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Spectral Mapping of Shortgrass Prairie Biomass

An airborne multispectral scanner, coupled with the use of a simple hand-held spectral radiometer, provide an accurate estimate of grass canopy biomass.

Introduction

Biomass measurements of shortgrass prairie vegetation have traditionally been made by hand clipping plots of known area and weighing the vegetation removed in order to determine the wet or dry biomass per unit area. The use of this traditional method is tedious, inefficient, and prevents biomass with time, i.e., the productivity of the vegetation. Several methods have been devised to nondestructively estimate standing crop biomass by using various techniques such as ocular estimation, capacitance measurements, and beta-attenuation techniques and have been referenced in a previous paper (Tucker *et al.*, 1975).

Abstract: *Multispectral scanner data have been processed to yield biomass maps of imagery from shortgrass prairie vegetation. The results of the image processing of these data were compared to actual biomass values measured at the time the aircraft data were acquired. The comparison demonstrated that image processing predicted 1.15 times the actual biomass present with a correlation coefficient of 0.98 for 26 biomass ground-truth areas sampled from a flight line containing a large range of biomass values. A simple, hand-held device has been constructed which utilizes a spectral ratio between two specific wavelengths, 0.68 and 0.80 μm, to accurately estimate grass biomass. Several field experiments have demonstrated correlation coefficients between 0.95 to 0.98 for the hand-held device in estimating undisturbed grass canopy biomass. The hand-held device has been shown to be an accurate and expedient method for estimating grass canopy biomass. This type of device could be used to gather greater amounts of ground-truth information from overflight areas and thus would add greater statistical significance to image processing results.*

remeasuring of the same plot again at a later date to obtain an estimate of the change in

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Analysis of *in situ* collected spectral reflectances from a wide range of blue grama grass plots has yielded the method for a simpler approach to measuring grassland biomass nondestructively. This approach uses remote sensing of the grassland area in question coupled with a double sampling procedure in order to establish the relationship between canopy radiance of reflectance and the amount of grass biomass present in the canopy. Airborne multispectral imagery and ground-based measurements were used to evaluate these remote sensing methods.

The utility of airborne multispectral scanner data to assess grassland biomass distributions were first evaluated. In the course of this analysis it became apparent that one of the limiting factors was the ground-truth collection of biomass data. These data were collected by hand clipping plots of known area which were subsequently weighed.

The tedious and inefficient method of collecting multispectral scanner ground-truth data by clipping led to the development of a hand-held radiometer designed to spectrally estimate the biomass present in the grass canopy. The hand-held radiometer system, called the biometer for biomass meter, was designed for rapid, nondestructive estimation of rangeland biomass after a double sampling approach had calibrated the instrument. After completion of the calibration procedure, which entailed the radiometric measurement and hand clipping of 20 to 30 plots, the biometer could be used to accurately measure up to one plot per minute in a field situation. The versatility and speedy operation of the biometer would then enable greater ground-truth to be collected with a high degree of accuracy and small investment of person-hours. This greater ground-truth data base would allow for more accurate classification of the multispectral scanner imagery. The development and preliminary testing of the hand-held radiometer will be described first.

Methods, Materials, and Equipment

Spectral reflectance and total dry biomass data of 40 ¼ $-$ m² sample plots of blue grama grass (*Bouteloua gracilis*) were subsampled into two sets representing 20 plots each. The data from the first subset were input into a regression routine to establish the relationship between the ratio of the reflectance at 0.800 μm and 0.680 μm and the dry biomass (Figure 1). A ratio approach was taken because the ratio of the reflectances in two narrow wavelength intervals in close proximity is directly proportional to a first approximation of the ratio of the radiances in those same intervals.

The ratio was selected for specific reasons. The radiance or reflectance at 0.680 μm and the amount of biomass present in the grass canopy exhibits a strong, statistically significant, and inverse relationship for these two variables. The physiological basis for this relationship results from strong chlorophyll absorption centered at ~0.680 μm. Radiance or reflectance at 0.800 μm and the amount of biomass present exhibit a strong, statistically significant, and direct relationship between these two variables. The physiological basis for this results from the lack of appreciable absorption at this wavelength and the leaf or blade scattering mechanism which results in high levels of radiance or reflectance (Tucker *et al.*, 1975). The ratio of these two radiance or reflectance measurements has been shown to be more accurate than either one separately (Pearson *et al.*, 1976).

