AUTOR RESPONSAVEL
RESPONSIBLE AUTHOR

Evlyn Marcia L.M.Novo

TÍTULO/TITLE

REMOTE SENSING ESTIMATION OF TOTAL CHLOROPHYLL
PIGMENT DISTRIBUTION IN BARRA BONITA RESERVOIR

AUTORES/AUTHORSHIP

Evlyn Marcia Leão de Moraes Novo
Cláudia Zuccari Fernandes Braga
José Galisia Tundisi

RESUMO - NOTAS / ABSTRACT - NOTES

Este trabalho apresenta os primeiros resultados de um projeto de pesquisa conduzido no reservatório de Barra Bonita para se avaliar a utilidade da técnica de sensoriamento remoto nos estudos de limnologia. Dados de campo coletados simultaneamente à passagem do satélite LANDSAT-5 sobre a área de estudo foram usados na calibração dos dados do "Thematic Mapper" e para gerar um modelo empírico para a estimativa da distribuição da clorofila total na superfície do reservatório.

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Evlyn Marcia Leão de Moraes Novo
Cláudia Zuccari Fernandes Braga
Instituto de Pesquisas Espaciais
Caixa Postal 515 - São José dos Campos - SP - 12201

José Galisia Tundisi
Centro de Recursos Hídricos e Ecologia Aplicada - CRHEA-USP

Abstract

This paper reports preliminary results of a research project carried on the Barra Bonita Reservoir to assess how the current remote sensing technology can provide useful information for limnological studies. Water samples collected simultaneously to the Landsat-5 overpass were used to calibrate Thematic Mapper data and to generate an empirical model for estimating the total surface chlorophyll pigment distribution in the reservoir.

Introduction

The growing population exerts a constant pressure on water resources, thus, without adequate water supplies of unpolluted freshwater, life on Earth is apt to finish. The management of inland water is based largely on empirical relations between forcing functions such as nutrients and sediments, and responses of biological communities. Those models, however, were mostly based on a limited subsampling of inland water, and large areas of freshwater comprising a diversity of natural ecosystems usually are not adequately sampled.

Remote sensing technology can be applied to water studies so as to make those subsamples more representative of the variety of freshwater ecosystems. Water color data have been collected since 1968 (Clark and Ewing, 1969) as a remote indicator of the water biological properties. Since 1978 a special sensor (Coastal Zone Color Scanner) has been used to assess mesoscale processes in the ocean. Recent work is mainly focused on the estimation of water column primary productivity using pigment concentration derived from satellite data (Kirk, 1983). Inland waters, however, have several distinctive characteristics which requires special

attention if remote sensing is to succeed (NASA, 1987). Current remote sensing technology has had modest success in the examination of inland waters, mainly because of wide range of optical conditions occuring in space and time in these ecosystems. A large amount of research is still needed to make remote sensing applications on inland water management operational.

This paper reports preliminary results of a research project oriented to assess the information content of TM/Landsat data as far as water quality parameters are concerned.

Theoretical Background

Water remote sensing studies have involved two main directions. The first research line (McCluney, 1976;Philpot and Klemas, 1979; Bricaud and Sathyendranath, 1981; Witte et al., 1982) is oriented to assess what are the water components affecting water spectra. The second research line is oriented to the use of orbital remote sensing data to estimate water parameters (Welby et al., 1979; Nielsen et al., 1983; Schiebe et al., 1984; Braga, 1988).

Water components affecting water spectra were classified into four groups according to laboratory researches performed by Bricaud and Sathyendranath (1981) : live phytoplancton; biogenic detritus matter associated to phytoplancton; terrigenous matter and suspended sediments; and dissolved organic matter. Spectral features of these components were measured in laboratory and parameters (concentration, cell diameter, etc) affecting water spectra were identified.

Experimental results showed that absorption efficiency per unit chlorophyll concentration varied widely from one water body to the other. Figures 1 and 2 illustrate some of those laboratory experiments.
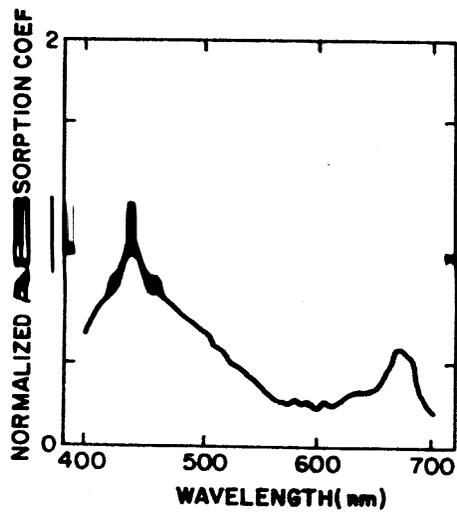
Fig. 1 _ Absorption curve (normalized at 440 nm) of phytoplancton and covarying detrital matter. Obtained in the study of Prieur and Sathyendranath apud Bricaud and Sathyendranath (1981), p.44.

