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Technical note: Estimating aboveground plant biomass using a photographic technique

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Abstract

We present a non-destructive, photographic method to estimate biomass in semiarid grasslands. Though the method needs to be calibrated, it allows for a dramatic increase in the number of samples compared with the clipping method. The method is based on a relationship between the percentage of "green pixels" in a digital image and green biomass. We identified "green pixels" as those satisfying the following condition: G/B > 1 and G/R > 1, where G, B and R are the intensities of a particular pixel in the green, blue, and red bands respectively. The percentage of green pixels of the image and green grass biomass showed a correlation of 0.87 (n = 36, p < 0.001) when data were pooled from 3 sample dates. The relationship was slightly curvilinear and a log transformation of green biomass yielded a better correlation (r = 0.91, n = 36, p < 0.001). The percentage of green pixels showed a lower correlation with total green biomass than with grass biomass (r = 0.59 for the linear model and 0.73 for the log transformed model). The relationship between the percentage of green pixels and either green grass or total green biomass changed during the growing season. Both the slope and the Y-intercept of the model differed significantly among dates. Correlation coefficients for different dates ranged between 0.76 and 0.95.

Resumen

En este trabajo presentamos un método fotográfico no destructivo para estimar biomasa en pastizales semiáridos. A pesar de que necesita ser calibrado, este método permite un aumento dramático en el número de muestras, en comparación con el mEtodo de cortes. Este método está basado en la relación entre el porcentaje de "pixeles verdes" y la biomasa verde en una imagen digital. Identificamos "pixeles verdes" como aquellos que satisfac°an la siguiente condición: G/B >1 and G/R >1, donde G, B y R son las intensidades de un pixel particular en las bandas del verde, azul y rojo, respectivamente. El porcentaje de pixeles verdes en la imagen y la biomasa verde de los pastos mostró una correlación de 0.87 (n= 36, p < 0.001) al agrupar los datos de 3 fechas de medición. La relación era ligeramente curvilínea y una transformación log de la biomasa verde arrojó una mejor correlación (r = 0.91, n = 36, p < 0.001). El porcentaje de pixeles verdes mostró una menor correlación con la biomasa verde total que con la biomasa de pastos (r = 0.59 para el modelo lineal y 0.73 para el modelo transformado log). La relación entre el porcentaje de pixeles verdes y la biomasa verde de pastos o la biomasa verde total cambió durante la estación de crecimiento. Tanto la pendiente como la ordenada al origen del modelo difirieron significativamente entre fechas. Los coeficientes de correlación para las diferentes fechas oscilaron entre 0.76 y 0.95.

Key Words: ANPP estimation, non-destructive methods, semiarid grassland

Aboveground net primary production (ANPP) is a key attribute of grassland ecosystems. Aboveground net primary production data are relevant for both theoretical studies and applied research. Many functional and structural ecosystem traits are tightly related to aboveground net primary production, i.e. secondary production (McNaughton et al. 1989), root biomass and soil organic carbon (Sala et al. 1997). Aboveground net primary production can be used as an integrative attribute of ecosystem function (McNaughton et al. 1989). Aboveground net primary production is an important variable in natural resource management because it determines forage availability for both wild and domestic herbivores. Oesterheld et al. (1992) found a strong connection between stocking density and ANPP for South American rangelands.

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Despite its importance, ANPP estimates for grasslands are scarce. Only a few experimental sites carry out regular long-term measurements of aboveground net primary production (see for example, Fernández et al. 1991, Briggs and Knapp 1995, Lauenroth and Sala 1992 and the ORNL DAAC at http://www-ecot.ornl.gov/npp/npp-home.html for some examples). The reason behind the lack of extensive ANPP databases is quite simple: it is time consuming and therefore expensive to estimate.

Net primary production is the rate of carbon accumulation in plants in an ecosystem, and it is generally calculated annually. However, ANPP estimates are not based on this rate, but on the changes in biomass through time (Lauenroth et al. 1986). Biomass is estimated a number of different ways including harvesting (Sims et al. 1978, Sala et al. 1981), visual estimates (Waite 1994), capacitance meter (Fletcher and Robinson 1956, Winkworth et al. 1962, Murphy et al. 1995), and spectral data (Tucker 1977) to name the most common methods. Photo keys have been also used to estimate biomass, however the overall accuracy of the method is low (Catchpole and Wheeler 1992). Double sampling techniques have been widely used to estimate biomass (Ahmed et al. 1983, Catchpole and Wheeler 1992). This approach involves the development of a regression equation between biomass and a variable easy to measure. The variables more commonly used were ground cover, sward height, total blade length per tiller and point contacts (Pasto et al. 1957, t'Mannetje 1976, Williamson et al. 1987).

