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Estimating Phytomass of Sagebrush Habitat Types from Microdensitometer Data

Microdensitometry of large scale color infrared photographs is used to estimate phytomass production of mule deer sagebrush steppe winter range in late summer.

Abstract: *Microdensitometry of large scale color infrared photographs was investigated as an indirect technique to estimate phytomass production of three sagebrush steppe,* Artemisia tridentata, *habitat types on a mule deer winter range. Inverse relationships between phytomass production and reflectance varied between habitat types. Red reflectance explained 59 and 56 percent of the variation in phytomass production for two habitat types. Spectral variables were highly correlated, resulting in band ratios that were relatively constant with little predictive ability. An inverse curvi-linear relationship for data of two habitat types explained 76 percent of the variance in phytomass production with a standard error of 15 percent of the mean. In an evaluation of the regression models, phytomass production was underestimated due to incomplete representation in the models of large reflectance values from bare soil. Regressions using integral density and exposure had residual variances similar to those obtained using reflectance as the independent variable.*

Introduction

The difficulty in estimating phytomass production of shrub dominated communities has been widely recognized (Amer. Soc. Agron., 1952; Driscoll, 1963; Mueggler and Stewart, 1980). Knowledge of the primary productivity of sagebrush steppe is needed to understand winter food ecology of wild ungulates (Wallmo *et al.*, 1977). Operationally, phytomass production estimates obtained in late summer can be used as an index to forage potentially available to wintering ungulates. This paper describes a pilot survey to determine if optical density measurements of large scale color infrared photography obtained in late summer could be used to develop regression models for estimating phytomass production of sagebrush steppe habitat types.

The method used to estimate phytomass is determined by the vegetation type, season of year, equipment, caliber of worker, time, and objectives of the investigation (Reppert *et al.*, 1963). Weight of

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clipped phytomass from quadrats of known area is the oldest and most direct measure of phytomass. Clipping is accurate if plot location and boundaries are unbiased, clipping height standards are well defined, species and parts of plants to be clipped can be identified, and care is taken during drying, weighing, and recording (Reppert *et al.*, 1963). Time requirements often limit the precision of phytomass estimates from clipping techniques.

Non-destructive techniques require less time, allowing more observations and generally an increase in precision, but they are subject to bias. To be useful, a technique must be well defined, unbiased, precise, and consistent. Examples of non-destructive techniques used to estimate sagebrush phytomass include ocular estimates (Wilm *et al.*, 1944), dimension analysis (Uresk *et al.*, 1973), and electronic capacitance meters (Carpenter *et al.*, 1973; Morris *et al.*, 1976). Such relationships often vary with phenology, site, and time, so double sampling is necessary to obtain accurate phytomass estimates from indirect measurements.

Large scale aerial photography has been demonstrated as a sampling tool for shrubland attributes such as coverage, density, and species identification (Carneggie and Reppert, 1969; Driscoll and Coleman, 1974). Success of range inventory using aerial photographs depends upon the plant community, size and structure of individual species, phenology of vegetation, film type used, scale, and quality of photography (Poulton *et al.*, 1975; Francis and Driscoll, 1976). Microdensitometry of 70-mm photography has been used as an indirect method for estimating many parameters in the plant and soil sciences. Examples include phytomass estimates of seeded and native grasslands (Driscoll *et al.*, 1972; Driscoll *et al.*, 1974), quantification of tree stress (Lillesand *et al.*, 1979), and soil moisture (Piech and Walker, 1974).

Three levels of refinement to initial integral density measurements are suggested as a means of accounting for sources of variability in dye densities. These refined spectral variables are (1) analytical densities (Scarpace and Friederichs, 1978), (2) exposure (Lillesand *et al.*, 1979), and (3) reflectance (Silvestro, 1969; Lillesand and Kiefer, 1979). Because techniques to derive these variables increase time and cost of analysis, the optimum variate for correlation with ground phenomena depends on relative increase in precision compared to relative cost of obtaining the variables.

