Rangeland Ecol Manage 64:99–103 | January 2011 | DOI: 10.2111/REM-D-09-00180.1

Technical Note

Field Test of Digital Photography Biomass Estimation Technique in Tallgrass Prairie

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Abstract

Fuel loading information is important for prescribed fire planning, evaluating wildfire risk, and understanding fire effects in grassland. Yet fuel loads in grasslands often go unmeasured because of the time required to clip plots and process samples, as well as limited access or proximity to a drying oven. We tested the digital photography biomass estimation technique for measuring fuel load in grasslands in two national parks in the eastern Great Plains. The method consists of using percentage image obstruction, as determined by digital photography, to estimate vegetation biomass based on a linear transformation (i.e., regressing dry clipped weights against percent digital obstruction). We used the technique with some modification and measured digital obstruction at two sites at Wilson's Creek National Battlefield, Missouri (WICR), and three sites at Tallgrass Prairie National Preserve, Kansas (TAPR). The method did not result in strong correlations at either of the two sites at WICR (Site 1: $r^2 = 0.02$; Site 2: $r^2 = 0.32$), but performed relatively well at TAPR (Site 1 [<1 yr since burn]: $r^2 = 0.82$; Site 2 [2 yr since burn]: $r^2 = 0.57$; Site 3 [1 yr since burn]: $r^2 = 0.88$). Linear regressions for the three sites at TAPR did not differ in slope ($P > 0.05$). In general, the denser the vegetation, the weaker the relationship between the vegetation biomass of clip plots and the percentage image obstruction of digital images. The digital photography technique may not be useful for estimating fuel loads in grasslands with relatively high biomass (> 80 g $\cdot$ 0.1 m^{-2}) or digital image obstruction $> 50\%$. Large amounts of litter may also potentially reduce the accuracy of the technique.

Resumen

La información sobre la cantidad del combustible es importante para la planeación de incendios prescritos, evaluación de riesgo de incendios sin control y el conocimiento de los efectos del fuego en los pastizales. Sin embargo, la cantidad de combustible en pastizales es muy común que no se mida debido al tiempo que se requiere para cortar las parcelas y el procesar las muestras, así como el acceso limitado o la proximidad a un horno para el secado de las muestras. Evaluamos la técnica de estimación de la biomasa por medio de la fotografía digital para medir la cantidad de combustible en pastizales en dos parques nacionales en la parte este de las grandes planicies. El método consistió en utilizar el porcentaje de obstrucción de la imagen, según lo determinado por la fotografía digital, para estimar la biomasa de la vegetación, basándose en una trasformación lineal (i.e., usando la regresión del peso seco de la muestra contra el porcentaje de la obstrucción digital). Utilizando esta técnica con algunas modificaciones, medimos la obstrucción digital en dos sitios en Wilson's Creek National Battlefield, Missouri US (WICR) y en tres sitios en los pastizales altos en National Preserve, Kansas US (TAPR). Este método no proporciona una correlación sólida en ninguno de los dos sitios en WICR (sitio 1 $r^2 = 0.02$; sitio 2: $r^2 = 0.32$), pero funcionó relativamente bien en TAPR (sitio 1 [<1 año desde la quema]: $r^2 = 0.82$; sitio 2 [2 año desde la quema]: $r^2 = 0.57$; sitio 3 [1 año desde la quema]: $r^2 = 0.88$). Las regresiones lineales para los tres sitios en TAPR no difirieron en la pendiente de la regresión ($P > 0.05$). En general mientras más densa la vegetación, la relación era más débil entre la biomasa de la vegetación de las parcelas cortadas y el porcentaje de la obstrucción de las imágenes digitales. La técnica de la fotografía digital no es útil para estimar la cantidad de combustible en pastizales con altas cantidades de biomasa (> 80 g $\cdot$ 0.1 m^{-2}) o la obstrucción digital de $> 50\%$. Grandes cantidades de materia orgánica o mantillo puede también potencialmente reducir la exactitud de esta técnica.

