(NASA-CR-158618) FEASIBILITY OF REMOTE SENSING BENTHIC MICROALGAE Final Report (South Carolina Univ.) 36 p HC A03/MF A01 CSCL 08A

N79-24418

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G3/43 20901

FEASIBILITY OF REMOTE SENSING BENTHIC MICROALGAE

A Final Report of NASA Grant No. NSG-1523

by

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INTRODUCTION

Results of previous NASA support showed that multispectral scanning technology was capable of measuring the concentration of chlorophyll in benthic microalgae (mainly diatoms) on an estuarine mudflat (c.f. Final Report of NASA Grant No. NSG-1334, 1978). Modest support was requested in FY 79 to conclude work initiated in NSG-1334. Specifically, we needed additional time to 1. analyze further the large volume of data that we had accumulated on magnetic tape; and 2. to communicate the results of our research to the scientific community.

DATA ANALYSES

The data we collected in July 77 was initially very puzzling, as the correlation coefficients between the ground truth and the scanner derived data were disturbingly low (Table 1). We determined the cause of the poor correlations through an in-depth analysis of the data.

An intertidal estuarine mudflat is not uniformly flat. Rather, such muflats are alternately covered and uncovered with flowing tidal water twice each day in southeastern estuaries. The movement of the ebbing tide tends to form small, anastimosing rivulets that get larger as they approach the center of the mudflat. These rivulets lie between slightly elevated ridges. Collectively, the ridges and rivulets form a topographically complex surface in contrast to the relatively uniformly flat surface of the remainder of the mudflat. It was obvious from the graphically represented data that some of the data was clustered and other was scattered (Fig. 1). Thus, we separated the data derived from the rivulet areas from that from the flat areas and recalculated the correlation coefficients. This time the ground truth data from

Table 1. Correlation coefficients of all ground truth chlorophyll measurements and coincident signals levels of the multispectral scanner in July 1977.

SPECTRAL CHANNEL	CORRELATION COEFFICIENT
BLUE	-0.20
GREEN	-0.125
RED	-0.155
IR 1	0.13
IR 2	0.33
IR 3	0.36

the flat areas correlated well with that of the blue channel of the scanner, while the data from the rivulet areas was only slightly better correlated (Table 2). Graphic representations of the data make the differences stand out clearer (Figs. 1, 2). We conclude the obvious necessity to partition future data into subsets prior to computing the concentration of chlorophyll over the whole mudflat.

DISSEMINATION OF RESULTS

I attended and presented the results and conclusions of this research at the Fifth International Symposium of Living and Fossil Diatoms in Antwerp, Belgium (Appendix 1). The paper was well received and many fruitful discussions with colleagues followed. The paper was accepted for publication by the editor of the symposium's proceedings, but I declined the invitiation. I judged that the paper would be read by a larger and wider audience and be published sooner, if sent to a remote sensing journal. Following the symposium I visited the laboratories of Drs. Wim Admiraal and F. Colijn of the University of Gröningen, Netherlands, and with Dr. Klaus Wegmann of the University of Tübingen, West Germany. All are engaged in remote sensing research on benthic diatoms. These were rare and valuable opportunities to discuss in detail the import of our research and the future of multispectral scanning technology in estuarine and coastal ecological research.

The initial results of our research have been submitted to the journal Remote Sensing of the Environment and are presently undergoing peer review (Appendix 2).

CONCLUSIONS

We have determined that there is a stastically significant relationship between the ground truth measurement of chlorophyll of benthic microalgae and radiance levels in the blue spectral channel of a tower-mounted multispectral

Table 2. Correlation coefficients of subsets of all ground truth chlorophyll measurements and coincident signal levels of the multispectral scanner in July 1977.

SPECTRAL CHANNEL	CORRELATION COEFFICIENTS RIVULET AREA	CORRELATION COEFFICIENTS FLAT AREA
BLUE	- 0.33	-0.82
GREEN	- 0.45	-0.37
RED	-0.46	-0.24
IR 1	-0.02	0.25
IR 2	-0.18	0.51
IR 3	0.18	0.36

