six cone photosequences—*Larix occidentalis*, *P. ponderosa*, *Pinus monticola*, *Pinus flexilis*, *Picea engelmannii*, and *P. menziesii*.

Conclusions The new mastication and cone loading photosequences can be used together with existing Photoload sequences to obtain total estimates of surface fuel loads. The 1-page sequences can be printed and used in the field to estimate these additional fuel type loads quickly and easily.

Keywords Chipping, Surface fuel, Shredding, Fuel loading, Photoload, Cone loading

Resumen

Antecedentes El reconocer la complejidad y la naturaleza variada de las camas de combustible es crucial en el entendimiento del comportamiento del fuego y sus efectos en el paisaje. Mientras que los esfuerzos corrientes en el modelado frecuentemente consideran a los restos finos y gruesos en la carga de combustibles en superficie, estas opciones no siempre proveen de la descripción más completa de la cama de combustibles. Tanto las astillas trituradas como los conos pueden ser parte importante de esta cama, con el potencial de influenciar el comportamiento y efectos del fuego, aunque éstos no son capturados por el método de intersección planar o por la metodología basada en

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fotos de la carga de combustible (Photoload fuel sampling methodology). Los conos son prevalentes en la mayoría de los rodales de coníferas, mientras que el astillado es un tipo de tratamiento usado para compactar las camas de combustible mediante el chipeado y/o triturado de pequeños árboles, arbustos, o restos de troncos esparcidos en el suelo. Este tratamiento crea tamaños de partículas no uniformes que violan la suposición del método de intersección planar para estimar combustibles superficiales muertos. El método fotográfico de la estimación de carga de combustible permite estimaciones visuales de tipos de partículas y la flexibilidad de desarrollar foto-secuencias de nuevos tipos de combustibles.

Resultados Creamos foto-secuencias de triturado para estimar la carga de este tratamiento y también secuencias de la carga de conos. Nuestras foto-secuencias del triturado fueron desarrolladas en bosques de Pinus ponderosa y Pseudotsuga mienziesii siezii en Montana, aunque puede ser usado para proveer de estimaciones relativas de carga de cualquier material triturado. Los conos usados para desarrollar las foto-secuencias fueron tomados de diferentes tipos de bosques de las Montañas Rocosas de los EEUU. Creamos dos foto-secuencias de triturados (partículas finas < 7,62 cm, y partículas gruesas ≥ 7,62 cm de ancho), y cinco foto-secuencias de conos – Larix occidentalis, P. ponderosa, Pinus monticola, Pinus flexilis, Picea engelmannii, y P. menziesii.

Conclusiones Las nuevas foto-secuencias del triturado y de la carga de conos pueden ser usadas en conjunto con las secuencias de fotos del Photoload para obtener estimaciones totales de la carga de combustibles superficiales. La secuencia de una página puede ser impresa y usada en el campo para estimar esa carga de combustible adicional de manera rápida y fácil.

Introduction

Wildland fuels influence fire behavior and effects (Keane 2015). As fuels are the main controllable factor during burning (Agee and Skinner 2005; Hood et al. 2022), accurate estimation of fuel loads is important for predicting potential fire behavior and ensuing effects and evaluating fuel treatment effectiveness (Keane 2013). Quick, accurate assessments of surface fuels are needed and protocols have been developed to support fuel load quantification, such as the planar intersect method (Brown et al. 1982) and the Photoload method (Keane and Dickinson 2007). However, masticated fuels—shredded, chipped woody particles—and cones cannot be classified into the time lag surface woody fuel classes (e.g., 1-h, 10-h, 100-h) that the planar intersect method requires or used with existing Photoload sequences. This limits the ability to estimate surface woody fuel loads in masticated areas, which is increasingly used as a fuels treatment to reduce fire hazard (Kane et al. 2009; Jain et al. 2012; Kreye et al. 2014), as well as limits the ability to thoroughly describe the fuelbed for fire behavior and effects modeling. While current fuel inputs to predict potential fire behavior are typically limited to stylized and custom fire behavior fuel models that are abstractions of fuelbed characteristics (Keane 2015), more accurate fuel loading assessments are critical for monitoring fuel loading change over time and modeling potential fire effects. For example, fires burning in masticated fuels can produce more smoke and cause higher levels of tree mortality than fire behavior fuel models predict (Knapp et al. 2011; Kreye et al. 2014).