Key Words: fire, fuel load, grassland, photo board, techniques

INTRODUCTION

Information on fine fuel loading is important for understanding fire behavior and fire effects in grassland. Fine fuel loading directly influences fire intensity (Albini 1976), or the rate of heat released by the fire, which is important for prescribed fire planning, evaluating wildfire risk, and understanding fire effects in grassland (Anderson 1982; Wright and Bailey 1982; US Department of the Interior National Park Service 2003). In particular, the ability to control or

Research was funded in part by National Park Service (NPS) Grant J 6064 06 00113, cooperative agreement CAH6000030300. This work was supported by funding through the NPS Cooperative Ecosystem Study Unit program.

Views, statements, findings, conclusions, recommendations, and data in this report are solely those of the authors and do not necessarily reflect views and policies of the NPS. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the NPS.

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Manuscript received 30 November 2009; manuscript accepted 26 September 2010.

suppress fire is directly associated with the rate of heat released by the fire (Chandler et al. 1983). As a result, fire management objectives for tallgrass prairie habitat often include the reduction of hazardous fuels to reduce the potential for high fire intensities and uncontrollable wildfires (National Park Service 2003).

Differences in fine fuel loading can also lead to differences in fire intensity and consequently fire severity, i.e., fire effects on woody plants (Trollope and Tainton 1986; Briggs et al. 2002; Knapp et al. 2008; Twidwell et al. 2009). Fire intensity can be difficult to measure directly, but if fuel loads are known, the rate of heat released by the fire can be inferred by measuring rate of spread (Albini 1976) or by quantifying fire behavior and weather (Brown and Davis 1973; Trollope and Potgieter 1985). However, fine fuel loads in grasslands often go unmeasured because of the time required to clip plots and process samples, as well as limited access to a drying oven. There is also a need for nondestructive sampling approaches that enable fire monitors to characterize fine fuel loads at appropriate spatial scales to understand fire effects in grasslands (Twidwell et al. 2009). Methods that are quick and repeatable will also enable more accurate monitoring of both pre- and postburn fuel loads to assess fuel reduction.

As part of an emerging fire ecology program in the eastern Great Plains, we evaluated the digital photography method described by Limb et al. (2007) as an alternative to clip plots for measuring fuel loads. The digital photography method was reported to reduce the time required for field sampling and increase the precision of results, making clipping samples unnecessary once calibration curves are established (Limb et al. 2007). The objective of this study was to test the accuracy and efficiency of the digital photography method in estimating grassland fuels at two national parks with differing vegetation structure and management regimes.