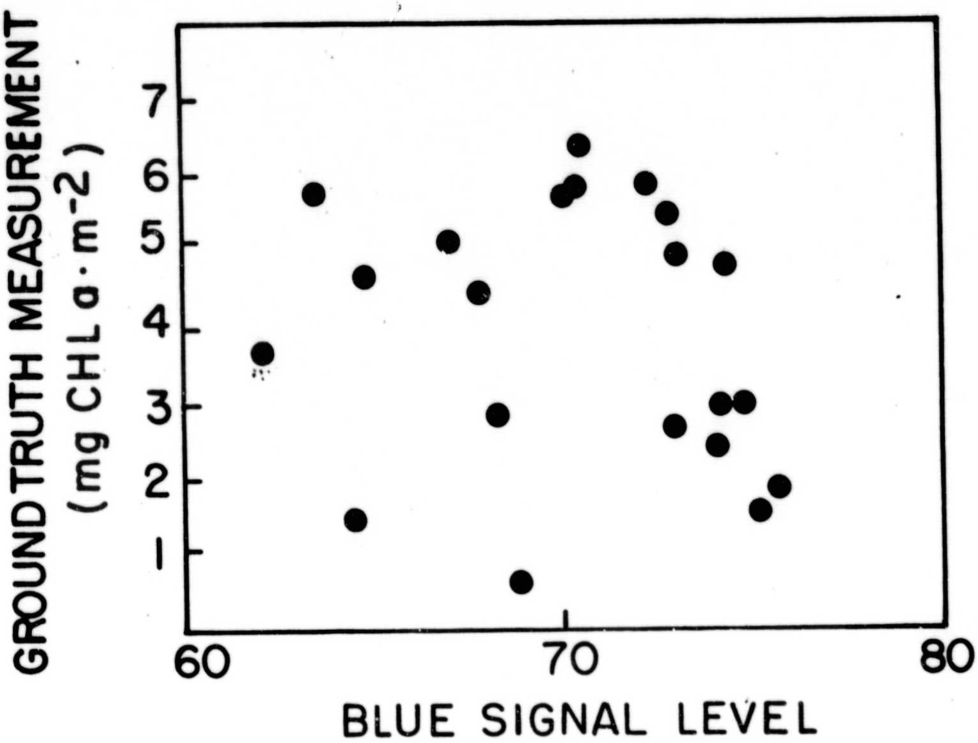

Figure 1. Scattergram plot of all ground truth chlorophyll measurements and coincident signal levels of the multispectral scanner in July 1977.

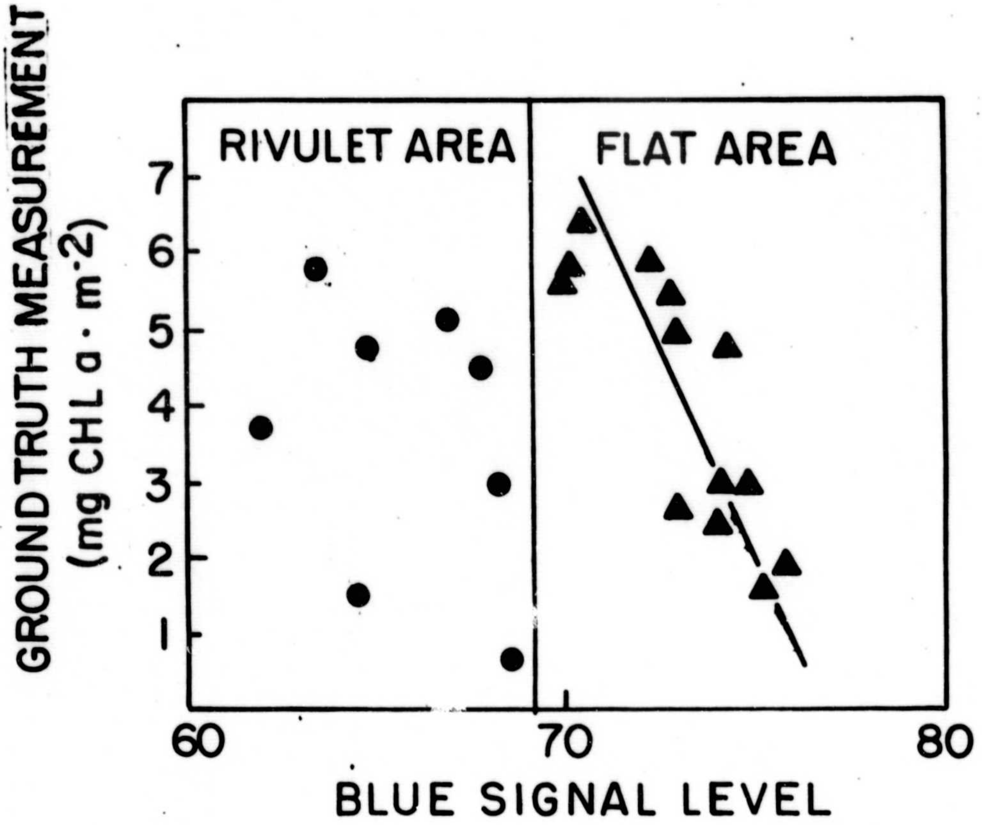

Figure 2. Replot of the scattergram seen in Fig. 1 but indicating the significant difference between the subsets.

scanner, provided that the data is first partitioned into similar subsets. We are encouraged by these results, have reported on them at scientific meetings and have submitted them for publication in the open scientific literature. We anticipate that continued financial support by NASA will allow us to experiment with aircraft remote sensing of the benthic microalgal community, an ecologically significant community in estuarine ecosystems.