Estimates of aboveground net primary production derived from changes in biomass are subject to under and over estimation errors (Lauenroth et al. 1986, Sala et al. 1988), both related to the number of biomass samples (in time or space) used to calculate ANPP. To increase both the availability of aboveground net primary production data and their accuracy, we need to be able to work with large sample sizes. Additionally, many studies need non-destructive methods because of small plot sizes or restricted areas. In this paper we present a non-destructive, photographic method to estimate biomass in grasslands. Biomass estimates are important in itself but also provide the basis to estimate ANPP (Lauenroth et al. 1986). Even though the method needs to be calibrated, it allows for a dramatic increase in the number of samples per operator compared to the clipping method. The method is based on a relationship between the percentage of green pixels in a digital image and green biomass.

Methods

This research was conducted at the Central Plains Experimental Range (CPER) in northcentral Colorado, North America (40° 49'N Lat, 104° 46' W Long). The CPER is administered by the USDA Agricultural Research Service (ARS) and is a National Science Foundation funded Long Term Ecological Research site. Mean annual precipitation is 321 mm (SD = 98 mm). Average annual temperature is 8.6° C (SD = 0.6° C). The climate of the CPER is typical of mid-continental semi-arid sites in the temperate zone except for the large influence of the Rocky Mountains 60 km to the west. Maxima in precipitation and temperature occur in June, July, and August and minima occur in December, January, and February.

The vegetation is typical of the northern portion of the shortgrass steppe (Lauenroth and Milchunas 1992). The dominant species is the perennial bunchgrass *Bouteloua gracilis* H.B.K. Lag. Important associated species include *Buchlöe dactyloides* (Nutt.) Engelm, *Opuntia polyacantha* Haw, *Sphaeralcea coccinea* (Pursh) Rydb, and *Carex eleocharis* Bailey. All nomenclature follows The Great Plains Flora Association (1986).

We took photographs on 3 dates during the growing season (21 May, 10 June, 26 June 1996) of 0.25 m^2 circular plots using a 35 mm single lens reflex camera (PENTAX PZ10) with a 28-70 mm zoom lens. The camera was mounted on a tripod facing down 1.4 m above the ground with an angle lower than 10 degrees from the vertical. We used color slide film (200 ASA) (Kodachrome). Pictures were taken between 11:00 and 15:00 on clear days. The slides were digitized as TARGA files (TGA) at a resolution that yielded an average size for an individual pixel of approximately 0.25 mm^2 (ground area) (Fig. 1).

Aboveground biomass was harvested from each plot after the picture was taken. Plants were clipped at the soil surface and biomass was sorted into live and dead and by the following categories: grasses, forbs, lichens, and cactus. After sorting, the material was oven-dried at 50° C and weighed.

The estimates of green biomass from the images were based on the separation of the image into the 3 colors: red, green and blue. These primary colors are additive because their combination produces white. An image consists of 3 layers or matrices. Each layer is assigned to 1 additive color. Each pixel of each band has a particular intensity. In an 8-bit image, the intensity will range from 0 to 255 (2^8). A pixel with an intensity of 255 on each of the 3 bands will be white. For a black pixel the intensity in each of the 3 bands will be 0.

We identified "green pixels" as those satisfying the following condition:

$$G/B > 1 \text{ and } G/R > 1 \qquad \textbf{(1)}$$

where G, B and R are the intensities of a particular pixel in the green, blue and red bands respectively. We calculated the number and proportion of green pixels for the whole image. G_PIX is a DOS-based C-program that processes a pixel by pixel list of the input file (*.TGA) (a free copy of the program (G_PIX.EXE) is available at http://www.ifeva.edu.ar/pictures).

We performed simple correlation and regression analyses to investigate the strength of the relationship between the percentage of green pixels of the image and green grass biomass and total green biomass. We cropped the portion of the picture corresponding to the 0.25 m^2 quadrat using Adobe Photoshop 3.0 (Adobe Systems Incorporated 1994).