Mastication is a mechanical fuel treatment in which brush and small diameter trees are shredded and broken into smaller pieces, transferring live ladder fuels to a compacted surface fuels layer with the objective of reducing fire hazard (Knapp et al. 2011; Kreye et al. 2014). However, masticated fuels differ structurally from natural or logging slash fuelbeds; they are characterized by irregular shapes and relatively small, fractured fuels that create densely compacted fuelbeds (Kane et al. 2009; Kreye et al. 2014). When estimating surface fuel loads in masticated areas using the planar intersect method (Brown 1974), inaccurate estimates may result due to the irregular shapes and sizes of masticated fuel that violate assumptions of round fuel pieces (Hood and Wu 2006). The cover-depth method developed by Hood and Wu (2006) allows estimation of masticated fuel loads, but it is not easily compatible with the Photoload method.

Cones are also a common component of forest floor fuelbeds not currently captured in most fuels description methodology. Cones are a source of fire brands that can cause spot fires (Ganteaume et al. 2011), with potential to also increase fire effects through duff smoldering and flame height (Fonda and Varner 2004, Kreye et al. 2013). New Photoload photosequences, which are central to applying the Photoload method of visually estimating surface fuels in the field (Keane and Dickinson 2007), can be developed to extend this method to other fuel types (Stalling and Keane 2020). Our objectives were to develop masticated fuel and cone Photoload sequences that can be used in conjunction with other Photoload sequences to estimate total surface woody fuel loads.

Methods

We collected masticated material from a recently treated site at the University of Montana's Lubrecht Experimental Forest in June 2023. Prior to treatment, the area was dominated by ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*), with a dense midstory of mostly Douglas-fir saplings (see Hood et al. 2024 Mech treatment for full description). The site was thinned from below in February and March 2023 using whole-tree tractor logging to a residual basal area of approximately 10.3 m^2 ha^{-1}. In June 2023, the site was masticated using a tracked Timber Jack 608L feller buncher equipped with a modified JD Highspeed, 61-cm disc saw that had every other out edge tooth removed and welded to the bottom of the disc (Fig. 1). The modification allows the saw to cut and shred small trees and surface fuels. The objective was to masticate approximately 80% of the regeneration in the unit by masticating the bulk of the small trees to within 15 cm of the ground and compact slash generated during the thinning (Fig. 1). To reduce costs and operator time, the crowns of larger saplings were masticated first, then the hot saw attached to the equipment head cut the main stem near groundline rather than masticating the entire tree stem.

We collected masticated fuels throughout the unit, choosing only woody particles that looked chipped and uneven as opposed to intact round branches. We collected a representative range of particle sizes from the site, from small to large pieces. We filled 4, 115-L paper lawn and leaf bags and transported them to the laboratory for drying and weighing.

In the laboratory, we sorted the masticated fuels into fine or coarse particles prior to drying. Fine masticated fuels were particles < 7.6 cm in width in at least one dimension regardless of fragment length; coarse masticated fuels were particles with a width ≥ 7.6 cm in all dimensions regardless of length. The largest particles used for developing the coarse masticated fuels had a maximum width of approximately 13 cm. While diameter is the common method for classifying down surface fuels, we used width due to the irregular and fragmented shape of the masticated particles. We chose the fine and coarse thresholds to align with existing time lag fuel classes where fine surface fuels are those < 7.6 cm in diameter and coarse fuels are ≥ 7.6 cm in diameter (Brown 1974). Coarse woody fuels (i.e., 1000-h fuels) do not have a consistent classification system, with some classifications grouping all fuels ≥ 7.6 cm in one class and other classifications dividing coarse fuels into different diameter classes (Keane 2015). We did not include masticated pieces larger than 13 cm in the coarse masticated sequence because they share more characteristics with large logs than masticated fuels. After sorting, fuels were placed in drying ovens set to 80 °C for 3 days.

Dried fuels were sorted and weighed into increasing fuel loading groups and photographed. White, 1 m^2 printer paper was taped to the ground to simulate a 1 m^2 area, the standard plot frame used in the Photoload method. We took individual photographs of fine masticated fuels by randomly arranging particles for each load. The sequence began with a 0.01 kg m^{-2} fuel load and increased incrementally up to 10.00 kg m^{-2}. When the heavier fuel loads covered 100% of the quadrat at accumulated depths greater than a single layer, we measured depths for inclusion in the photosequence. The depths used were based on field experience about the general conditions encountered at masticated sites in the Northern Rockies, but the method allows loading for deeper depths to be easily estimated in the field. Coarse masticated fuels were photographed

Fig. 1 Machine used to masticate the site (left) and the area from which the masticated material was collected to develop the Photoload sequence (right; photo credit: Justin Crotteau)

with the sequence starting at 0.10 kg m^{-2} and increasing incrementally to 11.0 kg m^{-2}. We tested the photographs of the different loadings at a masticated site to narrow the set to twelve photographs per sequence to be consistent with other fine fuel sequences and for the practical purposes of limiting the photographs to a reasonable number that could be formatted to one page. We chose the photographs that best covered a range of loadings, where intermediate loadings could also be easily estimated (Keane and Dickinson 2007; Stalling and Keane 2020).