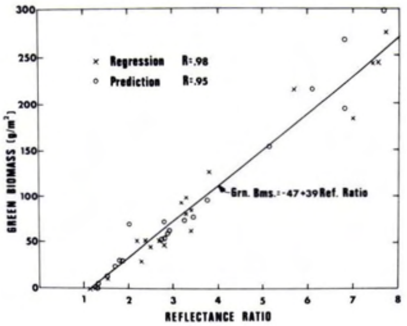

FIG. 1. The linear relationship between biomass of a sample plot and the ratio of the reflctance of that plot at 0.800 μm to that at 0.680 μm was established on 20 plots using regression methods. Next, this linear relationship was used to predict the biomass on 20 new sample plots.

Note, however, that this approach to estimating grass biomass is restricted to grass canopies which contain at least 30 per cent live or green vegetation.

The data analyzed demonstrated a basically linear trend with a correlation coefficient of 0.98 between the estimated and actual amounts of green biomass on the 20 plots. Next, the regression-derived equation was applied to the ratios of the reflectances of the second subset of 20 plots to predict their biomasses (Figure 1). The correlation coefficient of prediction for the second set of plots was 0.95, indicating that the concept could be used accurately in a double sampling system of measuring and clipping a few plots to establish the relationship and then measure many more plots not clipped in order to estimate their biomass.

The Design and Testing of a Prototype Biomass Meter

Using the validation procedure outlined

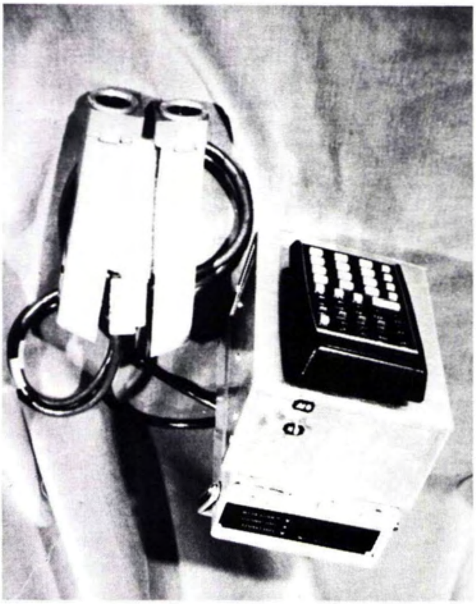

FIG. 2. The prototype hand-held biomass meter, consisting of a radiometer with two probes interfaced to a pocket calculator through a programmable data collection digital interface.

above as a guide, a simple hand-held instrument has been designed and constructed in order to estimate grassland biomass nondestructively (Figure 2). The prototype unit consists of a modified two-channel digital radiometer[1] interfaced to a pocket calculator[2] (Pearson *et al.,* 1976). The radiometer has been equipped with two probes to measure the radiance from a grass plot at approximately 0.680 μm and 0.800 μm. A digital interface was constructed to cycle the radiometer and calculator through a maximum of 32 program steps under the control of a diode pin programmed Read-Only-Memory (ROM). The initial program in the prototype instrument uses 20 of these instructions to step the calculator through the solution of a linear equation by using the two radiance values measured by the radiometer on demand. During this sequence, the calculator computes the ratio of the two radiances being measured from the grass plot; and, using slope and intercept values determined in the calibration procedure that were noted and stored in its memory register, it computes and displays the estimated biomass of the plot in g/m². The entire measurement-conversion program, including the radiance measurements, takes approximately 4 seconds and is completely automatic once the start button is pressed.

The hand-held device has been field tested to verify its accuracy in estimating biomass. A series of 25 of ¼−m² grass plots of blue grama with a wide range of biomass were chosen. The natural solar radiance from each of the sample plots in each of the two spectral bands was measured by the hand-held radiometer and ratioed. Every sample plot was immediately clipped and the total dry biomass of each was determined. The reression routine noted earlier was used to determine the relationship between the ratio of the two spectral radiances measured by the hand-held radiometer and the biomass clipped from the plot (Figure 3). The results showed a correlation of 0.98 for all 25 plots measured. The trend of the data indicated that a simple slope and intercept method of *biomass estimation* is adequate for shortgrass to midgrass grass canopies. Other grassland types with higher amounts of biomass will require the use of a nonlinear estimation due to the inability of the radiometer to measure radiances equally from lower-leaf layers in a multiple-leaf-layer vegetation canopy. There is every reason to suppose however, that the device will work for heavier biomass ranges.