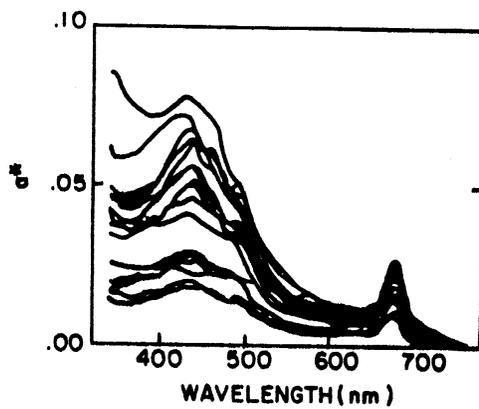

Fig. 2 _ Spectral values of specific absorption, a* (expressed in m-1 (mg (chl a + pheo a) m-3)-1) determined on intact cells during exponential growth, for different algal species in batch cultures. In: Bricaud and Sathyendranath (1981), p.45.

For spherical cells experimental results suggested a decrease in the absorption coefficient as the cell size increases (Figure 3). A comprehensive review on this subject can be found in Braga (1988).
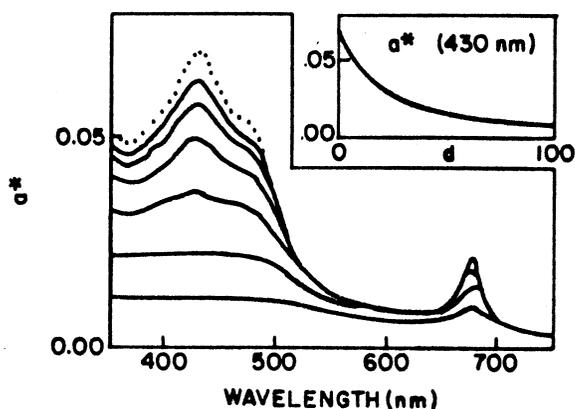

Fig. 3 _ Change in spectral values of the specific absorption coefficient a* (in m-1 (mg chl a m-3)-1) for algal cells containing the same material but diferring size (diameter, d, in μm). The dotted curve represents the spectral absorption values of this material (arbitrarily chosen) as dispersed in solution (d ➔ 0). The continuous curves, from the upper to the lower one, correspond respectively to the diameters 2, 4, 8, 16, 32 and 64 μm. Inset: variations with the cell diameter of the specific absolute value of absorption at 430 nm. In: Bricaud and Sathyendranath (1981), p.46.

MSS/Landsat data were applied to detect algal blooms of the water surface. MSS band 6 (red/near-infrared wavelengths) was found to be more sensitive to algal blooms (Nielsen et al., 1983). Similar results were found (Schiebe et al., 1984) using TM/Landsat data. According to them the best waveband for estimating chlorophyll concentration was TM3 (red wavelengths).

Study Area

Barra Bonita reservoir is located in the Tiete river, at 22o29'S and 48o34'W . Tiete drainage basin has 32,330 km2 and the reservoir open water is around 324 km2.The reservoir

catchment basin encompasses the most populated and urbanized area in Brazil. Sugar cane plantation is the main agricultural activity. More information on the area can be found in Calijuri (1988).

Methodology

Two data sets were used in this study :a) digital data from TM/Landsat bands 1,2,3,4 (path 220; row 76) referring to July, 17th ,1988 ; and b) water quality parameters determined on the ground and in laboratory according to procedures defined in Golterman et al. (1978). Table 1 presents the spectral range of each TM band used in this study. The following parameters were determined for each of the eight water sampling stations: Secchi depth; surface temperature; light penetration; total suspended solids (organic and inorganic); total chlorophyll pigment concentration; and nutrients.

TABLE 1
SPECTRAL RANGE OF UTILIZED TM/LANDSAT-5 BANDS

BAND	SPECTRAL RANGE (nm)
1	(450 -520)
2	(520 -600)
3	(630 -690)
4	(760 -900)

TM digital data were processed acording to the methodology suggested by Godoy and Novo (1989). An average of 16 pixels was obtained for each sample area to derive water reflectance values in the four TM bands used.