The major objective of this research was to develop and evaluate regression models estimating phytomass production of sagebrush steppe habitat types using spectral reflectance variables from microdensitometry of large scale color infrared photographs and ground data. As an adjunct to this objective, we examined radiometric transformations to integral densities for predicting phytomass production of sagebrush steppe habitat types.

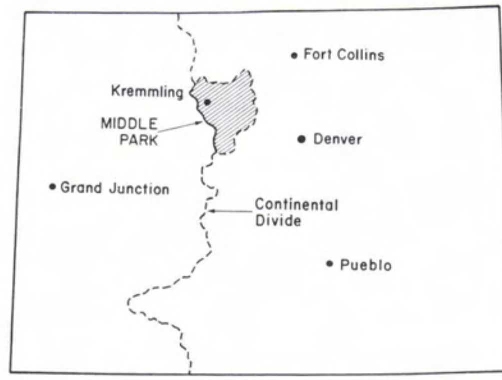

FIG. 1. Geographic location of Middle Park, Colorado.

STUDY AREA

Middle Park is a high mountain watershed located in north central Colorado approximately 160-km west of Denver (Figure 1). Vegetation and soils of the critical winter range for mule deer (approximately 5000 ha where deer are forced to concentrate in years of heavy snow accumulation) have been investigated (J. A. Tiedeman, unpublished data, 1978). Species coverage, phenology, and abiotic characteristics of range sites were the basis for classification of the rangeland by habitat types (Daubenmire, 1968).

Three habitat types representing a gradient of big sagebrush communities were investigated in this survey. The *Artemisia tridentata wyomingensis*/*Agropyron smithii* habitat type (ARTRWY/AGSM) is a climatic climax occurring on undulating terrace and plateau tops at elevations ranging from 2225 m to 2315 m. Most soils are represented by the Harsha series, a member of the fine-loamy, mixed family of Borollic Haplargids. *A. tridentata* subspecies *wyomingensis* (Wyoming big sagebrush) dominates the overstory. Important species include *Agropyron smithii* (western wheatgrass), *Chrysothamnus viscidiflorus* (Douglas rabbitbrush), *Poa secunda* (Sandberg bluegrass), *Sitanion hystrix* (bottlebrush squirreltail), *Phlox muscoides* (phlox), and *Penstemon caespitosus* (mat penstemon).

The *Artemisia tridentata wyomingensis*/*Agropyron spicatum* habitat type (ARTRWY/AGSP) is an edaphic climax occupying gravelly soils on sloping uplands, ridges, and gravelly outwash terraces at elevations from 2285 m to 2500 m. Most soils are represented by the Quander series, a member of the loamy-skeletal, mixed family of Argic Cryoborolls. Other important species besides Wyoming big sagebrush include Douglas rabbitbrush, *Koeleria cristata* (june grass), *Poa fendleriana* (mutton bluegrass), *Stipa* spp. (needlegrass), *Astragalus convallarius* (timber poison milkvetch), *Balsamorhiza sagittata* (arrowleaf balsamroot), and *Erigeron*. spp. (fleabane).

The *Artemisia tridentata vaseyana*/*Festuca ida-*

hoensis habitat type (ARTRVA/FEID) is a topographic climax occupying swales and shallow depth snow drift areas at low elevations but occurring on plateaus in deep soils as a climatic climax at higher elevations. Elevations for this habitat type range from 2345 m to 2680 m. The Leavitte series, a member of the fine-loamy, mixed family of Argic Cryoborolls is representative of most soils. *A. Tridentata* subspecies *vaseyana* (mountain big sagebrush) dominates the overstory. Important species in this community include Douglas rabbitbrush, *Symphoricarpos oreophilus* (mountain snowberry), *Carex* spp. (sedge), mutton bluegrass, *Lupinus* spp. (lupine), and *Phlox multiflora* (flowery phlox). *Erigonum umbellatum* (sulfur erigonum) assumes a large mat-like growth form uncommon to other big sagebrush habitat types.