The hand-held device has been used by

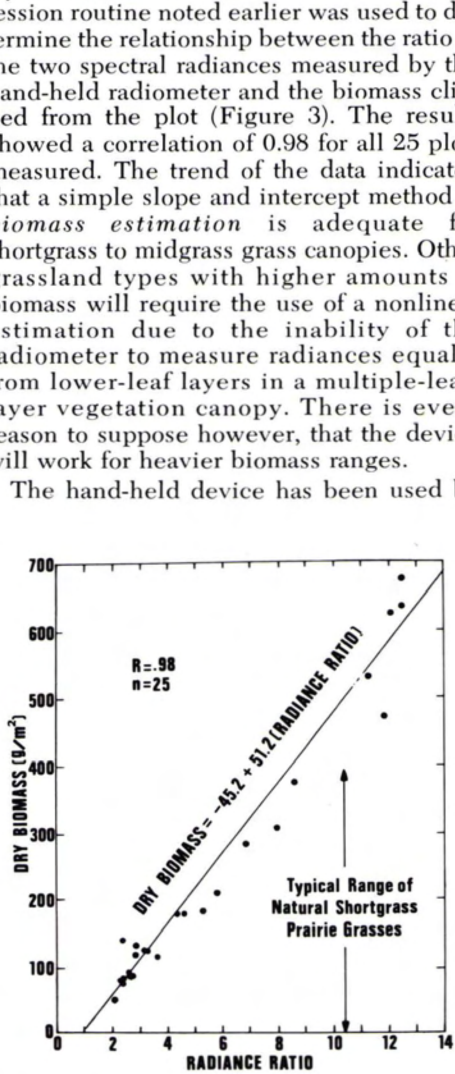

FIG. 3. Dry standing crop biomass for 25 ¼−m² sample plots of blue grama (*Bouteloua gracilis*) as a linear function of the ratio of the solar induced radiance of the plots at 0.800 μm referenced to that at 0.680 μm.

[1] A Tektronics Model J-16 portable radiometer modified to use two probes.

[2] A Hewlett-Packard Model 35 hand-held, battery-operated calculator.

other investigators to estimate rangeland biomass in the Serengeti grasslands of Africa (McNaughton, 1976). In addition, it has been field tested on algal biomass in Yellowstone National Park. The algal data are currently being reduced.

Aircraft Biomass Mapping

The Environmental Resources Institute of Michigan (ERIM) in cooperation with the Grassland Biome Program of the IBP and under the sponsorship of North American Rockwell Corporation, Space Division, collected several flight lines of 12-band multispectral imagery over the Pawnee National Grassland on 17 September 1968. Selected flights of the imagery were processed by ERIM (Wagner and Colwell, 1969) and subsequently a digital tape of the original imagery was made available to the Grassland Biome Program in exchange for field data sampled during the overflight. Preprocessing for scan angle adjustment was performed by ERIM before the tape was shipped. One flight line of this multispectral imagery was recently reanalyzed using the multispectral image processing package available at Colorado State University and entitled RECOG (Smith *et al.*, 1972). The motivation behind this reprocessing of the data was to map the spatial distribution of biomass directly using the knowledge and results obtained in the basic field spectrometry experiments outlined earlier. A total of 87 biomass measurements of one square meter areas were made at the time of the overflight for control and 35 of them occurred in the multispectral image set processed. Three general processing methods were applied:

(1) The RECOG version of spectrum matching using maximum likelihood computations and training sets representing known biomass,
(2) A multiple regression of all available scanner channels with the biomass training sets, and
(3) A simple ratio of the two spectral bands most closely representing the bands used in the hand-held device described earlier.

Part of the available ground samples of measured biomass were used as the training sets in all three cases, and the biomass of the balance of the ground samples was predicted by the image processing activity and then statistically compared with the remaining field measurements to evaluate the processing method used (Table 1). The results in all three cases were significant with correlation coefficients (R values) greater than 0.79 even though the imagery was obtained at an inopportune time of year (September). The RECOG spectrum matching results (Figure 4) were the most significant, yielding a value R = 0.98 for 26 predicted values. A summary computation of the total amount of biomass

Table 1. A Statistical Summary of the Results of Three Methods for Biomass Estimation from Multispectral Scanner Imagery (Plate 1) Which is Based Upon a Comparison of the Predicted Biomass of an Image Cell and the Biomass Sampled for $1M^2$ on the Ground in that Same Cell

Summary of the wavelengths of the multispectral images available

Ch 1 = 0.40 − 0.44 μm	Ch 2 = 0.46 − 0.48 μm	Ch 3 = 0.50 − 0.52 μm
Ch 4 = 0.52 − 0.55 μm	Ch 5 = 0.55 − 0.58 μm	Ch 6 = 0.58 − 0.62 μm
Ch 7 = 0.62 − 0.66 μm	Ch 8 = 0.66 − 0.72 μm	Ch 9 = 0.72 − 0.80 μm
Ch 10 = 0.80 − 1.00 μm		

