

# Estimation of Plant Biomass by Spectral Reflectance in an East African Grassland

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## Abstract

Canopy spectral reflectance measurements at 0.800 and 0.675  $\mu\text{m}$  were made in a grassland in Masai Mara Game Reserve, Kenya. The reflectance ratio (0.800/0.675  $\mu\text{m}$ ) was shown to be a reliable predictor of green biomass, accounting for 70% of the variance in green biomass values. Significant error in the biomass estimates was shown to be due to plots which contained less than 30% of the total vegetation in the live condition. Estimation error tended to increase when time of sampling departed from the interval of 1000 to 1400 hours, although this trend was not statistically significant. We conclude that the spectral reflectance technique can provide reliable estimates of plant biomass in grassland ecosystems where the proportion of live:total vegetation exceeds 30%.

The distribution and abundance of plant biomass in space and time are important properties of rangeland ecosystems. However, the accurate measurement of vegetative biomass by traditional clipping and weighing is a time-consuming and labor-intensive process. As a result, many indirect methods of monitoring plant community biomass have been developed with varying degrees of success. Some of these methods have been reviewed by Tucker (1980).

One of the more promising methods of biomass estimation involves the measurement of canopy spectral reflectance in the red (0.600–0.700  $\mu\text{m}$ ) and the near infrared (0.750–1.00  $\mu\text{m}$ ) wavelengths. The red wavelength region is measured because chlorophyll has an absorption maximum at 0.675  $\mu\text{m}$ , whereas green biomass is highly reflective in the near infrared region (Tucker 1977). The reflectance at 0.800  $\mu\text{m}$  divided by the reflectance at 0.675  $\mu\text{m}$  yields a ratio which is sensitive to the amount of green biomass present in a given area. Several studies have reported success using spectral reflectance techniques to predict green biomass in rangeland ecosystems (Pearson et al. 1976; McNaughton 1976, 1979; Waller et al. 1981). The purpose of this investigation was to provide a further test of the relationship between standing green biomass and the reflectance ratio and to assess the feasibility of using this technique to monitor rangeland vegetation dynamics.

## Study Area and Methods

The study was carried out in the 1673 km<sup>2</sup> Masai Mara Game Reserve in southwestern Kenya. This park lies between 1 and 2 degrees S latitude and 35 and 36 degrees E longitude at an average elevation of 1600 m and is the northernmost portion of the Serengeti ecosystem. Mean annual temperature from 1975–1980 was 20.5°C with little monthly variation, while mean annual precipita-

tion during this same period was 1034 mm. Soils are mainly of volcanic origin and range from brown sandy loams to black heavy clays.

Fourteen plant communities have been identified within Masai Mara (Taiti 1973), but most of the reserve consists of open or lightly wooded grasslands dominated by the grass *Themeda triandra* Forsk. (red oat grass). Peak values of standing crop vegetation (live plus dead) occur in June shortly after the rainy season and range up to 700 g m<sup>-2</sup>.

The diversity, density, and biomass of wild herbivores in this ecosystem are extremely high throughout the year. During 1978–1979, average monthly biomass of wild herbivores in our study areas was 19.3 metric tons km<sup>-2</sup> (Stelfox et al. 1980). These herbivores consume at least 30% of the total annual aboveground net primary production (Stelfox et al. 1980). The most important species on a biomass basis included *Connochaetes taurinus* (wildebeest), *Equus burchelli* (zebra), *Syncerus caffer* (buffalo), *Damaliscus korrigum* (topi), *Giraffa camelopardalis* (giraffe), and *Loxodonta africana* (elephant). More detailed information on this ecosystem can be found in Sinclair and Norton-Griffiths (1979).

Canopy reflectance at 0.800 and 0.675  $\mu\text{m}$  was measured with a Tektronix portable radiometer on 58 0.25-m<sup>2</sup> plots in the eastern half of Masai Mara Game Reserve between July 26 and 28, 1980. These plots were randomly arranged within 15 study sites where studies assessing annual biomass dynamics were in progress. These study sites were initially chosen so that all grassland types in the eastern half of the game reserve were represented. The probes of the radiometer were held approximately 1.2 m above the surface of a plot to be measured, giving an effective viewing area of 0.25-m<sup>2</sup>. Most readings were taken between 0900 and 1500 hours, although some were taken as early as 0645 and as late as 1600. Readings were taken irrespective of atmospheric conditions or substrate color. The sun was intermittently obscured by clouds on both days on which reflectance readings were taken.