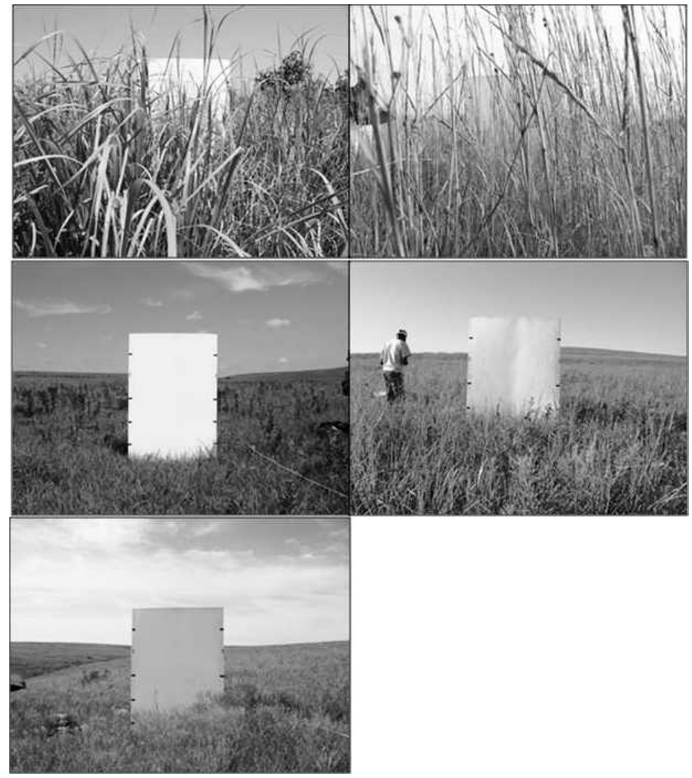

Figure 1. Sample images for measuring digital obstruction at WICR Site 1, a warm-season grass–dominated reconstruction (upper right), and WICR Site 2, a tallgrass prairie restoration (upper left), both at Wilson's Creek National Battlefield, Missouri; and a native tallgrass prairie remnant at Tallgrass Prairie National Preserve, Kansas: Site 1 (center left), Site 2 (center right), and Site 3 (bottom). All images were taken 4 m from the board with a 1-m camera height.

STUDY AREA

We sampled two sites at Wilson's Creek National Battlefield (WICR) in Republic, Missouri, in August 2009. WICR contains restored prairie near the transition zone to oak–hickory forest, and has not been grazed since the 1960s. Both sites were dominated by warm-season grasses, primarily big bluestem (*Andropogon gerardii* Vitman) and Indian grass (*Sorghastrum nutans* [L.] Nash). WICR Site 1, last burned in 2007, had very tall and dense grass (Fig. 1). WICR Site 2, last burned in 2008, had greater woody plant and invasive species cover, and reduced overall height, compared to WICR Site 1. We sampled three sites at Tallgrass Prairie National Preserve (TAPR) in Strong City, Kansas, in August 2009 (Fig. 1). The preserve is dominated by big bluestem and little bluestem (*Schizachyrium scoparium* [Michx.] Nash). Sampling focused on a pasture under patch burn grazing (PBG) management (Fuhlendorf and Engle 2001). Intensive early stocking was used for nearly two decades prior to a change to PBG, with steers occurring in 1996 (K. Hase, personal communication, October 2007). The three sites differed in burn history (Table 1).

METHODS

The sampling protocol was based on Limb et al. (2007) with modifications, as follows: each site was defined as a reference frame, and, with the use of Hawth's tools (Beyer 2004) in a GIS, plots were randomly selected as points within each site. At WICR, we sampled 29 plots at each site and at TAPR we sampled 45 total plots, 15 at each of three sites. At each plot (1 m wide × 4 m long), we placed a photo board (constructed from white, composite wood paneling) oriented to provide the highest-quality data considering the terrain and position of the sun. We used a photo board 1 m wide × 1.5 m tall, instead of 1 × 1 m as in Limb et al. (2007), to accommodate the tall grasses (often > 1 m high) at WICR. The camera was mounted on a monopod with a lens height of 1 m; levels were used to keep the camera and photo board plumb and level.

Based on presampling in 2008, we developed decision rules to guide observers prior to entering the field. The plot had to be level, oriented perpendicularly to the sun, and have relatively homogeneous vegetation structure to be a representative sample. If vegetation structure between the photo board and the camera was not representative of the overall plot, we evaluated the cardinal directions around the plot relative to the criteria listed above and either moved the photo board to a spot within 5 m of the GPS point, or rejected the sample. Only one plot at any of the TAPR sites had any vegetation taller than 1 m, and thus we converted the digital image obstruction data at TAPR to match the photo board size of Limb et al. (2007) by calculating the digital image obstruction based on the bottom two-thirds of the board (1 × 1 m).

Table 1. Comparison of two sites under rotational burning management at Wilson's Creek National Battlefield (WICR) and three sites under patch burn grazing management at Tallgrass Prairie National Preserve (TAPR). Data are from the 4-m distance.