Methods

Ground data

Phytomass of the three habitat types was estimated within seven days of photography. Phytomass was defined as annual growth incorporated into aerial parts (leaf, stem, seed, and associated organs) of a plant. Clipped phytomass was stored at room temperature for approximately two months, dried at 100° C for 24 hours in a forced-air oven, and weighed to the nearest 0.1 g.

Three 0.1-ha primary sample units (PSUs) (50- by 20-m) were located for each habitat type at range sites investigated by J. A. Tiedeman (personal communication). From a population of 24 transects spaced two metres apart, 14 sample transects were randomly selected. Twenty secondary sample units (SSUs) were systematically spaced along each transect. Phytomass was estimated in a double sampling method using a Neal Electronics capacitance meter (Model 18-1000)* (Neal and Neal, 1973). Three SSUs from each transect were randomly selected for clipping. This resulted in 42 clipped quadrats and 280 capacitance meter-estimated quadrats per PSU.

The electronic capacitance meter estimated phytomass in a hexahedron 30.5- by 61.0- by 45.7-cm in width, length, and height, respectively. After calibration, the meter was placed along the transect with corner probes of the meter making contact with the ground. A meter reading was then taken and recorded for total vegetation within the quadrat. For clipped quadrats, a 60-cm steel pin was placed at each corner of the meter and vegetation immediately outside the probes of the meter was removed. Phytomass within the hexahedron was then clipped and sacked.

* Use of trade and company names is for the benefit of reader; such use does not constitute an official endorsement by the authors' affiliations or by sponsors of this research.

Aerial photography

A twin-engine Aero Commander equipped with a Maurer 70-mm format camera, a 152-mm lens, and an intervalometer set for 60 to 70 percent overlap of photographic frames was used to obtain photography between 1100 and 1500 hours on 23 August 1979. Stereo photography was taken at an average speed of 160 km per hour at an altitude of 150 m above ground level. Aerochrome Infrared-Type 2443 film was exposed with a Wratten 12 yellow filter during good weather with few clouds.

Ground-to-photo control was established by flightline and PSU boundary markers, beginning and end markers for phytomass transects, and 6 grey scale panels. White, grey, and black reflectance calibration panels 61- by 61-cm in size were constructed. Two panels of each color were placed at each 0.1-ha PSU prior to photography.

To evaluate phytomass prediction equations developed from the 0.1-ha PSUs, aerial photographs were obtained at three 65-ha test areas consisting primarily of mixtures of the ARTRWY/AGSM and ARTRWY/AGSP habitat types. Four 2.2-ha sample units were randomly selected from each 65-ha test area, and prepared for aerial photography with flightline markers and grey scale panels. Phytomass of these 65-ha test areas was estimated in late July using an electronic capacitance meter (L. H. Carpenter, unpublished data). A systematic sample of 700 meter-estimated and 100 clipped and meter-estimated quadrats was taken at each 65-ha area.

Microdensitometry

A Perkin-Elmer Pds flatbed microdensitometer (Model 1010) was used to measure integral spectral densities at selected areas on the photographs. A circular aperture 400 μm in diameter used on photographs at a typical scale of 1:1200 represented a sampled area 48 cm in diameter on the ground. This aperture size approximates the quadrat size used to estimate phytomass on the ground and size of grey scale panels. Measurements were made with two narrow-band interference filters and one short-wavelength absorption filter to provide optical bandwidths of 0.420 to 0.443 μm (blue), 0.534 to 0.559 μm (green), and 0.640 to 0.680 μm (red). Filters isolated spectral regions of maximum absorption by yellow, magenta, and cyan dyes, respectively.

Photography of the nine 0.1-ha PSUs and 12 2.2-ha sample units required three rolls of film. A density step wedge was exposed on rolls one and two using a U.S. Forest Service sensitometer. On roll one, a density step wedge was exposed during processing by Precision Photo Laboratories. No step edge was available for roll three. Density measurements, centered in each step, were obtained for 17 steps of each step wedge. D-log E curves were constructed by pairing step wedge measurements with their respective relative log exposure values and fitting polynomial functions (Dana 1973).