After obtaining reflectance measurements, each plot was assessed for species composition, cover, grazing intensity, and then clipped to ground level. Plant material was separated into litter, grass, forb, and sedge categories in the field. Each category (except litter) was then separated into green and dead components in the lab. All vegetation was dried at 80°C for 48 hours and then weighed to the nearest 0.1 gram. Regression and correlation analyses were then employed to assess relationships among the variables and to assess the predictive value of reflectance ratio as an estimator of green biomass.

In order to assess the ability of the radiometer to measure reflectance from lower leaf layers in dense canopies, 4 plots of high total biomass were clipped in a stratified manner. Spectroreflectance measurements were taken in each plot before clipping all biomass above 100, 80, 60, 40, and 20 cm. In addition, spectroreflectance was measured after all standing biomass was removed and only litter remained, and again after litter was removed. Thus, 7 measurements were made on each of 4 plots.

Four additional plots were selected to test the effect of time of day on spectroreflectance values. Each plot was measured at approximately hourly intervals from 0645 to 1600 hours, after

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Table 1. Correlation coefficients among the variables. An \* indicates significance at the .05 level. N = 58 for all correlations.

	Reflectance ratio <sup>1</sup>	Total green	Green grass	Green forb	Green sedge	Total dead
Total green	0.84*					
Green grass	0.82*	0.99*				
Green forb	0.20	0.22	0.10			
Green sedge	0.07	-0.02	-0.11	-0.09		
Total dead	0.13	0.20	0.19	0.33*	-0.24	
Litter	-0.24	-0.20	-0.16	-0.01	-0.37*	0.45*

<sup>1</sup>Defined as canopy reflectance at .800  $\mu\text{m}$  divided by reflectance at .675  $\mu\text{m}$ .

which time the plots were clipped as described above.

## Results

The 58 plots sampled in this study had an average of 5 species per 0.25-m<sup>2</sup> plot (range = 2-10). Standing crop (live plus dead) ranged from 18 g·m<sup>-2</sup> to 588 g·m<sup>-2</sup>. Grasses composed 94% of the total biomass, forbs 2%, and sedges 4%. The percentage of live material in the standing crop ranged from 6.8% to 74.3% (mean = 54%).

Correlations between the vegetation categories were generally weak (Table 1). The strong relationship between green grass and total green biomass was expected since 94% of the total green biomass was grass. The reflectance ratio showed significant correlations with total green biomass and with green grass biomass, suggesting that the ratio could be used as a predictor of green biomass.

Regression analysis showed that reflectance ratio is a predictor of total green biomass (Fig. 1), accounting for a significant proportion of the variation of biomass values ( $r^2 = 70\%$ ,  $P < .001$ ). It should be noted that the standard error of the estimate is large (38.6 g·m<sup>-2</sup> or 386 kg·ha<sup>-1</sup>) when the reflectance ratio is used to predict the dry weight of green biomass (Fig. 1). Standing crop (live plus dead) is also significantly correlated with reflectance ratio, but predictability is much lower ( $r^2 = 25\%$ ). There is no evidence from our results that the amount of biomass present in the plots was high enough to require a nonlinear predictive equation (Tucker 1977).

Some of the scatter about the regression line in Figure 1 may be explained by Figure 2. When the average percent errors of the biomass values predicted by the equation in Figure 1 are plotted against the proportion of live biomass, it is clear that error becomes unacceptable in plots having less than about 30% live biomass.

