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Seasonal Changes in Reflectance and Standing Crop Biomass in Three Salt Marsh Communities[1]

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ABSTRACT

Reflectance of red (656–705 nm) and infrared (776–826 nm) solar radiation and standing crop biomass were measured in three salt marsh communities at intervals of approximately 2 weeks between February and August 1974. Red reflectance declined at the onset of greening in each community and was correlated with standing crop of green biomass. Infrared reflectance increased substantially in the shrub community but less in the grass and sedge communities. The inverse of red reflectance was found to be a reliable predictor of green biomass in sedge and grass communities, but not in a shrub community.

Solar radiation that penetrates the epidermis of leaves is strongly scattered and, if not absorbed by water or the pigments associated with photosynthesis, emerges about equally from both surfaces (7-9). For most green leaves, reflectance of solar radiation is weak in the red region (656-705 nm), because of absorption by Chl, but strong in the IR region (776-826 nm) because absorption is low. In principle, reflection of red and IR from plant canopies is similar to reflection from single leaves but complicated by background, angle of incidence, biomass, and canopy structure. Measurements of canopy reflectance in prairie grass show that reflectance of solar radiation declines in the red region and increases in the IR region as the community changes from brown in the spring before greening to full growth in summer (9). Similar results were also obtained with sorghum, wheat, and soybeans (6), and in some forest communities (2).

In order to investigate the extent to which patterns of seasonal change in reflectance of red and IR can be related to changes in community biomass, I have studied three communities having similar total biomass, but different structure. For convenience, each is characterized here as being either a shrub, sedge, or grass community. All three are commonly found in brackish salt marshes on the East Coast of the U.S. The shrub community is dominated by *Iva frutescens;* 65% of the green biomass in this community is in the herbaceous portion of the shrub with the remaining 35% in grasses and sedge that are the ground cover. The grass community is a mixture of *Spartina patens* and *Distichlis spicata*. These two grasses have nearly identical growth form, are virtually the only species in this community, and are present in about equal amounts, on the average. The sedge community is a mixture of approximately 50% biomass in the sedge, *Scirpus olneyi,* with the remainder made up of the two grasses named above.

METHODS

Reflectance was measured with a portable, battery-operated radiometer (Tektronics J-16) equipped with two silicon photodiodes and interference filters (Corion). The filter on the red sensor had peak transmission at 666 nm and 92% of total transmission between 656 and 705 nm. The IR filter had peak transmission at 792 nm with 93% transmission between 776 and 826 nm. The interference filters were mounted between the sensor and a collimator that permitted at 15° field of view. Calibration with an incandescent standard lamp as source gave constants of 2.63×10^{-3} μw/cm^2 and scale division for the red sensor and 2.43×10^{-3} μw/cm^2 and scale division for the IR sensor. Errors due to nonlinearity within the lower 5% of sensitivity in the digital radiometer as well as temperature sensitivity of the silicon sensor were estimated to be less than 10% and since data presented here are relative, the error will be even smaller. Reflectance is defined in this paper as the ratio of the radiance of vegetation to the radiance of a white plate suspended beneath the sensor. The white paint (Duron No. 17006) used on the plate had a spectral reflectance of 84 to 85% of white light. No distinction is made between that portion of the radiance of the vegetation that is reflected from the surface of leaves or other plant parts and that portion that penetrates the plant and re-emerges as a result of back scattering. It is believed that most of the radiant energy returned from a leaf toward the source results from scattering within the leaf and not from the surface (3, 7). The sensors were mounted on an aluminum rod so that they could be held above the vegetation and allowed to view it from a distance of 1.5 to 2 m. The field of view at this distance was 0.13 to 0.23 m^2. Preliminary experiments showed that reflectance was little affected as irradiance changed through the upper 80% of maximum solar irradiance; however, reflectance increased as solar elevations decreased to less than 40°. In order to insure that both solar angle and irradiance were high, measurements of reflectance were made between 10:00 a.m. and 2:00 p.m. on clear days. Data were also taken on overcast days, but were not used unless radiation measured from the white plate varied less than 5% before and after a series of 10 measurements of radiation from the vegetation. It took approximately 3 min to make 10 measurements. No attempt was made to convert the relative values reported here to values of total reflectance.

Standing crop biomass was determined as follows. Circular hoops, 1/2 square meter area for the shrub and 1/4 square meter area for the sedge and grass, were tossed into the stand to be sampled. All plant matter within the hoop was clipped to the surface of the marsh. The green and brown plant material and major species were separated, dried in a forced air oven at 65 C for 3 days, and weighed. In the shrub community, the green herbaceous parts of the shrub and the total underlying cover were harvested.