APPENDIX 1. Abstract of a paper read at the Fifth International Symposium on Living and Fossil Diatoms, Antwerp, Belgium, September, 1978

MEASURING THE BIOMASS OF BENTHIC DIATOMS USING A REMOTE-SENSING MULTISPECTRAL SCANNER

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Abstract:

A remote sensing instrument, similar in design to the multispectral scanner on the NASA VIKING lander on Mars, was mounted on a 50 foot tower overlooking North Inlet Estuary, South Carolina. The instrument was programmed to take multispectral imagery data along a 90^{o} horizontal frame, while measuring relative radiance in six spectral bands ranging from 400-1100 nm and had a ground resolution of 2-5 cm. Imagery measurements were encoded in digital form on magnetic tape and were stored, decoded, and manipulated by computer. Correlation coefficients from data on scans of tidally exposed mud were highest in the blue and were negative, possibly indicating the absorbtion of sunlight by the chlorophyll containing benthic microflora (mainly diatoms). Concurrent, quantitative "ground truth" measurements of extracted chlorophyll a from cores were made to calibrate the digital data as recorded by the scanner. The data from the two widely different techniques had correlation coefficients between 0.81 and 0.91 on three separate sampling periods. Seasonal patterns of chlorophyll concentration on the mudflat followed a predictable pattern, with a winter low and a spring high. The scanner has provided encouraging results and promises to be a useful tool in sampling the biomass of the benthic microflora over large intertidal estuarine areas.

APPENDIX 2. Copy of manuscript sent to the journal, Remote Sensing of the Environment.

REMOTE SENSING OF BENTHIC MICROALGAL BIOMASS WITH A TOWER-MOUNTED MULTISPECTRAL SCANNER[1, 2]

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[1]Research by Richard G. Zingmark was sponsored by NASA Grant NSG-1334 and NSG-1523.

[2]Contribution No. 000 of the Belle W. Baruch Institute for Marine Biology and Coastal Research.

ABSTRACT

A remote sensing instrument, was mounted on a 50 foot tower overlooking North Inlet Estuary, South Carolina. The instrument was programmed to take multispectral imagery data along a 90° horizontal frame in six spectral bands ranging from 400-1050 nm and had a ground resolution of about 3 cm. Imagery measurements were encoded in digital form on magnetic tape and were stored, decoded, and manipulated by computer. Correlation coefficients were calculated on imagery data and chlorophyll a concentrations derived from ground truth data. The most significant correlation occurred in the blue spectral band with numerical values ranging from -0.81 to -0.88 for three separate sampling periods. Mean values of chlorophyll a for a larger section of mudflat were estimated using regression equations. The scanner has provided encouraging results and promises to be a useful tool in sampling the biomass of intertidal benthic microalgae.

INTRODUCTION

Benthic microalgae are significant components of estuarine food webs (Pomeroy, 1959; Marshall, Oviatt and Skauen, 1972; Ranwell, 1972), and probably play an important role in stabilizing estuarine sediments (e.g., Holland, Zingmark and Dean, 1974). Yet most of the literature on primary producers in estuaries has concerned the vascular plants and the phytoplanktonic communities. Consequently, our present understanding of benthic microalgal biomass and productivity is based on a relatively small number of data points.

The biomass of the benthic microflora is usually estimated by measuring chlorophyll a in discrete cores of surface sediments; (Grøntved, 1960, 1962, 1965; Gargas, 1970; Cadée and Hegeman 1974). The number of such samples that can be taken in any area is limited by time and financial constraints. Yet, because the benthic microflora does not form a homogeneous layer, a large number of replicate samples must be measured to provide a "representative sample" of an area. This is especially true when one considers that the composition and size of the sediments influences to a large degree the species composition and biomass of the benthic microflora (Sullivan, 1975; Amspoker and MacIntyre, 1977; DeFelice and Lynts, 1978) and that the composition of estuarine sediments is variable depending on bottom topography and the velocities, current flow and wave patterns of the overlying water which influence the deposition, mixing, and erosion of sediments.

More extensive sampling of benthic microalgal communities is necessary to understand the differences in biomass on the various sediment types than is financially feasible, especially in large estuarine areas. Frequent personal observations in North Inlet Estuary, South Carolina, at low tide have demonstrated that exposed benthic microalgae are often visible as gold to brownish patches or films to the unaided eye. These observations illustrate the potential of using a remote sensing technique for measuring the chlorophyll biomass of this community. Such methods have the potential of surveying large areas in a short time at a reasonable cost.

Remote sensing of the primary converters of solar energy in estuarine and marine food webs have heretofore focused on measuring dissolved and particulate matter in the water, and mapping coastal vegetation and other terrestrial features (Clarke, Ewing and Lorenzen, 1970; Stoertz, Hemphill and Markle, 1970; Carter and Schubert, 1974). These studies demonstrated the feasibility and usefulness of obtaining reliable, duplicable measurements that were largely independent of the sample size, since such methods scanned a wide surface area.

We report here an investigation designed to determine the feasibility of using existing multispectral technology for detecting and recording high resolution, quantitative information on the biomass of benthic microalgae on an intertidal, estuarine mudflat in South Carolina. The primary purpose of this study was to determine whether a statistically significant relationship could be demonstrated between relative spectral radiance measured by a tower mounted, multispectral scanning instrument and the concentration of chlorophyll <u>a</u> measured in discrete ground truth samples. This approach was chosen primarily for reasons of high spatial resolution and low cost. The ground resolutions available from existing aircraft scanners ranges from about 7 to 70 meters while the minimum ground resolution of the current LANDSAT multispectral scanner is about 80 meters. Current techniques of in-situ sampling use core samples a few centimeters in diameter. In view of the complete absence of any background research in remote sensing of benthic microalgae we considered an exact match in scale between image resolution and ground truth samples was essential. The tower-mounted scanner provided this match with a spatial resolution of approximately 3 centimeters at the sample area. Likewise, economics was a prime factor in choosing a tower platform since aircraft, depending on size cost typically $150 to $1,000 per flight hour. The cost of operating the tower mounted scanner is negligible. While a tower mounted scanner sufficed for this feasibility study, an aircraft scanner would be required for research requiring large area coverage.