Photography of 0.1-ha PSUs was viewed in stereo, and sample frames were chosen to locate phytomass transects and grey scale panels within the center one-third of the frame, thereby minimizing variation in densities due to the focal plane shutter and fall-off effects. Density measurements were systematically spaced every 400 μm along each transect. This resulted in 30 to 40 density measurements per transect, depending on scale of the 0.1-ha PSU. No phytomass transect markers were placed at the 65-ha test areas. Four scan lines approximating a ground distance of 30 m were systematically spaced within the center third of each photograph of the test areas. Density measurements were made of the same spatial locations along each transect for the three spectral filters. Integral spectral density measurements of each transect were averaged and converted to exposure using the appropriate D-log E curve.

Density measurements of the grey scale panels were repeated on two or three selected photographs for each sample unit. Reflectance of the panels was measured in the lab using a broad band (0.5 to 0.9 μm) radiometer. Panel reflectances were regressed against spectral exposure values of the panels for each PSU and 65-ha area to establish reflectance calibration equations. Using the appropriate equation and transect exposure values, estimates of spectral reflectance were obtained for each transect.

DATA ANALYSIS

Descriptive statistics for ground data were calculated following procedures for double sampling with regression estimators (Cochran, 1977, pp. 338-343). A regression equation predicting phytomass from capacitance was developed for each PSU. Phytomass for the nine 0.1-ha PSUs was estimated using the large sample of metered quadrats.

Coefficients of polynomial regressions for the D-log E curves were tested for significance using an F-test. D-log E curves from the U.S. Forest Service density step wedge were tested for coincidence between rolls of film (Zar, 1974, p. 234).

Integral density, exposure, and reflectance variables for the three spectral bands were paired with transect phytomass estimates to develop regression equations for the three habitat types. Band ratios and band difference ratios were also used to develop phytomass prediction equations. Coefficients of linear and polynomial models were tested for significance using an F-test. Ability of spectral bands and photographic variables to predict phytomass was compared using Bartlett's test for homogeneity of residual variances.

Phytomass prediction equations developed from the 0.1-ha PSUs were evaluated using measurements of red reflectance and ground phytomass estimates for the three 65-ha test areas. Mean estimates of phytomass predicted from red reflectance and from ground measurements were calculated for each 65-ha test area. The two mean phytomass estimates for each 65-ha area were tested for significant differences.

RESULTS AND DISCUSSION

GROUND DATA

Phytomass of the nine 0.1-ha PSUs was estimated with high precision using the capacitance meter in a double sampling method with clipped plots (Table 1). Differences in sample sizes between PSUs are due to elimination of outliers identified by notes taken during sampling and by large standardized residuals. Graphics of residuals plotted against meter estimates supported assumptions of linear regression.

MICRODENSITOMETRY

No part of PSU 5 and only 40 percent of PSU 8 (representative of the ARTRWY/AGSP and ARTRVA/FEID habitat types, respectively) were covered by photography despite use of flightline markers as guides to the pilot and photographer. Weathering of flightline markers during photo mission delays accounted for the omissions. Therefore, these two 0.1-ha PSUs were not used in the analysis.

The limited range of transect densities and panel densities required fitting only a portion of the D-log E curve for each dye layer. Comparison of D-log E curves from the U.S. Forest Service density step wedge on film rolls one and two indicated equality of third order polynomials between rolls for each spectral band ($P > 0.25$). Because roll three had no step wedge, statistical tests could not be conducted, and it was assumed roll three had D-log E curves similar to rolls one and two. Relationships between reflectance and film exposure (calibration curves) varied temporally and spatially between PSUs. This was attributed to variation in scene irradiance or camera settings, although illumination angle and surface texture effects may have contributed some variability.