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RESULTS

Green, dead, and total biomass, red reflectance, and IR reflectance for three communities are plotted against sampling date in Figure 1. Results presented here are for 7 months, February to August, 1974.

Dead biomass declined from February through June. During this period, loss of carbon (dry matter × 0.47) was approximately 3.1 g carbon/meter square/day (g Cm^{-2} d^{-1}) in the grass community, 1.4 g Cm^{-2} d^{-1} in the sedge community, and 1.1 g Cm^{-2} d^{-1} in the shrub community.

Green biomass began to increase in all communities during May, so that total biomass (green plus dead) stopped declining and began to increase in May for the sedge and shrub and in mid-June for the grass.

The change in IR-reflectance from lowest values during winter to highest values in summer began to occur in each community at about the time total biomass ceased to decline and began to increase. This change in both total biomass and IR reflectance occurred simultaneously in each community, but the date of this occurrence was different for each community; in the grass, it was mid-June; in the sedge, it was early June; and in the shrub, it was mid-April.

There is an apparent relationship between total biomass in each community and the level of IR reflectance. In winter, IR reflectance was approximately 0.22 for the sedge and grass communities. Total biomass was approximately 1,000 g dry weight in the grass, and 800 g dry weight in the sedge. In the shrub community, IR reflectance was 0.15 during winter, and total biomass was approximately 400 g dry weight.

At the onset of growth, mid-April to early May, depending on the community, red reflectance declined abruptly and continued to decrease until the first of June in the shrub and until the first of July in the grass and sedge. The initial decline in red reflectance stopped in all communities before the peak of growth was achieved.

The level of red reflectance during the first 3 months of the year and the magnitude of the change during the season were different for each community type. Initially, red reflectance was approximately 0.12 for the shrub, 0.18 for the grass mixture, and 0.20 for the sedge. The seasonal change in red reflectance, computed by subtracting the mean value before growth began from the mean value at peak of growth, was approximately 0.07 reflectance units in the shrub, 0.12 units in the grass, and 0.16 units for the sedge. Thus, the change in red reflectance measured for the shrub was about one-half that measured for the sedge and grass communities.

The decline in red reflectance was associated with an increase in green community biomass, but the increase in IR reflectance seemed to be related to total community biomass; however, regressions computed on the means of reflectance against the means for total, green, and dead community biomass yielded low values for the correlation between biomass and IR reflectance. These regressions and their relevant statistical parameters are summarized in Table I. The highest values of r^2 were found for the relationship between green standing crop biomass and inverse of red reflectance, and they are consistently high for all three communities: 0.70 for the shrub, 0.82 for sedge, and 0.86 for grass.

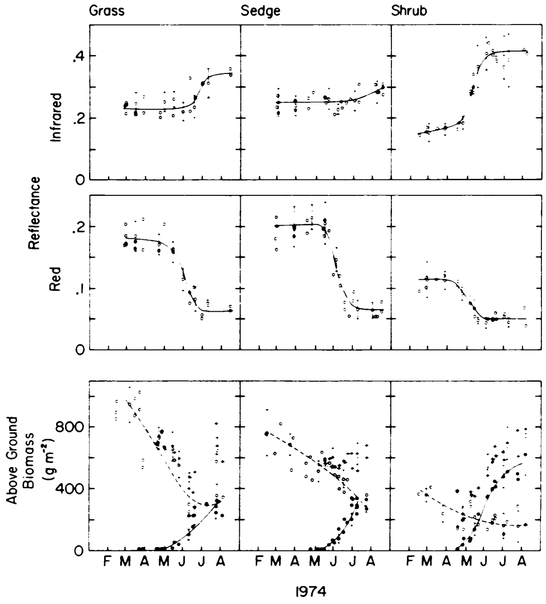

FIG. 1. Reflectance of red (656–705 nm) and IR (776–826 nm) and standing crop biomass in three salt marsh communities. Reflectance data are means and selected standard deviations of 10 random measurements in each community. Biomass data are means and selected standard deviations of dry weight of five samples that were separated into green biomass (●) (——); dead biomass (○) (- - -); and total biomass (+) (· · ·).

Table I. *Best Fit Power Functions of the Form log y = log a + x log b for Correlation between Standing Crop Biomass and Reflectance in Three Communities for the Period April to August 1974*

Data for these correlations were means of five measurements of biomass selected at random in a community against means of 10 random measurements of reflectance.