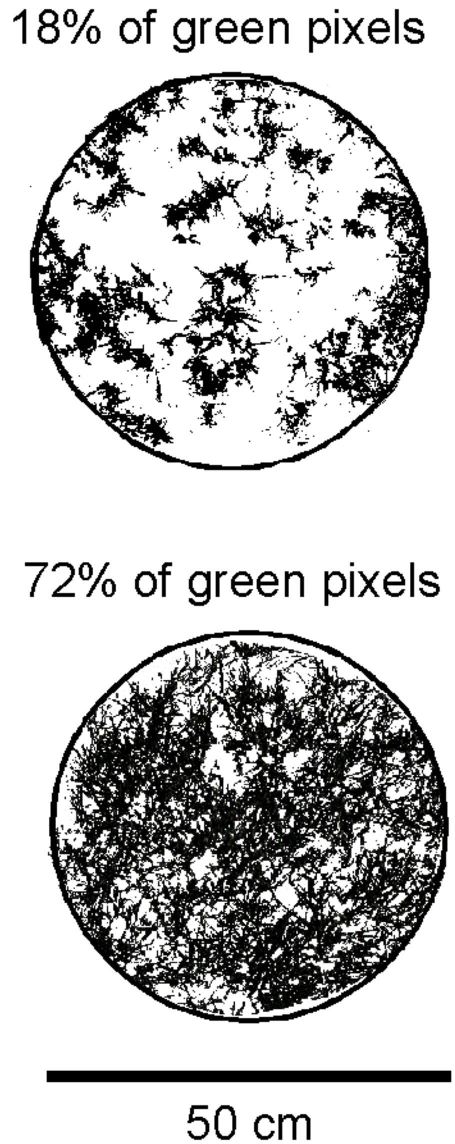

Fig. 1. Pictures that show contrasting biomass and percentage of green pixels in the shortgrass steppe. The circle corresponds to the area sampled in the calibration experiment (0.25 m^2). Green pixels appear as black and everything else as white.

Results and Discussion

The percentage of green pixels and green grass biomass showed a correlation of 0.87 (n = 36, p < 0.001) when data were pooled from all 3 sample dates (Fig. 2). The relationship was slightly curvilinear and a log transformation of green biomass yielded a better correlation r = 0.91, n = 36, p < 0.001) (Fig. 2). The percentage of green pixels showed a lower correlation with total green biomass than with green grass biomass r = 0.59 for the linear model and 0.73 for the log transformed model).

The relationship between the percentage of green pixels and either green grass or total green biomass changed during the growing season (Table 1 and Fig. 2). Both the slope and the Y-intercept of the regression model differed significantly among dates (Table 1). However, the differences of slopes and Y-intercepts were more marked for the relationship involving total green biomass than for green grass biomass. Changes in the relative contribution of different plant functional types (forbs, succulents, lichens, and grasses) and modifications of the canopy structure may account for the greater differences in the relationship between the percentage of green pixels and total green biomass compared to grass biomass.

Our results showed that digital images and an algorithm based on color theory can provide good estimates of plant biomass in semiarid grasslands. The method of counting green pixels is a variation of the point-quadrat method (Greig-Smith 1983). In this method plant cover, leaf area index, or biomass is calculated from the proportion of hits on green tissues over the total number of observations. By counting the number of green pixels we are dramatically increasing the total number of observations. The area sampled in this study (0.25 m^2) included more than 70,000 pixels (it varies approx. 1% among pictures). As with the point-quadrat method, counting green pixels on a picture is a non-destructive method. That makes it especially useful for long-term studies of ANPP, plant cover or plant biomass.

This method also offers an interesting alternative for studying patch dynamics in arid and semiarid systems. Pictures allow one to track the dynamics of bare soil patches through time, recruitment of seedlings or the spread of clonal plants. The method proposed will be a useful tool for grassland and shrubland ecologists and managers. A picture represents a more objective alternative to assess plant cover or plant biomass than visual estimates. The use of digital cameras will speed up the process of assessing structural attributes of grassland and shrubland ecosystems. Pictures can be downloaded to the hard disk of a notebook computer from a digital camera directly in the field. G_PIX can calculate the percentage green pixels for a group of pictures and store the results in an ASCII file. Clearly multiple layers of leaves or complex canopies would reduce the accuracy of this approach. The shortgrass steppe presents a canopy structure near ideal to apply this method. For non-postrate vegetation camera angles different from vertical may provide better estimates of green biomass.