Inverse linear relationships were found between phytomass and reflectance for the ARTRWY/AGSM and ARTRVA/FEID habitat types (Table 2). Correlation coefficients for all spectral variables were highly significant ($P < 0.01$); however, red reflectance accounted for only 56 percent and 59 percent of the variation in phytomass for the ARTRWY/AGSM and ARTRVA/FEID habitat types, respectively. Failure of data for the ARTRWY/AGSP habitat type to show a trend in the relationship of reflectance with phytomass is probably due to the small range in reflectance. Strong positive correlations between spectral bands, $r > 0.96$, resulted in no significant differences ($P > 0.50$) in residual variances between spec-

TABLE 1. PHYTOMASS MEANS (g/m²), STANDARD ERRORS, SAMPLE SIZES, AND COEFFICIENTS OF DETERMINATION FROM RELATIONSHIPS OF PHYTOMASS AND CAPACITANCE FOR NINE 0.1-ha PRIMARY SAMPLE UNITS REPRESENTATIVE OF THREE BIG SAGEBRUSH HABITAT TYPES.

Habitat Type	Primary Sample Unit	Phytomass Mean $\bar{y}$	Standard Error $S(\bar{y}_{1r})$	Sample Size$_a$ n	n'	Coefficient of Determination R^2
	1	95.3	5.9	41	279	0.81
ARTRWY/AGSM	2	106.0	4.8	41	279	0.90
	3	109.8	5.4	42	280	0.87
	4	89.9	5.4	42	280	0.80
ARTRWY/AGSP	5	92.6	7.5	42	280	0.81
	6	91.0	4.8	42	280	0.88
	7	122.7	4.8	42	280	0.86
ARTRVA/FEID	8	129.2	6.5	40	278	0.77
	9	162.0	7.5	42	280	0.68

a_n = clipped samples, n' = metered samples

tral band predictions of phytomass within any habitat type. Band ratios of spectal reflectance were relatively constant and had little correlation with phytomass. Similarity in spectral reflectance between soil and vegetation components of sagebrush steppe in late summer, i.e., lack of "greenness," and overlapping dye layer sensititives could explain the poor predictive ability of reflectance ratios.

The ARTRWY/AGSP habitat type had phytomass values similar to the ARTRWY/AGSM habitat type, but reflectance values were generally lower (Figure 2). Piech and Walker (1974) demonstrated that reflectance of soils is inversely related to particle size. Assuming equal soil moisture, reflectance from coarse gravel on the soil surface of the ARTRWY/AGSP habitat type would be less than reflectance from the fine-textured soil surface of the ARTRWY/AGSM habitat type. The low reflectance of the ARTRWY/AGSP habitat type may also be the result of differences in composition of total phytomass and canopy coverage by vegetation life forms (Strong, 1980). Low reflectance of the ARTRVA/FEID habitat type resulted from greater vegetation coverage, greater shrub height, and shadow.

Combining data for the ARTRWY/AGSM and ARTRVA/FEID habitat types, the relationship between reflectance and phytomass is curvilinear (circles and squares of Figure 2). Coefficients of cubic polynomial regressions were highly significant, with red reflectance explaining 76 percent of the variation in phytomass. The standard error of the polynomial fit was 16.3 g/m². All spectral variables appeared asymptotic at high phytomass levels. Colwell (1974) and Vinogradov (1969), working in grasslands, concluded that the asymptotic nature of visible spectral bands is due to increases in shadow with increases in percent vegetation coverage. Asymptotic spectral reflectance is also a function of

TABLE 2. CORRELATION COEFFICIENTS, STANDARD ERRORS (g/m²), AND SAMPLE SIZES BY HABITAT TYPE FOR LINEAR REGRESSIONS PREDICTING PHYTOMASS PRODUCTION FROM REFLECTANCE, FILM EXPOSURE, AND INTEGRAL DENSITY SPECTRAL VARIABLES.

Habitat Type	Sample Size	Photographic Variable	Green 0.5 − 0.6 μm r	Green SE	Red 0.6 − 0.7 μm r	Red SE	Infrared 0.7 − 0.9 μm r	Infrared SE
ARTRWY/AGSM	42	Reflectance	−0.69	12.9	−0.75	11.9	−0.73	12.3
		Exposure	−0.60	14.3	−0.61	14.2	−0.56	14.8
		Density	0.53	15.9	0.55	15.0	0.51	15.4
ARTRWY/AGSP	28	Reflectance	−0.16	14.7	−0.29	14.3	−0.11	14.8
		Exposure	0.16	14.7	0.14	14.7	0.16	14.7
		Density	−0.12	14.8	−0.09	14.8	−0.11	14.8
ARTRVA/FEID	28	Reflectance	−0.74	23.2	−0.77	22.2	−0.69	25.2
		Exposure	−0.70	24.7	−0.75	22.8	−0.68	25.4
		Density	0.81	20.2	0.79	21.2	0.70	24.7