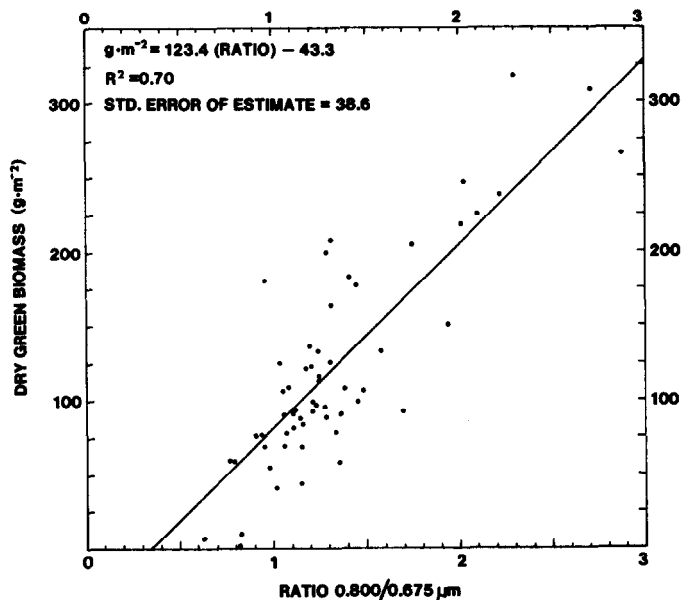


Fig. 1. Relationship between reflectance ratio (.800/.675  $\mu\text{m}$ ) and dry weight of green biomass ( $N = 58$ ).

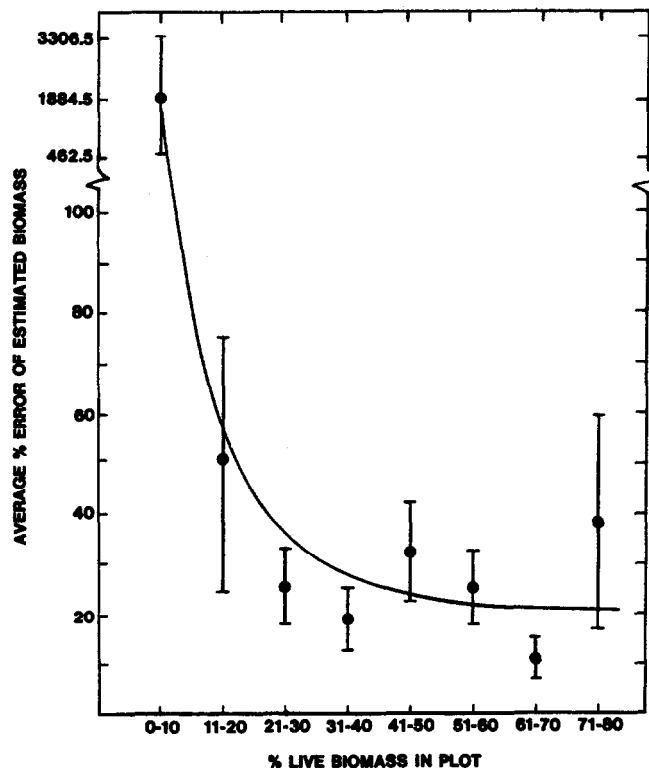


Fig. 2. Percent error of the estimates from the equation in Figure 1 as a function of the proportion of live vegetation. Vertical bars are standard errors of the means.

This same result has been obtained by other investigators (Pearson et al. 1976). Nineteen of the points in Figure 1 are from plots having less than 30% live vegetation, and undoubtedly represent much of the variation unaccounted for by the regression. In plots with more than 30% live biomass, error of estimates is still substantial (10-30%), but much smaller than plots with a lower proportion of live biomass (Fig. 2).