Park	Site	Plots[1]	Years since last burn	Litter cover (%) mean (SD)	Dry clipped weight range ($g \cdot 0.1\ m^{-2}$)	Digital image obstruction range (%)	Digital obstruction/ weight r^2
WICR	1	27	2	97.5 (0)	91.6–213.9	32.1–96.0	0.02
WICR	2	29	1	1.2 (3.1)	52.1–122.5	36.1–91.5	0.32
TAPR	1	14	0.2	0.5 (0)	9.5–40.3	9.7–30.2	0.82
TAPR	2	11	2	48.2 (32.8)	31.0–87.5	24.0–43.3	0.57
TAPR	3	14	1	1.2 (1.1)	27.1–102.3	17.5–53.9	0.88
TAPR	All sites	39	—	12.8 (20.1)	9.5–102.7	9.7–53.9	0.87

[1]Images that were not well lit (i.e., the board appeared dark or the plants white when converted to black and white) were not included in the analysis; these images severely underestimated the clipped weights ($n = 4$ at TAPR). This decision rule was developed as a result of a presampling trial. Additional plots were rejected (two plots at WICR Site 1, one at TAPR Site 2, and one at TAPR Site 3) because the board was too obstructed to be accurately cropped for analysis.

Photographs were taken with a Canon PowerShot® S40 (Canon Inc., Japan) camera in landscape mode at 4- and 3.5-m distances from the photo board (in that order). We took photographs at two different distances to determine if variation in distance affected the linear transformations. The photo board and camera were leveled vertically and centered to keep focal distances equal across the image. We did not zoom into the board as recommended, to better maintain equal focal distances across all images and ensure the bottom of the board was captured in the image. We used a clip plot frame size of 0.5 $\times$ 1 m (0.5 m^2), rather than the 0.25 $\times$ 0.5 m (0.125 m^2) size used by Limb et al. (2007), to provide estimates on a scale that more closely matched the width of the photo board. The clip plot was placed directly in front of the photo board with the long axis against the board. Plants were clipped to within 1 cm of the ground or grass crown. Litter was also collected, because it contributes substantially to fuel load. Clipped samples were bagged and transported to Missouri State University for drying. Samples were dried at 70°C until mass stabilized (48 h).

The amount of litter present was estimated with the use of a cover class index modified from Daubenmire (1959). For each plot, litter cover was classified as one of seven cover percentage classes: <1%, 1–4%, 5–24%, 25–49%, 50–74%, 75–94%, and 95–100%. The class midpoints were averaged to obtain mean litter cover values for each site.

Photographs were processed with Photoshop CS4 (version 11.0; Adobe Systems Inc., San Jose, CA). We followed the procedure described by Limb et al. (2007), with the exception of using the default threshold when converting to black and white. We found that the default threshold (128) rarely accurately represented the visual obstruction in the image. Consequently, each image had to be evaluated individually and a threshold that yielded the best conversion to black and white applied, which approximately doubled processing time. (The same conversion threshold was applied to both photographs [3.5-m and 4-m distances] at each plot.)

At each site, dry clipped weights were regressed against percent digital obstruction with simple linear regressions using PROC REG (SAS, 2001). At TAPR, we tested whether there was a difference in the slopes of the lines among the sites by evaluating the interaction term in an analysis of covariance (SPSS 2007). Results for the 3.5-m and 4-m distances were similar, and unless noted, results presented here are for the 4-m distance.

RESULTS

The results differed greatly between parks. The majority of digital obstruction values at WICR were > 50%, whereas nearly all measurements at TAPR were < 50% (Table 1; Fig. 2). Likewise, clipped weights were much less at TAPR (Table 1; Fig. 2). Digital obstruction at both WICR sites demonstrated very poor correlations with clipped weights (Fig. 2A). At TAPR, however, relationships were much stronger (Fig. 2B). Litter cover was relatively high at TAPR Site 2 and WICR Site 1, and these sites had the weakest regression relationships for each park, respectively; the time since prescribed burn for both sites was 2 yr. When all sites at TAPR were combined, the 3.5-m and 4.0-m distances produced very similar results (3.5 m: $P < 0.01$, $r^2 = 0.82$, $y = 2.01x - 14.88$; 4.0 m: $P < 0.01$, $r^2 = 0.87$, $y = 2.08x - 17.35$). We further investigated the TAPR data to see whether results differed among sites. Although coefficients of determination varied among sites, the slopes of the regression lines did not differ significantly at either distance (3.5 m: $F = 1.91$, df = 2, 33, $P = 0.16$; 4.0 m: $F = 1.65$, df = 2, 33, $P = 0.21$).