The study site was a 10 x 200 m intertidal mudflat emptying into Clambank Creek, North Inlet Estuary, South Carolina (Figure 1). North Inlet Estuary is a 30 Km^2, high salinity, tidal, salt-marsh estuary dominated by the marine halophyte Spartina alterniflora.

SCANNER SYSTEM DESCRIPTION

Present day multispectral scanners unlike film cameras take image data as a sequence of image elements which form a line. Then a sequence of lines of image are taken to form a frame in each spectral band of interest. The basic physical quantity measured by any multispectral scanner is spectral radiance (power per unit area - solid angle - wavelength interval) either reflected or emitted by a scene. A scanner responds with an electrical signal proportional to the spectral radiance of an image element defined by the instantaneous field of view (IFOV) (See Figure 2). This IFOV is set by the size of a photodetector and its distance from the imaging objective lens. For far field imaging this distance is approximately the focal length of the lens.

The signal current due to the spectral radiance of an image element is

$$I = kA\Omega \int_{\lambda_1}^{\lambda_2} N(\lambda)\tau(\lambda)R(\lambda)d\lambda \tag{1}$$

for a given spectral band $\Delta\lambda = \lambda_2 - \lambda_1$ where k is a proportionality constant representing primarily electronic gains and/or calibration factors, A is the aperture area of the imaging objectives, Ω, the solid angle of the IFOV, $N(\lambda)$, the spectral radiance of the scene element, $\tau(\lambda)$, the spectral transmissivity of optics $R(\lambda)$, the spectral responsivity of the photodetector, and $d\lambda$ the differential wavelength.

For far field imaging with a circular photodetector

$$\Omega \approx \frac{\pi}{4} \frac{d^2}{(F.L.)^2} \tag{2}$$

where d is the photodetector diameter and F.L., the lens focal length. The current signals are then usually converted to voltages and digitized for telemetry or direct recording on magnetic tape.

The particular multispectral scanner used in this investigation was designed and built at NASA Langley Research Center except for the array of photodetectors. A detector array which was a backup flight unit for the Viking Lander Cameras was used because it was readily available and had known spectral responsivities which provide the desired measurement capability. A list of scanner characteristics is given in Table 1. One item not listed is cost. It is of interest that the cost of this instrument would be lower, if the Viking detector array is excluded. This array was only used as a matter of convenience and could have been replaced by a more conventional detector array with interference filters at a cost of less than about $1,000. The resulting overall cost would have been under $11,000.

Since the scanner was designed to be operated by unskilled technicians, most of the scanner operation was automated to such an extent that the operator could take frames of multispectral image data by manipulating a few switches. The automatic control functions are scanning of lines, switching of detector elements to provide line sequential color and multispectral near infrared images, and data recording. All azimuth positioning to start a frame is performed automatically. The operator is required to select the extent of the azimuth frame, to turn the scanner controls and data storage device on and off, and to insert and replace the magnetic tape cassettes.

The cassettes are the data storage medium for the digitized multi-spectral data. This medium was selected for compactness, light weight, ease of operation, and ease of shipment of the cassettes. This later reason was important since image data analysis was performed in Virginia. The cost of the data storage unit was $2500.

EXPERIMENTAL PROCEDURE

All experiments were run on completely clear or uniformly overcast days to eliminate signal variations due to moving clouds. Dates of sampling were chosen when a minus low tide was predicted between 10 a.m. and 2 p.m. to provide high sun angle conditions.

The experimental procedure began by running the scanner through its programmed cycle after the mudflat had been exposed to dry for at least one hour. Following this initial run, one or two linear series of at least eighteen 5.43 cm^2 x 1 cm cores were taken for chlorophyll analysis. The depression left by the removed mud was covered by a 200 ml white styrofoam cup to mark the specific image elements where ground truth measurements were taken. This was followed by running the scanner through its cycle a second time to record the specific sites of ground truth samples on magnetic tape. Later it was possible to calibrate the scanner by comparing the radiance values as measured by the scanner at the ground truth sites with the laboratory values obtained for chlorophyll from these sites. Then it was possible to estimate the distribution of chlorophyll over the whole mudflat transect.

Chlorophyll was extracted from well mixed, moist cylindrical core samples (2.54 cm dia. x 1 cm deep) in 25 ml 90 percent Acetone in the dark at 4°C for four hours. Subsamples of 0.05 to 0.10 ml from each extract was diluted to 10 ml with 90 percent Acetone and the resulting mixture analyzed for chlorophyll a in a Turner ~~IIIR~~ 111R Fluorometer (Strickland and Parson, 1977).

DATA ANALYSIS

A brief discussion of radiometry is given to provide an understanding of the variables which influence the multispectral imagery data of the mudflat. In addition, this discussion centers on the inability to determine benthic microalgae chlorophyll concentrations directly by radiometric analysis. The statistical approach which was used instead is detailed.