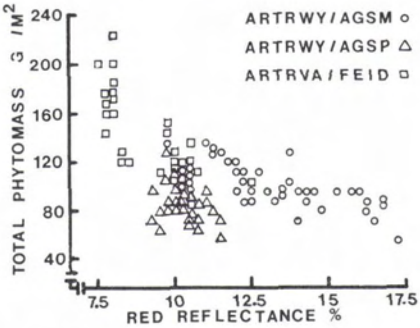

FIG. 2. Relationship of red reflectance and phytomass for sagebrush steppe habitat types.

leaf density and leaf physiological state (Gausman *et al.*, 1976). Tucker (1977) found reflectance in the near infrared was asymptotic at three times the grass phytomass at which asymptotic reflectance occurred in the visible spectral region. Near infrared reflectance was more variable than reflectance in the visible bands at high phytomass levels.

Regression equations predicting phytomass from red reflectance were evaluated with photographs and phytomass measurements for three 65-ha test areas of Wyoming big sagebrush. Regression equations evaluated were the linear equation for the ARTRWY/AGSM habitat type and the polynomial equation for the combined data of the ARTRWY/AGSM and ARTRVA/FEID habitat types. Phytomass estimates from ground measurements and predicted from red reflectance are presented in Table 3. Phytomass was underestimated by both models compared to ground phytomass measurements, but differences were not significant for two of the three test areas ($P > 0.05$). Ground phytomass measurements had greater precision than phytomass estimates predicted from red reflectance. The linear model from the ARTRWY/AGSM habitat type performed better than the polynomial model for the ARTRWY/AGSM and ARTRVA/FEID habitat types. The polynomial model intercepted the x-axis at lower reflectance than did the linear model. Therefore, the former model predicted negative phytomass at large reflectance values.

Range in reflectance for the twelve 2.2-ha sample units exceeded the range in reflectance from the 0.1-ha PSUs used to construct phytomass estimation models (Table 4). The reflectance range for area B more nearly matched the reflective range of transects used for development of the models. Area B had less bare ground compared to areas A and C. Therefore, the most accurate prediction of phytomass was expected to occur on area B rather than on area A as Table 3 depicts. This result may be due to differences in sampling and date of sampling between aerial photography and use of the electronic capacitance meter.

Phytomass was modeled by the reflectance variable because of its greater physical meaning in explaining both changes in irradiance during photography and film processing variations. Empirical results using film exposure and integral density to predict phytomass were similar to those of reflectance and phytomass (Table 2); significant linear relationships were found for the ARTRWY/AGSM and ARTRVA/FEID habitat types. Spectral bands had strong positive correlations, resulting in relatively constant spectral ratios with little predictive ability. Correlation of phytomass to exposure and integral density for the ARTRWY/AGSP habitat type was poor.

Although standard errors of phytomass estimates for the ARTRWY/AGSM habitat type progressively increase going from reflectance to exposure to integral density as the independent variable, no significant differences ($P > 0.25$) were detected between residual variances. Similarly, standard errors of phytomass estimates for the ARTRVA/FEID habitat type were not significantly different ($P > 0.50$); however, their rank order was not expected. Integral density had a lower residual variance than either reflectance or exposure as a result of transformation of integral density to relative exposure and relative exposure to reflectance.

CONCLUSIONS

Given a sufficient range in reflectance, useful cor-

TABLE 3. COMPARISON OF PHYTOMASS ESTIMATES (g/m²) FOR THREE 65-ha AREAS DOMINATED BY WYOMING BIG SAGEBRUSH FROM GROUND MEASUREMENTS AND PREDICTED USING RED REFLECTANCE LINEAR AND POLYNOMIAL MODELS.