Results from the 4 plots clipped in a stratified manner are shown in Figure 3. These data indicate that the radiometer predicts biomass from tall, dense canopies as well as from lower canopies, at least within the range of biomass values encountered in this study. Slopes of regression lines in Figure 3 are significantly different from the regression line in Figure 1 ( $P < 0.001$ ). This could be due to

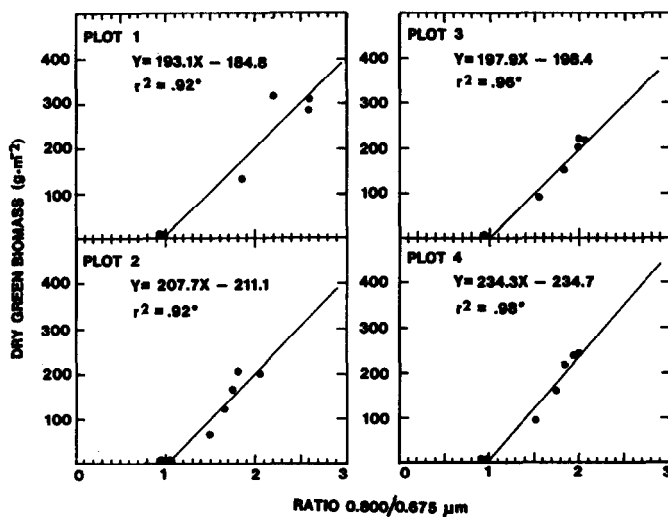


Fig. 3. Results of reflectance measurements made on plots clipped in a stratified manner. S.E. EST. is the standard error of the estimate.

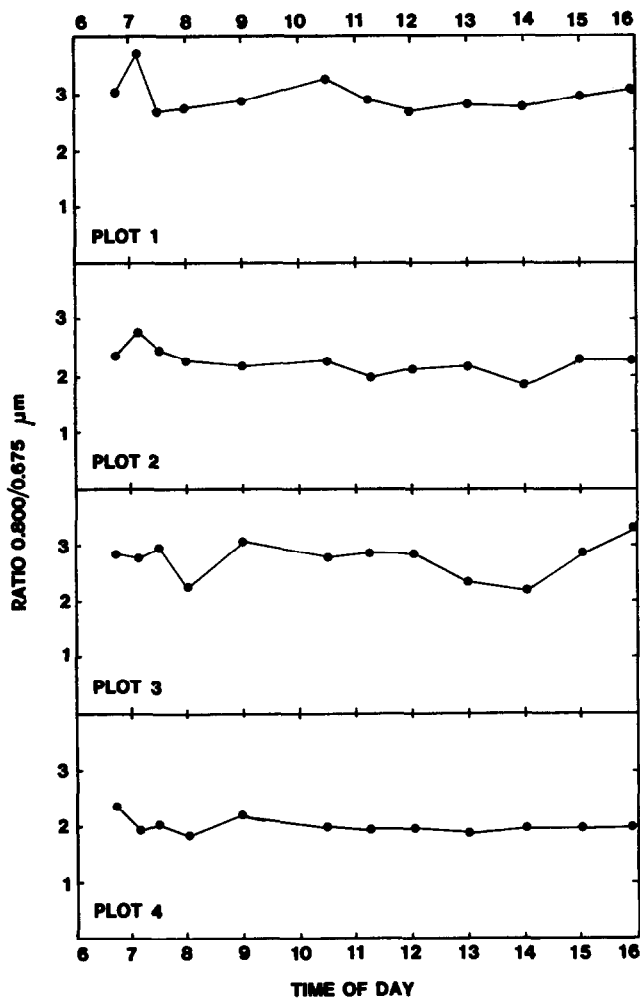


Fig. 4. Effect of time of day on canopy spectral reflectance values of four replicate plots.

reduced variability of cloud cover, substrate color, time of day, and percentage of live biomass encountered while collecting the data in Figure 3 compared with conditions encountered while collecting data for Figure 1. All of these variables have been shown to influence spectral reflectance from plant canopies (Colwell 1974, Tucker 1980).

Based on the data from the 4 plots that were measured repeatedly during the course of an entire day, it appears that spectral reflectance measurements made between 1000 and 1400 hours are less variable than those taken at other times of day (Fig. 4). Furthermore, spectrorreflectance measurements taken between 1000 and 1400 hours are somewhat less prone to prediction error than measurements at other times of day (Fig. 5). However, analysis of variance shows that estimation errors for measurements taken between the times of 0600–1000, 1000–1400, and 1400–1600 hours are not significantly different from each other ( $P > .05$ ).