Radiometric Considerations

The spectral radiance sensed by a multispectral scanner for a mudflat is a combination of diffusely reflected direct sunlight and specularly reflected skylight. The reflectance properties of the mudflat are also complicated by the algae film--mud substrate combination. The reflectance of the mud is a function of surface structure, topography, moisture content and soil composition. Even if all these variables could be taken into account the chief hindrance to radiometric analysis would still be the unknown relationship between the optical properties of the alga~~e~~l film and the chlorophyll concentration ~~of~~ in the film. Since radiometric analysis poses seemingly intractable problems, a straightforward statistical approach is used. Two aspects of radiometry however are still pertinent to a statistical analysis of the multispectral data, since they deal with sources of extraneous variability. In this case the two factors are terrain features and view angle effects. The main terrain feature is a "rivulet pattern" confined mainly to the center portion of the mud flat. The view angle is a variation in signal with view angle which is due to the specular component of mud flat reflectance being a fairly strong function of view angle for the vertical view angle range of the multispectral scanner. The two factors are eliminated as sources of extraneous variability in the following way:

(1) samples occurring in "rivulet patterns" are excluded from the analysis, and

(2) all samples are taken in horizontal lines of nearly constant view angle.

Correlation

A correlation analysis was performed on chlorophyll concentrations and the multispectral signals in the six visible and near infrared spectral bands for image elements where chlorophyll concentrations were measured. This analysis takes the usual form.

$$r_j = \frac{\sum_{i=1}^{m} (I_{j,i} - \bar{I}_j)(c_i - \bar{c})}{\sqrt{\sum_{i=1}^{m} (I_{j,i} - \bar{I}_j)^2 \, \Sigma \, (c_i - \bar{c})^2}} \tag{3}$$

where r_j is the correlation coefficient for the j^{th} spectral band; $I_{j,i}$ the raw signals from the scanner for the i^{th} sample; and c_i the chlorophyll concentration for the i^{th} sample. Bars denote mean values.

This analysis, of course, provides a measure of the existence of a linear relationship between the two variables. The selection of correlation analysis was based upon the appearance of a roughly linear relationship in the data itself. This type of relationship cannot be expected in general.

Since the statistical distribution of r is not normal, a test of significance of r is on Fisher's transformation (Freund, 1962) of r

$$Z = \frac{1}{2} \log_e \left(\frac{1 + r}{1 - r}\right) \tag{4}$$

which does have an approximately normal distribution. The Z statistic can then be used in a one tailed test to determine the minimum value of r that allows the hypothesis $|r| \leq |r_o|$, to be rejected by

$$z = \left(\frac{Z - \mu_z}{\sigma_z}\right) \tag{5}$$

where $\mu_z = \frac{1}{2} \log_e \left(\frac{1 + r_o}{1 - r_o}\right)$ and

$$\sigma_z = \frac{1}{\sqrt{N - k}} \tag{6}$$

N is the number of samples and k the number of estimated parameters. This test can be applied for any confidence level but for 95 percent confidence level $z \geq 1.64$.

Regression

The goal of using remote sensing data to enlarge the number of samples of some variable compared to direct sampling can be performed with some confidence if a significant correlation is found between scene spectral radiance and the independent variable of interest. In this case an estimate of a regression equation is developed as

$$c = a_0 + a_1 I \qquad (7)$$

from the small sample by (Miller and Freund, 1977) where

$$a_1 = \frac{n \sum_{i=1}^{n} I_i^2 - \left(\sum_{i=1}^{n} I_i\right)^2}{n \sum_{i=1}^{n} c_i I_i - \left(\sum_{i=1}^{n} c_i\right)\left(\sum_{i=1}^{n} I_i\right)} \qquad (8)$$

$$a_0 = \bar{c} - a_1 \bar{I}$$

Using equation (7) a population mean of chlorophyll concentration can be estimated from camera signals. For large populations, the dominant error in absence of extraneous variabilities in the scene is in the estimates of a_o and a_1 since these errors are systematic biases in the population mean estimate of chlorophyll concentration. The bounds on a_0 and a_1 estimates can be determined for a given confidence level (Miller and Freund, 1977) as

$$a_0 \pm t_{\alpha/2} \left(\frac{S_{II} S_{cc} - (S_{ic})^2}{n(n-2) S_{II}}\right)^{1/2} \left(\frac{S_{II} + (n\bar{I})^2}{n S_{II}}\right)^{1/2} \qquad (10)$$

$$a_1 \pm t_{\alpha/2} \left(\frac{S_{II}S_{cc} - (S_{ic})^2}{n(n-2)S_{II}} \right)^{1/2} \left(\frac{n}{S_{II}} \right)^{1/2} \tag{11}$$

where $t_{\alpha/2}$ is the t statistic for $1 - \alpha$ confidence level and

$$S_{II} = n \sum_{i=1}^{n} I_i^2 - (\sum_{i=1}^{n} I_i)^2$$

$$S_{cc} = n \sum_{i=1}^{n} c_i^2 - (\sum_{i=1}^{n} c_i)^2$$

$$S_{Ic} = n \sum_{i=1}^{n} I_i c_i - (\sum_{i=1}^{n} I_i)(\sum_{i=1}^{n} c_i)$$

The bounds which are calculated from (10) and (11) are then used to determine two lines which bound the regression line for a given confidence level.