Test Area	Ground Measurements		Red Reflectance: Linear Model[a]		Red Reflectance: Polynomial Model[b]	
	$\bar{x}$	95% CI	$\bar{x}$	95% CI	$\bar{x}$	95% CI
A	82.8	75.3 – 90.3	75.3	49.9 – 100.7	---[c]	---
B	137.7	127.4 – 147.3	104.8	80.5 – 128.8	103.4	70.8 – 136.0
C	132.3	122.7 – 141.9	89.9	65.3 – 114.5	---	---

[a] Data of the *Artemisia tridentata wyomingensis*/*Agropyron smithii* habitat type.
[b] Combined data of the *Artemisia tridentata wyomingensis*/*Agropyron smithii* and *Artemisia tridentata vaseyana*/*Festuca idahoensis* habitat types.
[c] Phytomass estimates are not presented because model predicted negative phytomass at reflectance values ≥20%.

TABLE 4. MEANS, STANDARD DEVIATIONS, AND RANGES IN RED REFLECTANCE (%) FOR TRANSECTS OF LINEAR AND POLYNOMIAL MODELS FROM TWO HABITAT TYPES AND THREE 65-ha AREAS DOMINATED BY WYOMING BIG SAGEBRUSH.

Data Set	$\bar{x}$	sd	n	Range	Min.	Max.
ARTRWY/AGSM	13.1	2.1	42	7.6	9.7	17.3
ARTRWY/AGSM & ARTRVA/FEID	11.5	2.7	70	9.7	7.6	17.3
AREA A	17.3	5.6	355	28.4	10.1	38.5
AREA B	12.6	1.7	367	10.0	8.4	18.4
AREA C	15.0	4.0	365	17.4	9.0	26.4

relations, $r > 0.75$, can be obtained between photographic variables and phytomass of sagebrush steppe habitat types. Relationships of phytomass and reflectance are habitat type dependent with reflectance values obtained in a remote sensing application being the integration of reflectance from vegetation, soils, shadow, and atmosphere. Phytomass estimation models developed from the seven 0.1-ha PSUs failed to represent the entire range in reflectance experienced for the larger test areas of Wyoming big sagebrush. Given this shortcoming of the modeling process, predicted phytomass estimates for the areas dominated by Wyoming big sagebrush are encouraging. Phytomass predictions for the 65-ha areas may have been improved if analyst discretion had been used to locate microdensitometer scan lines to avoid areas composed primarily of bare soil. Large areas of bare soil not represented within the 0.1-ha PSUs were included within the 2.2-ha sample units by the undiscriminating systematic procedure of locating four scan lines within the center third of each photograph. In an operational inventory of sagebrush steppe phytomass, larger PSUs would be selected from strata developed from Landsat MSS, Thematic Mapper, or aerial photography (Strahler, 1981), and such regression scale problems would be minimized. Double sampling aerial photographs with ground data would be required to obtain phytomass estimates.

Several questions remain regarding the most efficient remote sensing procedures and independent variables for predicting phytomass of sagebrush steppe habitat types. Would spectral variables be less collinear and correlations with phytomass be greater if analytical densities had been derived? If photography had been obtained over different dates—presumably with greater variability in irradiance during photography, and with different film processing—would the precision of phytomass estimates be significantly improved using reflectance and exposure transformations rather than integral densities? How do the relationships of phytomass and reflectance vary with phenology and scale of photography?

Knowledge of total phytomass available in late summer does not satisfy all the natural resource manager's needs. Estimates of the composition of total phytomass by life forms, species, and even plant parts allows the manager considerably more precision in his decisions. A natural resource manager also needs to understand how availability of phytomass changes with progression of winter due to accumulation of snow and concentration of animals (Carpenter *et al.*, 1979). The frequency of phytomass inventories and/or monitoring will be determined by management objectives. Given just a few of the demands upon the natural resource manager's time, inventory techniques combining remote sensing and ground data would appear to be a practical method to accomplish phytomass inventories for mule deer winter ranges in sagebrush steppe.

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