DISCUSSION

Although biomass or fuel load is a critical factor in managing grasslands, it is difficult to estimate accurately (Vermeire et al. 2002). As a result, we tested the digital photography biomass estimation technique at two very different national parks within the eastern Great Plains. Although both parks contained tallgrass prairie, one included ungrazed and rotationally burned restorations (WICR), whereas the other had a history of frequent burning and intense grazing and has been under PBG for 4 yr (TAPR). Our results validated the Limb et al. (2007) technique at TAPR, but not at WICR. The Limb et al. (2007) linear regression statistics (slope = 1.74, $r^2 = 0.89$, $P < 0.001$) were very similar to ours at TAPR, whether the sites were analyzed separately or combined (except TAPR Site 2). In contrast, at both WICR sites, the relationship between digital image obstruction and biomass was weak, and this technique would not be useful at WICR or structurally similar grasslands.

In general, the digital photography biomass estimation technique produced acceptable results at sites with relatively sparse vegetation and little litter. As the vegetation became

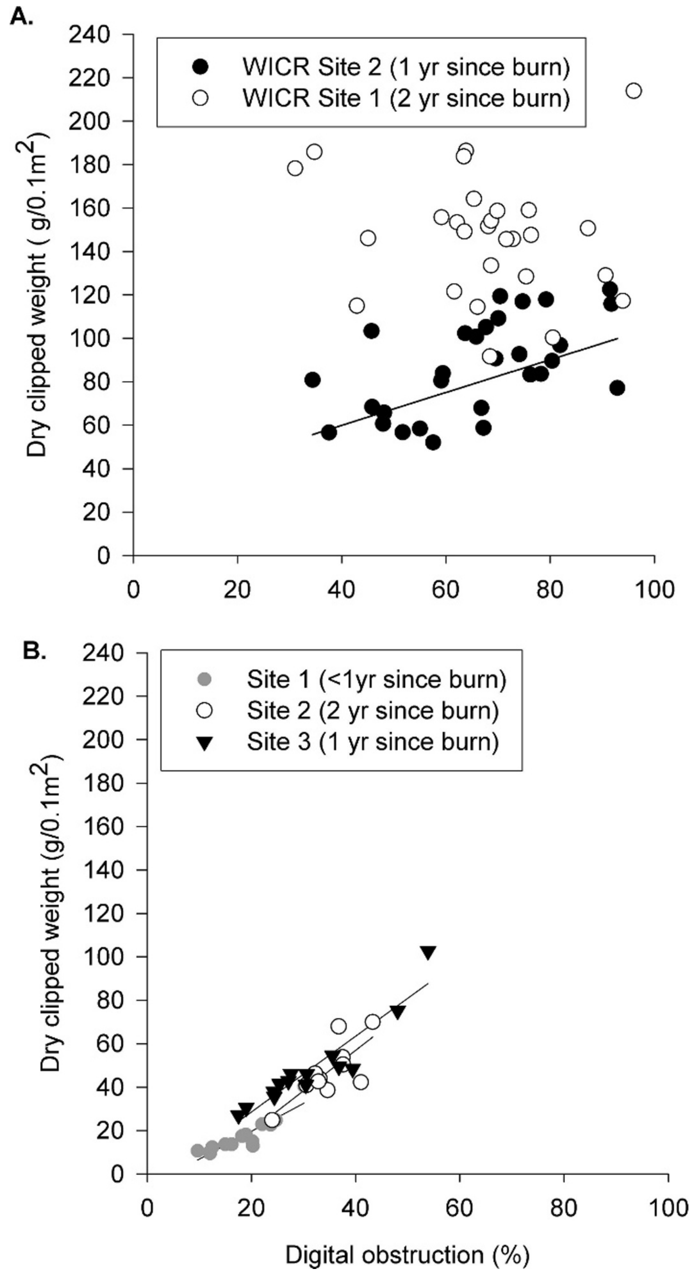

Figure 2. Relationship between digital obstruction and dry clipped weight at **A**, two sites at Wilson's Creek National Battlefield (WICR Site 1: $P = 0.45$, $r^2 = 0.02$, $y = 165.5x - 0.27$; WICR Site 2: $P = 0.01$, $r^2 = 0.32$, $y = 0.79x + 34.67$; regression line not shown for Site 1 due to lack of significance), and **B**, three sites in a pasture managed with patch burn grazing at Tallgrass Prairie National Preserve (TAPR; Site 1: $P < 0.01$, $r^2 = 0.82$, $y = 1.28x - 6.03$; Site 2: $P = 0.01$, $r^2 = 0.57$, $y = 2.32x - 21.63$; Site 3: $P < 0.01$, $r^2 = 0.88$, $y = 1.75x - 6.36$). Slopes of regression lines did not differ significantly among sites at TAPR. All data are from the 4-m distance.

denser, however, more of the vegetation was obscured from the camera by intervening vegetation, and the strength of the digital image obstruction/biomass relationship decreased. Plants in close proximity to the camera (e.g., within 0.25 m) may have disproportionate visual obstruction to plants closer to the photo board (e.g., 4.0 m from the camera; Fig. 1). Our data suggest that large amounts of litter may potentially decrease the efficacy of the technique, although this requires further study. In Limb et al. (2007), as well as all the sites at TAPR, dry clipped weights were almost always $< 80 \text{ g} \cdot 0.1 \text{ m}^{-2}$ and digital image obstruction was almost always $< 50\%$. At WICR, in contrast, dry clipped weights and digital image obstruction were much greater than those at TAPR and the Limb et al. (2007) study, and the images did not represent clipped fuel loads in this ungrazed grassland with tall (> 1.5 m), dense vegetation.