Multiple regression of all scanner channels
Correlation coefficient (R) = 0.79
N = 35
Dry biomass = −18.1 + 32.6 Ch 1 − 66.3 Ch 2 + 14.6 Ch 3 + 102.8 Ch 4 − 80.9 Ch 5 + 7.2 Ch 6 − 9.3 Ch 7 − 7.9 Ch 8 + 50 Ch 9 + 11.1 Ch 10

Two-channel ratio
Correlation coefficient (R) = 0.79
N = 26
Dry biomass = −327.7 + 429.2 Ch 10/Ch 8

RECOG spectrum matching
Correlation coefficient (R) = 0.98
N = 26
Dry biomass = 0.867 (spectrum matching classification)

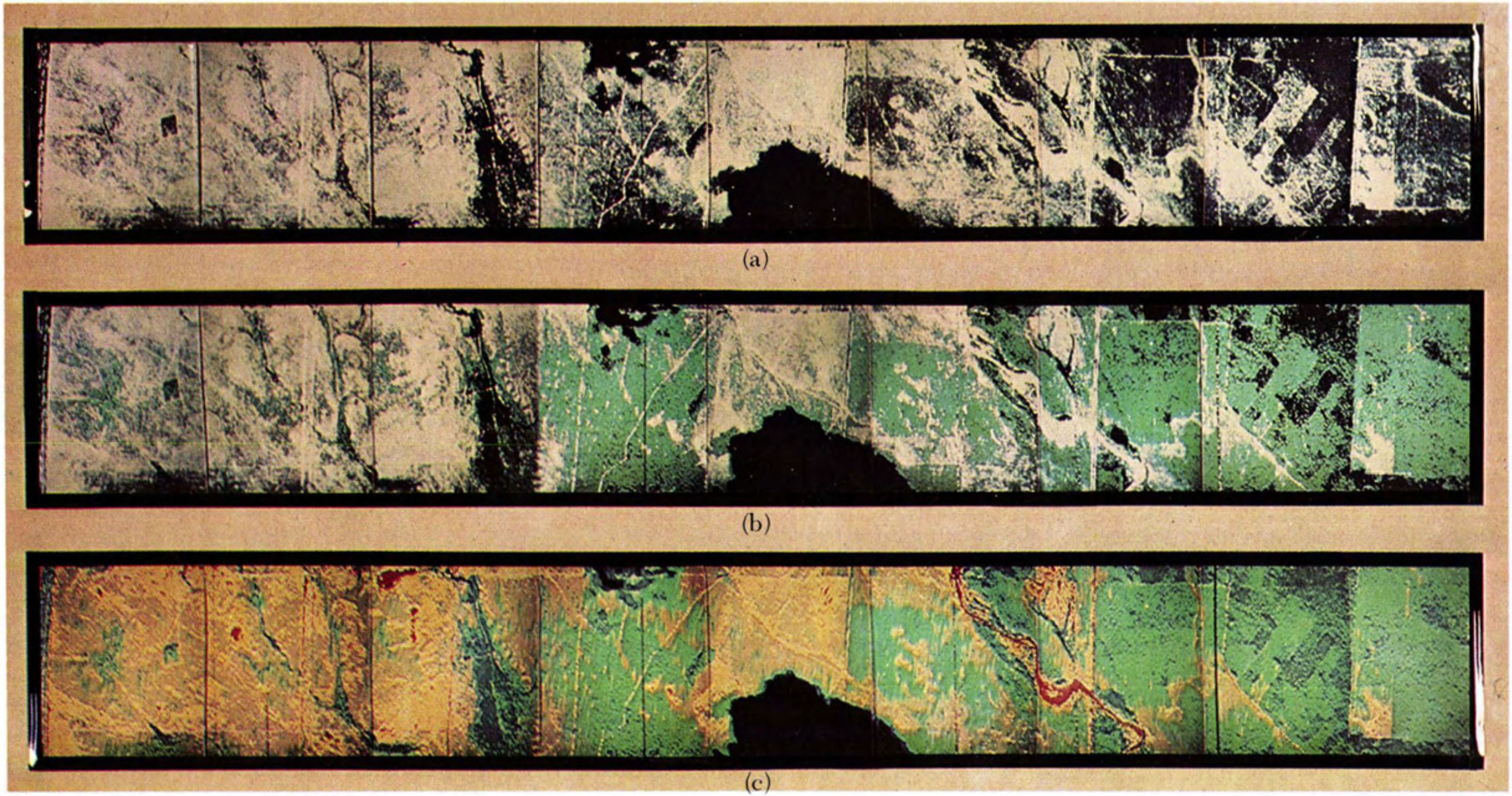

PLATE 1. Multispectral scanner images from the Pawnee National Grassland. All images were photographed from the CSU digital color television display as separate frames and mosaicked together to form the strips shown. Scale is approximately 1/30,000. (a) Graymap of the radiance from 0.58 to 0.62 μm of the multispectral scanner (channel 6). Note the rectangular grazing exclosure in the left end of the image and the large cloud shadow in the center. (b) 250 g/m^2 biomass class recognized by RECOG displayed as green overlaid on the graymap of radiance from 0.58 to 0.62 μm. (c) Recognition map of standing crop biomass. Black represents cloud shadow, blue represents 400 g/m^2 biomass, green represents 250 g/m^2 biomass, brown represents 100 g/m^2 biomass, yellow represents 50 g/m^2 biomass, and red represents bare soil. Note the linear boundary between areas of essentially green and brown color in the center of the image above the cloud shadow which corresponds to a section boundary between two pastures of different grazing treatments and biomass.

TABLE 2. THE TOTAL BIOMASS SUMMARY OF SEVERAL PASTURES BASED UPON THE PREDICTION OF THE BIOMASS FOR EACH GROUND CELL IMAGED AND REDUCED (PLATE 1)

Entire flight line shown (includes grazed and ungrazed pastures)			
Class biomass (g/m^2)	Average ground cell – area (m^2)	Number of occurrences	Total mass of standing crop biomass (kg)
400	100	10,305	4.2×10^5
250	100	35,208	8.80×10^5
100	100	33,145	3.31×10^5
50	100	14,493	0.72×10^5
	Average biomass per hectare =		1.696×10^6 kg
	$\frac{1.696 \times 10^6 \text{ kg}}{936 \text{ ha}} = 1812$ kg/ha		

NW quarter section 22 (lightly grazed year long)			
Class biomass (g/m^2)	Average ground cell – area (m^2)	Number of occurrences	Total mass of standing crop biomass (kg)
400	100	116	4,640
250	100	661	16,525
100	100	4,018	40,180
50	100	3,188	15,940
	Average biomass per hectare =		77,285 kg
	$\frac{77{,}285 \text{ kg}}{65 \text{ ha}} = 1189$ kg/ha		