The method requires, however, a proper calibration based on double sampling, harvesting biomass, and taking pictures. Our

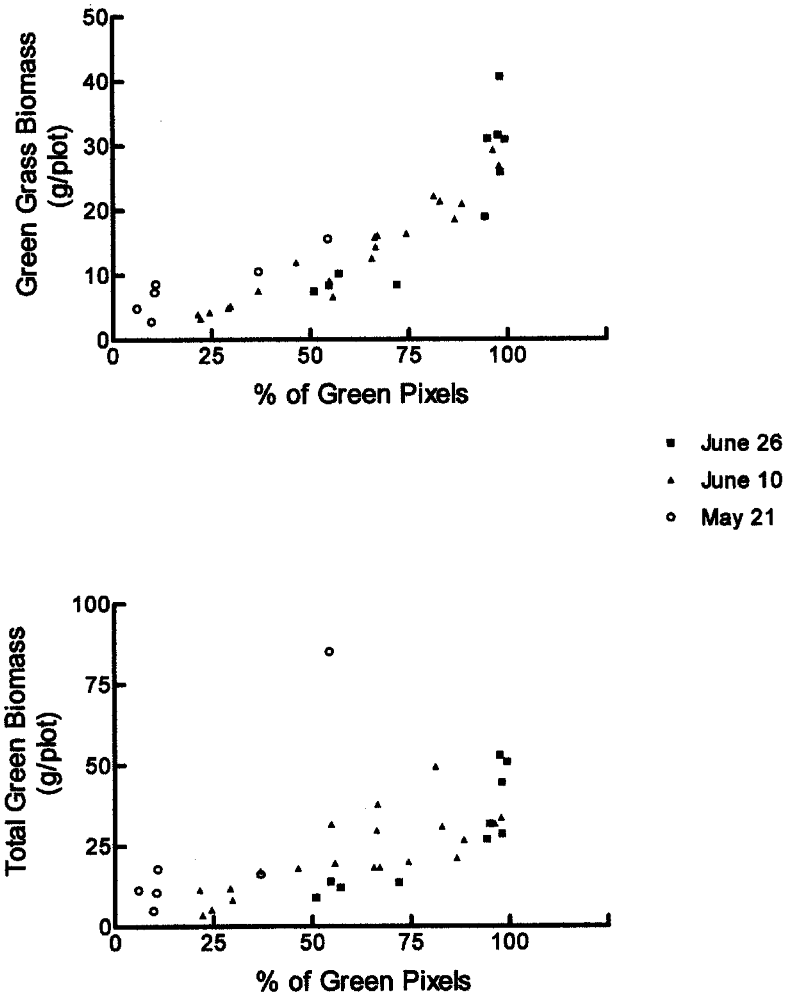

Fig. 2. Relationship between the percentage of green pixels and green grass biomass (GGB = 1.43 + 0.35 ln (%GP), r = 0.91, p < 0.001) (the upper panel) and total green biomass (TGB = 1.94 + 0.017 ln (%GP), r = 0.73, p < 0.001) (the lower panel). Open circles correspond to 21 May, triangles to 10 June and squares to June 26 sample dates.

Table 1. Correlation coefficients (r), slope, Y–intercepts, F–value and number of observations (n) for the linear models fit to the data of percentage of green pixels and green grass biomass (g/plot) (A) and total green biomass (g/plot) (B).

A) GREEN GRASS BIOMASS						
Date	Y–intercept	Slope	r	F	n	
21 May	3.91	0.21	0.90	17.5	6	**
10 June	–4.04	0.38	0.95	17.9	20	**
26 June	–21.3	0.52	0.88	28.6	10	**
**p< 0.01						

B) TOTAL GREEN BIOMASS						
Date	Y–intercept	Slope	r	F	n	
21 May	–3.54	1.30	0.86	10.7	6	**
10 June	1.42	0.35	0.76	25.1	20	**
26 June	–27.47	0.68	0.86	21.8	10	**
**p<0.01						

results suggest that our calibration was not stable throughout the growing season, mainly for total green biomass, and therefore requires a calibration at each sample date and vegetation type. The high correlation suggests that a small number of samples would be necessary to describe the relationship. Despite this requirement this method has a very high probability of improving the process of collecting aboveground biomass data in semiarid grasslands and shrublands.

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