For the development of the cone sequences, we collected intact 1- to 2-year-old cones from the forest floor that showed little to no sign of decay or animal damage at several sites around the Northern Rockies for six common conifer species—western larch (*Larix occidentalis*), ponderosa pine, western white pine (*P. monticola*), limber pine (*P. flexilis*), Engelmann spruce (*Picea engelmannii*), and Douglas-fir. Once collected, the cones were brought back to the laboratory and dried and weighed. We then used the protocol as described above for the masticated fuels to take photographs of the individual cone species from low to high loads.

Results and discussion

We created fine and coarse masticated fuel Photoload sequences that are each composed of 12 fuel loading photos (Fig. 2) and cone sequences that are comprised of 4 loadings options for each species (Fig. 3). We selected photos to provide a comprehensive sequence from very low to high loads of masticated fuel and cones. The new sequences are formatted similarly to existing Photoload microplot sequences (i.e., 1 m^2 quadrats), with both imperial and metric units, and are designed to be used together with other sequences. To use the sequences, we recommend printing and laminating the full page, high-quality images (Supplementary Information Figs. S1–6) for easy reference in the field.

The Photoload sampling protocol was first described by Keane and Dickinson (2007), and includes sequences of fine woody surface fuels (1-h, 10-h, 100-h), 1000-h coarse fuel, live shrubs, and herbaceous fuels. The masticated fuel and cone sequences can be used together with the 1-to-100-h Photoload sequences for round fuels to obtain a total estimate of fine dead woody surface fuels. These estimates can then be combined with a protocol to measure round coarse material (e.g., planar intersect,