mapped in this single overflight for several pastures subjected to various grazing pressures and also for one specific pasture lightly grazed all year long was also generated by RECOG to present the image processing results to the range manager in a format more understandable and useful to him (Table 2).

SUMMARY

A simple hand-held multi-probe spectral radiometer was used to accurately estimate the biomass of a blue grama grass canopy using a double sampling procedure.

Automatic computer processing of aircraft multispectral imagery resulted in accurate estimations of shortgrass prairie biomass present at the time of overflight. A two-channel ratio and the multiple regression of all scanner channels resulted in the same correlation coefficient of 0.79 for 26 ground-truth biomass samples. Spectral matching, using ten channels of the multispectral scanner, resulted in a correlation coefficient of 0.98 for the same 26 ground-truth biomass samples.

Results indicate that image processing of multispectral scanner data can accurately assess the distribution of shortgrass prairie biomass. Factors limiting the accuracy of multispectral scanner biomass estimations resulted from the modest number of ground-truth clipped plots. An instrument such as the hand-held radiometer could be used to accurately measure many ground-truth points in a minimum of time thus adding greater statistical significance to the results of the image processing.

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REFERENCES

McNaughton, S. J. 1976. Serengeti migratory wildebeest: Facilitation of energy flow by grazing. *Science* 191 (4222):92-94.

Pearson, R. L., L. D. Miller, and C. J. Tucker. 1976. A hand-held spectral radiometer to estimate gramineous biomass. *Applied Optics* 15(2):416-418.

Smith, J. A., L. D. Miller, and T. D. Ellis. 1972. *Pattern recognition routines for graduate training in the automatic analysis of remote sensing imagery—RECOG.* Dep. Watershed Sci., Sci. Ser. 3A, Colorado State Univ., Fort Collins. 85 p.

Tucker, C. J., L. D. Miller, and R. L. Pearson. 1975. Shortgrass prairie spectral measurements. *Photogrammetric Engineering and Remote Sensing* 41(9): 1157-1162.

Wagner, T. W., and J. E. Colwell. 1969. *An investigation of grassland resources using multispectral processing and analysis techniques. Willow Run Laboratories, Rep. 34795-1-F. Univ. Michigan, Ann Arbor. 77 p.*