The technique as described by Limb et al. (2007) was attractive because it appeared to reduce observer error, bias, and sampling time associated with visual observation methods. We found, however, that issues arose, both in the field and during image processing, that required subjective decisions or the implementation of decision rules. In the field, the relative placement of the photo board and the camera had to be evaluated and at times adjusted to obtain representative data. Dissimilar to Limb et al. (2007), we were not able to use a single threshold value for image conversion. Although subjectivity or bias may have been introduced in this way, it was obvious that more representative results would be obtained if such adjustments were made.

Limb et al. (2007) point out potential problems with shadows and the need for careful photo board placement and timing of sampling efforts with the position of the sun. We found the method to be extremely sensitive to changes in light intensity and shadows in the field, and several images had to be discarded because of lighting issues that could not be resolved even through adjustments in processing. Such issues with photo board placement and timing of sampling efforts may prove to be major logistical problems depending upon the terrain, the number of plots, and distances separating those plots.

Our results suggest that the grazing or burn history of an area may be informative in determining the usefulness of the digital photography biomass estimation technique. At the intensely grazed TAPR, for example, the digital image obstruction/biomass relationship was stronger for sites burned 1 yr ago or less than for the site burned 2 yr ago. Moreover, the relationships for all sites at TAPR, a continuously grazed grassland, were stronger than those at WICR, which had not been grazed by livestock in at least the last 50 yr. Thus, the technique may be more useful for areas with a higher frequency (or intensity) of grazing or burning.

MANAGEMENT IMPLICATIONS

The digital photographic technique of Limb et al. (2007) for estimating biomass or fuel load is appropriate for some, but not all grasslands. Our results indicate the technique may not be useful for grasslands with relatively high biomass ($> 80 \text{ g} \cdot 0.1 \text{ m}^{-2}$) or digital image obstruction $> 50\%$; large amounts of litter may also potentially reduce the accuracy of the technique. Use of the technique requires some decision rules be developed in both the field and the lab, to reduce potential sources of error and obtain representative results.

ACKNOWLEDGMENTS

We are grateful to WICR and TAPR for allowing us to conduct this research. Many thanks to field technicians Maria Gaetani, Melanie Weber, and Ashley Dunkle; Kristen Hase, Billy Robb, and Darin McCullough at TAPR also provided valuable assistance. We appreciate the support of Mike DeBacker. Thanks also to Ryan Limb and Dirac Twidwell.

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