RESULTS AND DISCUSSION

Multispectral image data and ground truth samples were taken on three dates May 2, July 26, and September 23, 1977. Data taking opportunities were limited by the number of days when low tides occurred at appropriate times and by weather.

Correlation Coefficient

The correlation coefficients for the three dates are given in Table 2 together with the number of samples. For the July 26 data some samples were taken in the "rivulet" pattern of the mud flat. These samples were eliminated from the correlation analysis. The September 23, 1977, data contained some areas with direc sun specular reflections. These were also eliminated from the correlation analysis by a threshold criterion. The results show a consistent high negative correlation in the blue spectral band. Scattergrams are presented in Figure 4 for the blue spectral band for all three dates. The high negative correlations in the green and red spectral bands for the September data cannot be explained at this time. Possible explanations are that the dominant species of microalgae may have shifted to some new species with different spectral properties or possibly some strictly seasonal change has occurred without a change in species.

Hypothesis Testing

The significance test used here is a one tailed test to determine how much lower the population correlation coefficient could be than the sample correlation coefficient and still maintain a 95 percent confidence in rejecting the hypothesis that the population correlation coefficient was lower than that value. Values for Table III are given for which $z = 1.64$ indicating the magnitude of the population correlation coefficient was equal or greater than $|r_o|$ with a 95 percent confidence level. This result confirms that a significant negative correlation was found in all three sets of data.

Linear Regression

Since the correlation coefficient for the blue is consistently and significantly below zero, a linear regression relationship can be derived with some confidence. This regression relationship can be expected to have limited application for the mud flat. It cannot be considered to describe view angle effects or rivulet pattern variations. As a result blue image elements signals can be used to esti e chlorophyll concentration of benthic microalgae only over a transect region of the mud flat for which samples were taken, and within this subset of data, the rivulet pattern pixels were excluded. With these restrictions a regression relationship was used to estimate the mean chlorophyll concentration for two or three thousand image elements based on the 8 to 20 core samples. This application of each regression equation yielded estimates of transect mean values of chlorophyll concentration which are given in Table 4 together with core samples means presented for comparison.

Discussion

The concentration of chlorophyll *a* as measured from discrete ground truth samples varied widely from sample to sample, indicating a patchiness of distribution of the benthic microflora. May samples varied from 4.09 - 7.79 mg Chl*a* $\cdot$ m^{-2} ($\bar{x} = 5.02$), July samples from 1.84 - 6.32 mg Chl*a* $\cdot$ m^{-2} ($\bar{x} = 4.07$), September samples from 0.86 - 7.50 mgChl*a* $\cdot$ m^{-2} ($\bar{x} = 3.54$). A steady decline of chlorophyll concentration was apparent through the course of this study as seen from the ground truth data.

Using the regression equations, we estimated the mean chlorophyll concentration over a large block of mudflat. Mean values thus calculated were 4.65 mg Chl*a* $\cdot$ m^{-2} (May), 5.65 mgChl*a* $\cdot$ m^{-2} (July) and 3.40 mgChl*a* $\cdot$ m^{-2} (Sept.), using from 1900 - 2700 pixel elements. A peak in chlorophyll was seen in the Summer in the data recorded by the scanner. By placing the means on the regression curves we could estimate 95 percent confidence intervals in the remote sensing data (Figure 4, Table 2).

Previous studies have indicated that the chlorophyll biomass of the benthic microflora fluctuates seasonally, with lowest values seen in the cold winter months and higher values seen during the warmer months (e.g. Marshall et al., 1971). However, sharp seasonal peaks, so well known for phytoplankton, are not as well defined (Cadée and Hegeman, 1974). Our data were taken at too infrequent intervals to show any distinctive seasonal pattern. However, there are differences between the pattern for the mean values for chlorophyll in the two methods used in this study. Highest values for chlorophyll were measured in the core samples in May, while the highest values sensed by the scanner were in July (Table 2). The variations in chlorophyll concentration between each of the discrete core samples was very great, and the discrepancy between the means for the two methods may be due to the relatively small sample set represented by the ground truth data set.

CONCLUSIONS

A statistically significant linear inverse relationship was found between chlorophyll concentration of benthic microalgae and radiance levels in a blue spectral band as measured by a tower mounted multispectral scanner. This result was found for three sets of data taken at different times during the growing season. One set of data exhibited high negative correlation coefficients in the green and red spectral bands as well. In all data, two major sources of extraneous variability had to be excluded from the correlation analysis. These were view angle effects and a "rivulet" pattern in the center of the intertidal mud flat. These variables were eliminated by experiment planning and data selection.

This statistical analysis of course cannot determine whether the relationship is a direct or an indirect one. The relationship, if direct, could be due to scattering and/or absorption by the algal film or, if indirect, possibly is a measure of moisture variations across the mud flat.