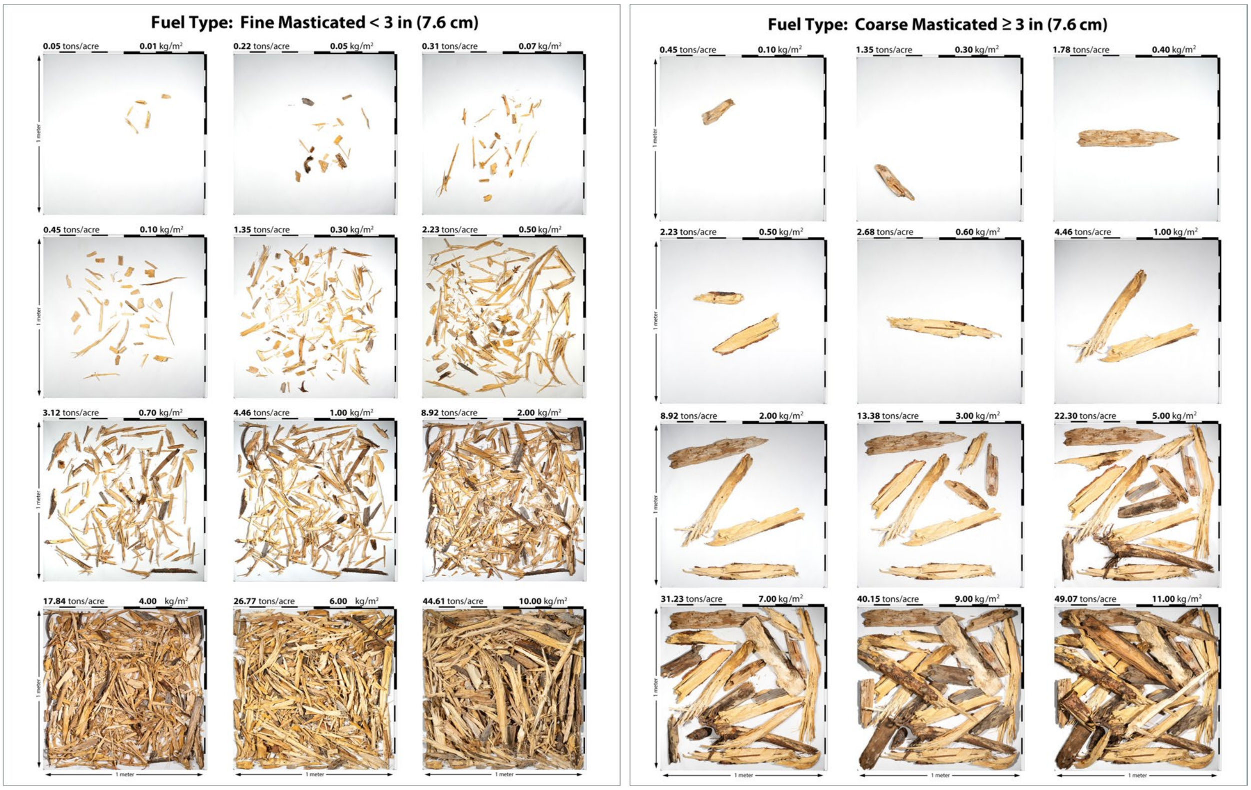

Fig. 2 Left panel: Fine masticated fuel Photoload sequence. Fine particles include those that are not round and < 7.6 cm in width in any dimension regardless of length. Right panel: Coarse masticated fuel Photoload sequence. Coarse particles include those that are not round and ≥ 7.6 cm in width in any dimension regardless of length. See Supplementary Information for full-sized, print-friendly files

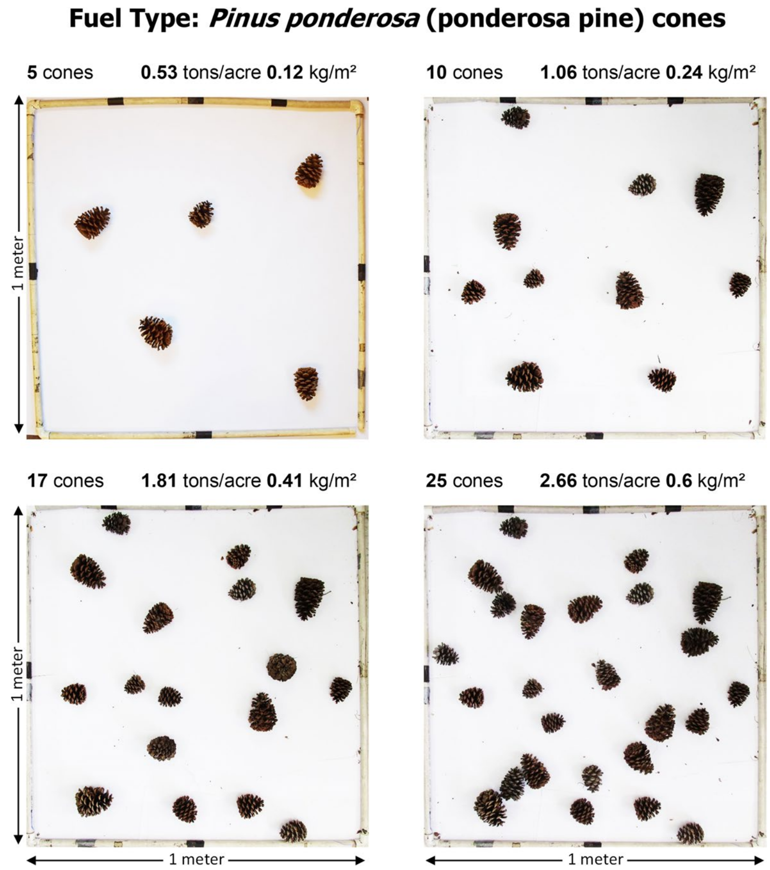

Fig. 3 Cone Photoload sequence for *Pinus ponderosa*. See Supplementary Information for full-sized, print-friendly files of cone sequences for *Larix occidentalis*, *Pinus ponderosa*, *Pinus monticola*, *Pinus flexilis*, *Picea engelmannii*, and *Pseudotsuga menziesii*

macroplot Photoload sequence) to estimate total dead woody surface fuel loads.

To estimate woody fuel loads in masticated areas or to estimate cone fuel loads, we recommend the following "microplot approach" steps described in detail in Keane and Dickinson (2007). Briefly, the general steps are (1) determine sampling intensity and layout, (2) estimate and record loading of each fuel component (e.g., 1-h, fine masticated fuel, cones), and (3) sum each component for an estimate of total fine woody, masticated, and cone surface fuel loading. To estimate loading, users will need a 1 m^2 plot frame. Place the frame on the ground according to the predetermined plot layout. Users should assess and record the estimated loading in the microplot for each fuel component separately using the published photosequences or user-developed sequences (Stalling and Keane 2020). Only masticated particles and cones that are above the litter and duff layer should be included in the estimate, as described in Brown (1974). The scalebars on the top and right side of each masticated loading image can assist with comparing the particle sizes in each sequence of photographs to the sample quadrat. Note that it is most important to match the general size and summed length of the pieces rather than the number of pieces, as there will be variability in masticated fuel. Following the explanation of the Photoload method in Keane and Dickinson (2007), if the actual loading falls between two photographs in the sequence, users can record an intermediate value. For example, if the fine masticated material in a sample quadrat looks slightly heavier than the 1.00 kg m^{-2} photograph but not as much as the 2.00 kg m^{-2} photograph, a user can record 1.25 kg m^{-2}. After estimating fine and coarse masticated fuel loadings separately, next use the individual 1-h, 10-h, and 100-h fuel sequences if there are round woody fuel pieces present. The cone sequences can be used the same way, estimating the loading of different cone species in the quadrat. Each fuel component loading estimate should be recorded separately. Lastly, measure and record coarse round material. These estimates summed together equal the total surface dead woody fuel load.