Community Type	y (Reflectance)	x (Biomass)	a	b	*N*	*r*	r^2
Grass	Red^{-1}	Green	5.5	1.004	9	+0.93	0.86
		Dead	14.7	.999	12	−0.81	0.66
		Total	16.9	.999	12	−0.59	0.35
	IR	Green	.23	1.001	9	+0.63	0.40
		Dead	.29	1.000	12	−0.50	0.25
		Total	.29	1.000	12	−0.30	0.09
Sedge	Red^{-1}	Green	5.4	1.004	14	+0.91	0.82
		Dead	32.8	.997	21	−0.89	0.79
		Total	25.6	.998	21	−0.33	0.11
	IR	Green	.26	1.000	14	+0.02	0.00
		Dead	.22	1.000	21	+0.34	0.12
		Total	.16	1.001	21	+0.55	0.30
Shrub	Red^{-1}	Green	11.2	1.001	14	+0.84	0.70
		Dead	25.4	.997	16	−0.51	0.26
		Total	7.0	1.002	16	+0.82	0.67
	IR	Green	.21	1.002	15	+0.88	0.77
		Dead	.56	.997	17	−0.60	0.37
		Total	.13	1.002	17	+0.81	0.66

The relationship between standing crop of green biomass and red reflectance was studied further. Within a stand of one of the three communities studied, green biomass and reflectance were measured on each of five quadrats selected at random. In the same stand, reflectance was measured on 10 additional quadrats, selected at random. This procedure was repeated in all three communities and paired values of reflectance and biomass data from the five quadrats were used to construct regressions (Fig. 2). The correlation of red reflectance with green biomass was high for the sedge (r^2 = 0.83) and grass (r^2 = 0.74), and very poor for the shrub community (r^2 = 0.19), even though the regression of means of community reflectance onto the means of community biomass was high (Table I). Each of the 10 random measurements of reflectance for a given community was converted to biomass using the regression equation from Figure 2. This estimated biomass was then plotted opposite the date when the reflectance used to compute it was measured (Fig. 3). Green biomass, measured by clipping, is also plotted against the collecting date in Figure 3. Polynomial regression equations were computed and plotted through clipping data. Agreement between the two sets of data was very good in the two communities.

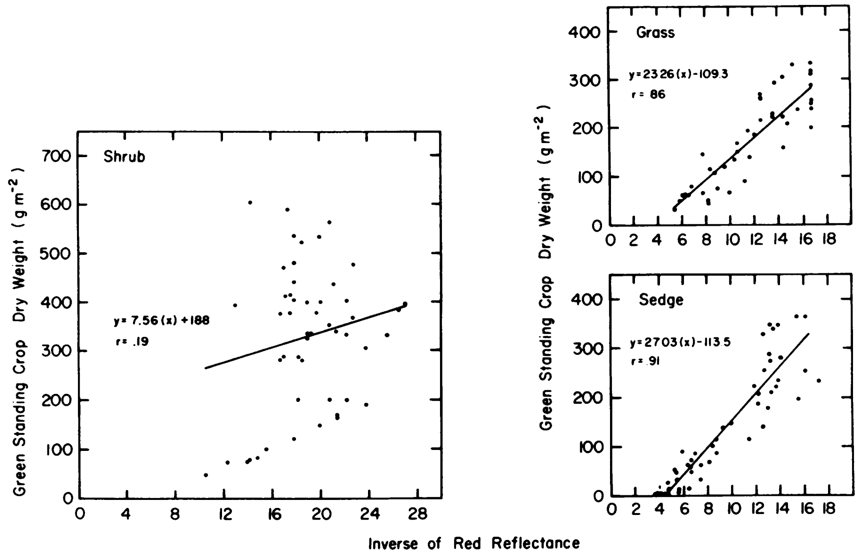

FIG. 2. Green standing crop biomass in three salt marsh communities as a function of inverse of red reflectance. Data are inverse of red reflectance and dry weight of the same quadrat selected at random within each community.

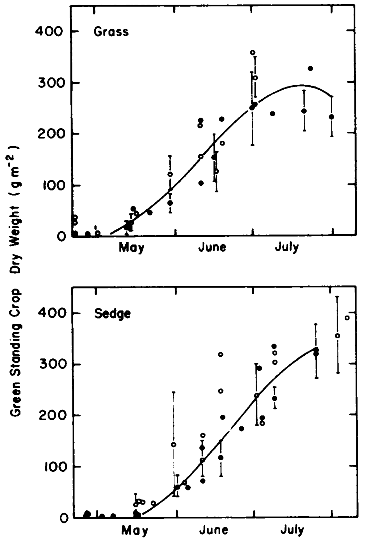

FIG. 3. Seasonal change in standing crop of green biomass estimated by reflectance (○), and clipping (●). The solid line is a third order polynomial regression through the clipping data. Biomass data are means and representative standard deviations of five samples of green biomass randomly selected. Biomass estimated from reflectance was computed using the linear regressions from Figure 2 and 10 measurements of reflectance selected independent of the biomass samples.