We are encouraged by these results that aircraft remote sensing of benthic microalgae may be possible. Anticipated problems which were not encountered in the tower measurement are scale mismatch between ground truth and imagery picture elements, atmospheric path radiance effects, and additional extraneous surface variables such as sediment type variations all of which may complicate an aircraft remote sensing measurement of benthic microalgae.

TABLE 1

Scanner characteristics

Instantaneous field of view, IFOV (deg)	Vertical FOV (deg)	Azimuth FOV (deg)	Lens		Spectral bands	
			Aperture diameter (cm)	Focal length (cm)	Visible (nm)	Near-IR (nm)
0.12	60	90 adjustable to 330	1.38 adjustable to 3.02	5.50	400-520	820-930
					500-600	910-990
					600-730	940-1050

TABLE 2

Correlation coefficients calculated from multispectral scanner and ground truth samples taken concurrently.

Spectral band (nm)	Sampling date		
	May 77	July 77	Sept 77
400-520	-0.88	-0.82	-0.81
500-600	-0.51	-0.37	-0.80
600-730	-0.33	-0.24	-0.91
820-930	0.11	0.25	0.03
910-990	-0.02	0.51	-0.01
940-1050	0.08	0.36	0.02

TABLE 3

Hypothesis Testing on Results of Blue Spectral Band (400-520 nm)

Sampling date	Accept the hypothesis that $\lvert r\rvert > \lvert r_0\rvert$ with 95% confidence for r_o:
May 77	-0.63
July 77	-0.56
Sept 77	-0.45

TABLE 4

Comparison of ground truth measurements of chlorophyll and estimates of chlorophyll as sensed by a multispectral scanner in the blue channel (400 - 520 nm).

Sampling date	Ground truth data					Scanner data	
	mean chlorophyll concentration (mg chl a • m^{-2})	Standard deviation	Standard error	95% Conf. intervals	No. of pixels	mean chlorophyll estimates from linear regression (mg chl a • m^{-2})	95% Conf. intervals
May 2, 1977	5.02	1.20	20.9	± 2.35	2700	4.65	± 0.11
July 26, 1977	4.07	1.72	47.6	± 3.37	2700	5.65	± 0.49
Sept 23, 1977	3.54	1.67	31.6	± 3.27	1900	3.40	± 0.11

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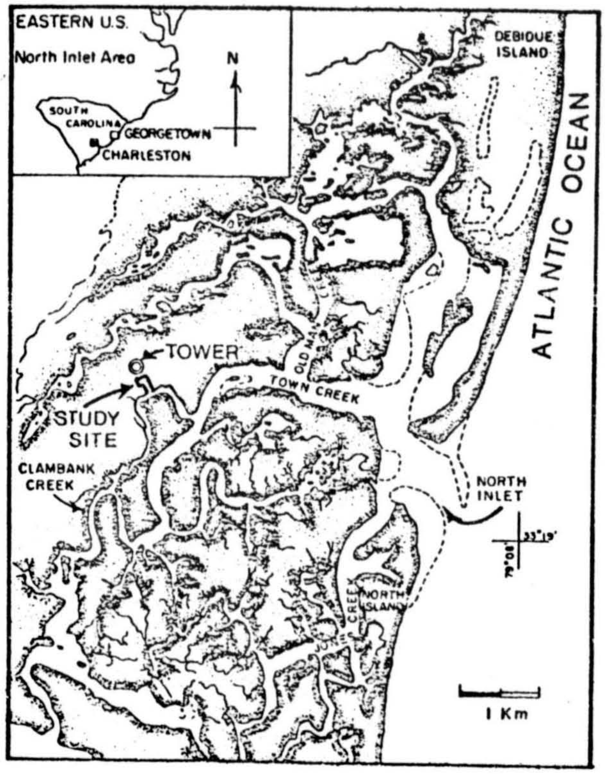

Figure 1.- North Inlet, South Carolina.

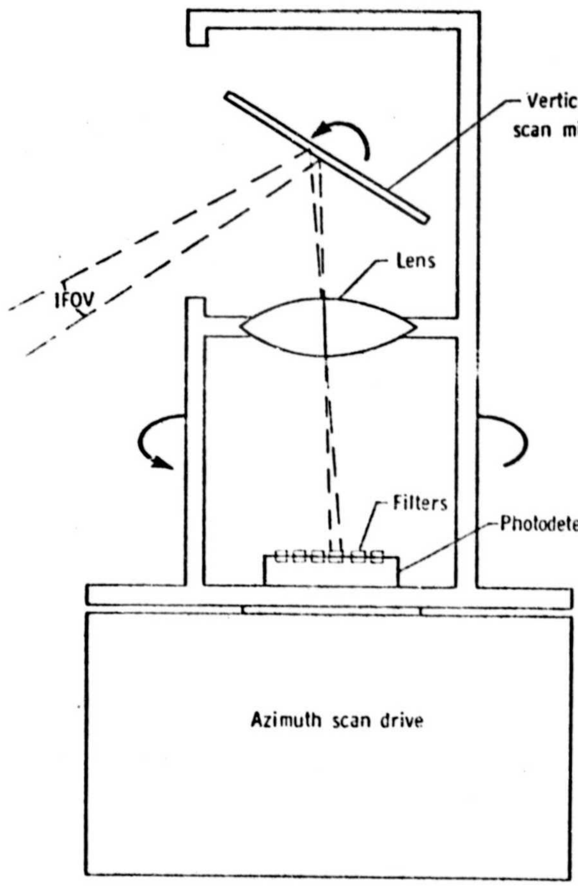

Figure 2.- Scanner schematic.