Masticated fuels can sometimes form deep fuelbeds of 100% cover (Kreye et al. 2014). In these cases, the fine masticated sequence shows loads for 100% cover at average quadrat depths of 7.6 cm and 14 cm (Fig. 2, left panel, bottom middle and right photographs). If the average masticated fuelbed depth is deeper than 14 cm at a site, there are a few different options. Users could sum or interpolate between any combination of the 7.6 cm and 14 cm deep loads. For example, if the depth is 28 cm at 100% cover, then estimate the load as 20.0 kg m^{-2} (14 cm @ 10 kg $m^{-2} \times 2 = 20$ kg m^{-2}) or if the depth is 18 cm at 100% cover, then estimate the load as 13 kg m^{-2} (14 cm @ 10 kg m^{-2} + 4 cm @ 3 kg $m^{-2} = 13$ kg m^{-2}). Alternatively, users could use the cover-depth method (Hood and Wu 2006) or create a new Photoload sequence that shows photographs of deeper fuelbed depths.

Masticated sites will likely have a continuum from larger diameter masticated material to coarse round fuels (i.e., logs) because of the wide variety of particle sizes created during the mastication process. The coarse masticated pieces we used to develop the sequence were less than about 13 cm wide on the narrow axis. We recommend treating pieces larger than this as traditional 1000-h fuels. Similarly, if there are logs ≥ 7.62 cm that have some degree of mastication but are mostly round, then these pieces should be included in the 1000-h fuel assessment. Our recommendation is based on the logic that larger particle sizes will have longer time lags to equilibrate to ambient conditions and burn more similarly to larger logs, with the same ensuing fire behavior and effects compared to smaller masticated pieces.

We used recently masticated material consisting mostly of Douglas-fir and ponderosa pine to develop the photosequences. In areas populated with other tree and shrub species, the actual loading may differ despite the appearance of a match between the photograph and the sample quadrat, as wood density can vary across species to influence fuel loading. However, the Photoload technique can still be used in any location or species mix to provide relative changes in fuel loads at a site, which may be sufficient for some monitoring purposes. A second caveat is that all Photoload sequences assume sound dead woody fuel (Keane and Dickinson 2007). Loadings can be adjusted if masticated material is rotten by multiplying the loading by 0.75 or 0.5, respectively (Lutes et al. 2006; Keane and Dickinson 2007).

Photoload sequences allow quick visual estimation of fuel loads and can be developed for additional fuel types as needed (Stalling and Keane 2020). While there are pros and cons to any method used to quantify fuel loading, the Photoload technique provides reasonable estimates of loading at a fraction of the time compared to other methods (Keane and Gray 2013). The newly developed mastication and cone loading Photoload sequences can be used with existing Photoload sequences to estimate fuel loads for a variety of particle sizes and types. We are now developing a Photoload sequence library website (https://www.firelab.org/project/photoload-visually-estimating-fuel-loading) that will collate existing photosequences for users to easily access. We encourage fuel practitioners to develop additional sequences in other fuel types following the methods described here and by Stalling and Keane (2020) and submit them to the website to help build a robust Photoload sequence library.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s42408-024-00302-x.

Additional file 1. Masticated fuel photosequences.

Additional file 2. Cones photosequences.

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Authors' contributions

Sharon Hood: conceptualization, funding acquisition, methodology, project administration, supervision, investigation, visualization, resources, writing—original draft, writing—review and editing; Sarah Flanary: methodology, visualization, writing; Christine Stalling: methodology, validation, investigation, writing—review and editing, visualization.

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Availability of data and materials

The supplement provides print-friendly photosequences for field use. The website for the Photoload Sequence Library is https://www.firelab.org/project/photoload-visually-estimating-fuel-loading or https://research.fs.usda.gov/firelab/projects/photoload.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

All authors consent to publication.

Competing interests

The authors declare that they have no competing interests.

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