DISCUSSION

There is a relationship between standing crop of green biomass and the inverse of red (656–705 nm) reflectance in the three communities studied here. In the spring at the outset of greening, red reflectance declined abruptly (Fig. 1). The correlation between biomass and reflectance is strong enough in two of the communities studied, namely, the grass and sedge community (Fig. 2), that reflectance can be used to predict the seasonal changes in community green biomass nearly as well as did clipping for the first half of the growing season (Fig. 3). Other data (unpublished) show that the method works as well in the last half of the growing season as during the first half.

There have been many efforts to develop nondestructive methods for estimating productivity as an alternative to harvesting above ground community biomass (see ref. 9 for a review). Most of the techniques that have been tried have limited usefulness because of some major drawback such as low accuracy, high cost in manpower, or the usual problems and restrictions associated with the field use of radioactive compounds. Photographic methods have been found to be useful for identifying and classifying vegetation types, but lack sensitivity to changes in biomass (5). Variations in pigment density between batches of film probably result in enough loss of sensitivity that the seasonal changes in red reflectance reported here could not be detected accurately. Furthermore, false IR type film and Ektachrome are sensitive to both the red and IR. Reflectance of IR is greater and undergoes more change throughout the season than does red reflectance. Therefore, in spite of the fact that increased Chl concentration in cotton leaves produced a darker image on Ektachrome IR film (4), seasonal changes in IR reflectance would probably have the greater effect in color density on IR-type film. Data reported here (Table I) show that IR reflectance is not a good indicator of green biomass except in shrub communities.

The grass and sedge communities studied here underwent less change in total community biomass throughout the season than the shrub community (Fig. 1) and probably little change in the number of leaf lamina/unit dry weight of biomass. In these two communities, old growth from the previous season decayed as it was replaced by new growth. The shrub community had a different structure and the number of leaf lamina in a vertical section underwent great change throughout the season. Coefficients of determination for the regression of IR reflectance on total biomass are 0.77 for the shrub, 0.40 for the grass, and 0.0 for the sedge (Table I). Allen and Richardson (1) found that as the number of cotton leaf lamina increased from two to eight, IR reflectance increased from 63 to 80%.

Kanemasu (6) found that leaf area index was highly correlated with IR reflectance (710–790 nm) in soybeans and sorghum but not in wheat; coefficients of determination were 0.96, 0.76, and 0.41, respectivley. Belov and Artsybashev (2) reported that IR reflectance (700–770 nm) showed a greater absolute seasonal change than reflectance in any region of the visible spectrum. Reflectance from forest communities during summer could be arranged in order of greatest to least reflectance as follows: aspen > birch > pine > spruce (2). Canopy reflectance for these four species in all regions of the solar spectrum studied was on the average one-half of the value of reflectance from individual branches or leaves (2).

The changes in IR reflectance observed in this study were probably not related to the relative water content of leaves in the communities studied. Reflectance of IR did not increase in single leaves until the leaf had dried below the wilting point (10, 11). There were no visible signs of wilting noted throughout the course of this study, and it is not likely that the salt marshes studied here experienced water stress to the extent required to effect increases in IR reflectance. Also, it is difficult to imagine how this mechanism would account for large seasonal changes in IR reflectance in the shrub community but not in sedge and grass.

However unlikely it may be that reduced leaf water content can account for differences in IR reflectance between the communities studied, it is possible that differences in IR reflectance of the magnitude reported here, 0.15 units between the shrub and sedge communities, may have consequences for the water balance of these plants. Assuming that this difference in reflectance is uniform for the region 700 to 1200 nm (which includes approximately 35% of the total incoming radiation), and that 80% of the remaining portion of the solar radiation is absorbed, then a rough estimate of the difference in total radiation absorbed by each of the two communities is approximately 10% more solar radiation absorbed by the sedge than the shrub community. The energy for evapotranspiration arises from the sum of the radiation balance and the heat gained or lost by convection. If the convection component is about equal for both communities, then the sedge community will use about 10% more water than the shrub community on the average.