### Discussion

The results of this study show that canopy spectrorreflectance measurements at 0.800 and 0.675  $\mu\text{m}$  in the open grasslands of Masai Mara Game Reserve can be useful as estimators of green biomass. Linked with the presently routine animal surveys in this area (Stelfox et al. 1980), these measurements could help provide a greater understanding of the properties of this ecosystem.

Between 1961 and 1979, the population of wild herbivore species in this area has increased by a factor of 5, and most species continue to have a high rate of increase (Stelfox et al. 1980). Effective study and management of these animals in relation to their resource

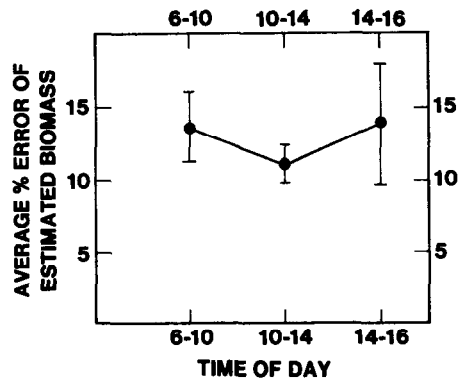


Fig. 5. Percent error of biomass estimates in Figure 4 as a function of time of day measurements were made. Vertical bars are standard errors of the means.

requirements necessitates a routine assessment of vegetation availability on a spatial and temporal basis. The spectral reflectance technique appears to be a suitable alternative to other more time-consuming methods and appears suitable for either ground or aerial measurements (McNaughton 1979, Pearson et al. 1976).

Our results are similar to those of McNaughton (1979) for the adjacent Serengeti National Park in Tanzania. His predictive equation accounted for a higher proportion of the variation in biomass values ( $r^2 = 96\%$  vs. our 70%), but this could be due to the fact that none of his calibration plots contained less than 36% live biomass. Nineteen of our 58 plots contained less than 30% live vegetation. As shown in Figure 2, error of estimation increases drastically as the percentage of live biomass falls below 30%. Intense herbivory, frequent fires, and a favorable rainfall regime maintain plant standing crop near or above 50% live during most of the year at Masai Mara (our unpublished data). Thus, a high proportion of standing dead would not be a regular hindrance to spectral reflectance studies in this region. Efforts to use spectral reflectance in more xeric grasslands in Kenya where the percentage of live biomass is consistently low have been less successful (Croze et al. 1978, Gwynne 1977), accounting for only 23 to 38% of the variation in biomass values, depending on whether data were transformed or not.

The standard error of the estimate of our predictive equation (Fig. 1) is 38.6  $\text{g}\cdot\text{m}^{-2}$  or 386  $\text{kg}\cdot\text{ha}^{-1}$ . This would be a significant source of error in investigations requiring precise measurements, such as productivity studies. However, this error would be less important for gross surveys of green biomass, for detecting large seasonal differences in biomass, or, in this ecosystem, for estimating consumption by large herbivores during annual migratory periods.

We suggest that it should be possible to improve the predictive value of spectral reflectance measurements. First, our data show a trend towards less error in measurements taken within 2 hours of noon (Fig. 5). Although this trend in our data is not statistically significant, other investigators have reported that error from solar zenith angle can be important (Tucker 1980). Second, our measurements were made irrespective of atmospheric conditions; some measurements were made under cloudless conditions, while others were made when the sun was obscured by clouds. Tucker (1980) reports that measurements obtained under cloud-free conditions may not be directly comparable with measurements taken under overcast conditions. One could conceivably develop a predictive equation for use on cloudy days and a separate equation for clear days. Alternatively, Waller et al. (1981) have had some success with minimizing both the influence of time of day and cloud cover by use of a calibration panel.

In summary, we have found that reflectance ratios (.800/.675  $\mu\text{m}$ ) obtained from plant canopies in an East African grassland are reliable predictors of green biomass. The method clearly has potential for monitoring spatial and temporal variability of plant biomass and could be used as a means of studying the relationship

between herb layer vegetation and the rapidly increasing herbivore populations in this region. This kind of information would be most useful in implementing effective management policies in the Masai Mara Game Reserve.

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