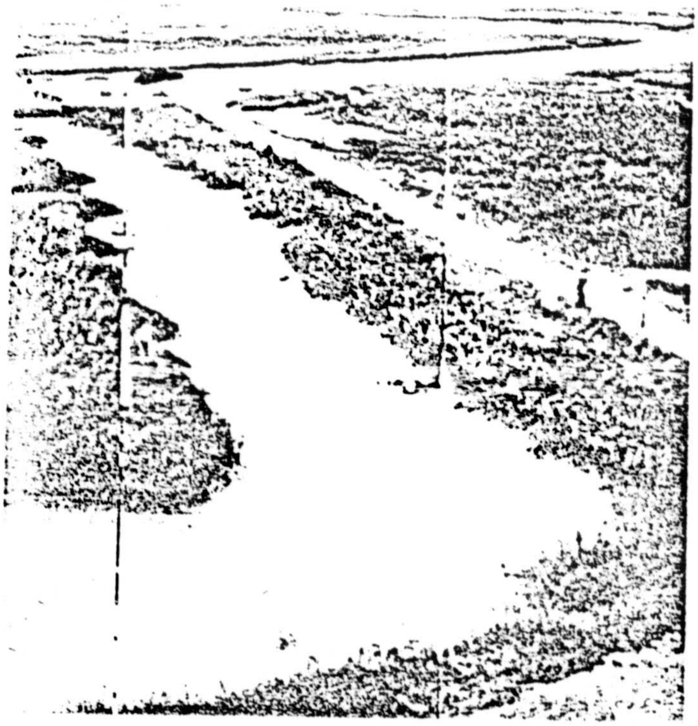

Figure 3.- Intertidal mudflat showing sample area outlined in white. This image was reconstructed from tower scanner data. The two sets of non-image lines occur during track switching by the cassette recorder.

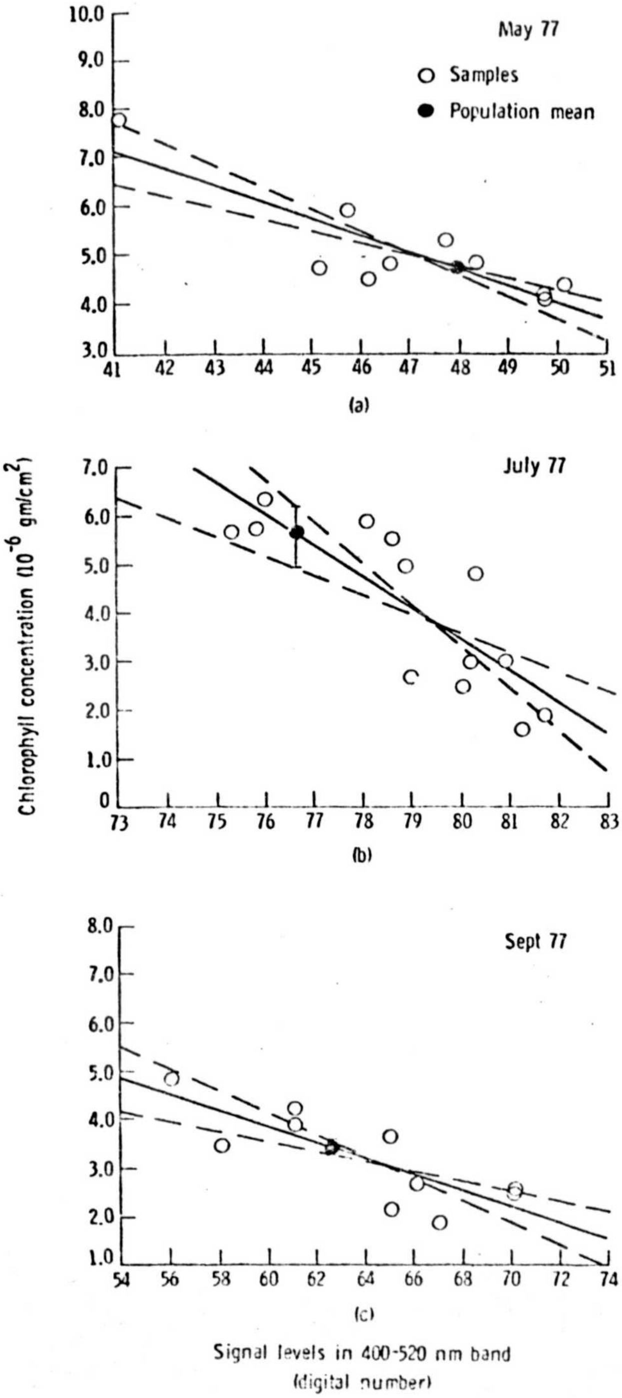

Figure 4.- Scattergrams and regression lines with bounds due to errors in estimating regression coefficients. Population means are also plotted on regression lines for a population of about 2000 picture elements.