Some workers (6, 9) have attempted to compare community biomass and a ratio of the radiance from the vegetation for a region of the spectrum that is reflected strongly to the radiance from the vegetation in a portion of the spectrum that is reflected weakly, for example, IR to red (6, 9). Measurement of the ratio of radiances is less complicated than measurement of reflectance because it eliminates the need for data on incoming radiation; however, an additional complication is added to this approach by the uncertainty as to the contribution of each region to the value of the ratio. The assumption that reflectance of one region of the spectrum remains constant while the other varies regularly with changes in biomass does not hold for the three communities in this study (Fig. 1). In Pearson's work, the ratio of IR to red was used, and very high correlation with green biomass was found. The relationship was linear only when green biomass was less than approximately 350 g dry weight per square meter. Kanemasu (6) found high correlation between the ratio of green (527-563 nm) to red (663-678 nm) and leaf area index in wheat, sorghum, and soybean, all of which were virtually 100% green biomass. When a large portion of the total biomass of the community is dead, as in the three individual communities in this study, the reflectance ratio of red and IR does not correlate with biomass as well as does red reflectance alone.

An abrupt decline in red reflectance was found in all three communities at the onset of greening in the spring. Regressions of inverse of red reflectance on green biomass had coefficients of determination that were consistently high in all three communities (Table I). Pearson (9) also found a strong negative correlation between dry weight of green biomass and red reflectance.

Correlations between paired measurements of green biomass and inverse of red reflectance are sufficiently high in the grass and sedge that they may be used to predict seasonal changes in community green biomass (Fig. 2). In the shrub, however, correlation is poor and prediction of biomass from red reflectance could not be made (Fig. 2). Community growth curves for the sedge and grass from clipping measurements of green biomass are shown in Figure 3. Also shown are estimates of green biomass from red reflectance measurements. It is not clear whether the poor correspondence between standing crop of green biomass and red reflectance in the shrub community (Fig. 2) is due to lack of correspondence between these parameters in communities having this type of architecture, or due to our method for measuring reflectance. The viewing angle of the radiometer (15°) may not have been sufficient to include a sampling area representative of the portion of the community harvested. The surface of the shrub community as viewed by the radiometer is probably more irregular than that of the sedge and grass communities.

Results obtained in this study and in two others (6, 9) strongly suggest that reflectance of the red region of solar radiation may be used to predict total green biomass in grass communities. If calibration techniques can be developed, then the use of reflectance for studies of productivity has much to recommend it: compared to other methods it is relatively cheap, simple to construct and use, requires little manpower, and permits studies of productivity in regions where collecting and drying would be difficult or where destruction of the community must be avoided.

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LITERATURE CITED

1. Allen, W. A. and A. J. Richardson. 1958. Interaction of light with a plant canopy. J. Opt. Soc. Am. 58(8): 1023-1028.
2. Belov, S. V. and E. S. Artsybashev. 1957. A study of reflecting properties of Arboreal species (Russian). Bot. Zhur. 42(4): 517-534.
3. Gates, D. M., H. J. Keegan, J. E. Schlefer, and V. R. Weidner. 1965. Spectral properties of plants. Appl. Opt. 4: 11-20.
4. Gausman, H. W., W. A. Allen, R. Cardenas, and R. L. Bowen. 1970. Color photos, cotton leaves, and soil salinity. Photogram. Eng. 36(5): 454-459.
5. Hoffer, R. M. and C. J. Johannsen. 1969. Ecological potentials in spectral signature analysis. *In:* P. Johnson, ed., Remote Sensing in Ecology. University of Georgia Press, Athens.
6. Kanemasu, E. T. 1974. Seasonal canopy reflectance patterns of wheat, sorghum, and soybean. Rem. Sens. Evn. 3: 43-47.
7. Knipling, E. B. 1970. Physical and physiological basis for the reflectance of visible and near-infrared radiation from vegetation. Rem. Sens. Evn. 1: 155-159.
8. Mestre, H. 1935. The absorption of radiation by leaves and algae. Cold Spring Harbor Symp. Quant. Biol. 8: 191-205.
9. Pearson, R. L. 1973. Remote multispectral sensing of biomass. Ph.D. thesis. Colorado State Univ.
10. Sinclair, T. R. 1968. Pathway of solar radiation through leaves. M.S. thesis. Purdue Univ.
11. Thomas, J. R., V. I. Myers, and C. L. Weigand. 1966. Factors affecting light reflectance of cotton. Proc. 4th Symp. Rem. Sens. Env., Univ. Mich. Ist Rep. No. 4864-11-x. pp. 305-312.