Water sample variables and reflectance data were submitted to linear correlation analysis. Stepwise multiple regression was applied to derive a model to estimate chlorophyll concentration from combinations of different wavebands. The model was then implemented into the digital image processing system to classify the chlorophyll concentration in the entire reservoir.

Results and Discussion

1- Correlation Analysis

Correlation coefficients between optically active water variables and remotely sensed reflectance are presented in Table 2.

TABLE 2

CORRELATION COEFFICIENTS BETWEEN WATER SAMPLE VARIABLES AND REMOTELY SENSED REFLECTANCE

	CLORO	TSS	SECCHI
B1	-0.59	-0.29	-0.19
B2	-0.77	-0.48	-0.05
B3	-0.74	-0.51	-0.07
B4	-0.30	-0.21	-0.12

where:
    B1= average reflectance of band 1
    B2= average reflectance of band 2
    B3= average reflectance of band 3
    B4= average reflectance of band 4
    CLORO= Total chlorophyll pigment concentration
    TSS= Total suspended solids
    SECCHI= Secchi depth

Only chlorophyll concentration presented significant linear correlation with the remotely sensed reflectance in the visible bands at the 5% level. The correlation coefficients were inverse for the whole visible spectrum, what was expected only for bands 1 and 3, which correspond to the chlorophyll absorption bands.

For band 2 the inverse correlation was not expected, since an increase in chlorophyll concentration tends to shift the maximum water reflectance towards the green (Clark and Ewing, 1969). Figure 4, however, suggests that for certain types of aquatic systems the correlation can be inverse.
The 80 μg/l chlorophyll concentration curve presents the lowest radiance value in the blue region (430 nm), that is in accordance with the theory. It would be also expected a very high radiance in the green region (550 nm) for this curve, too, which did not happen. The 0,86 μg/l curve also presented an anomalous behaviour in the green region but not

in the blue one. In the green region the radiance does not follow a pattern either increasing or decreasing as the concentration does. In the red region the radiance value increases as the chlorophyll concentration increases. Considering that all the water samples used to build the figure presented very low TSS concentration, departure from theory can be explained by differences in phytoplancton composition. Literature shows the influence of the concentration range on the spectral behavior of the optically active substances (Kirk, 1983).
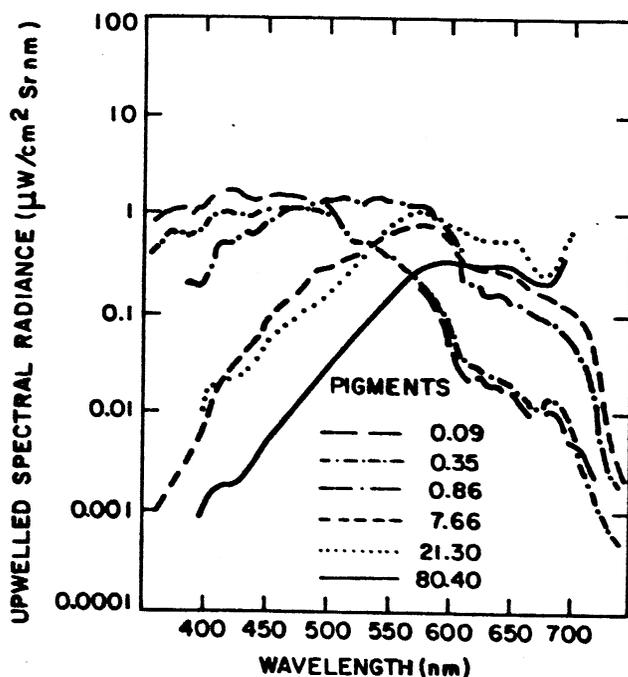

Fig. 4 _ Upwelled spectral radiance as a function of chlorophyll pigment concentration for various ocean waters. In: NASA (1987), p. 14.

Figure 5 shows the effect of changes in turbidity and chlorophyll concentration on the water spectral reflectance. For the red region, considering the chlorophyll concentration , it would be expected the highest absorption coefficient for curve c_L followed by a_L, b and d_L respectively. If turbidity is assessed, however, one can conclude that this variable is controlling water spectral response. The absorption coefficient increases with increasing turbidity for the whole visible spectrum, except for the blue region (400-440nm).

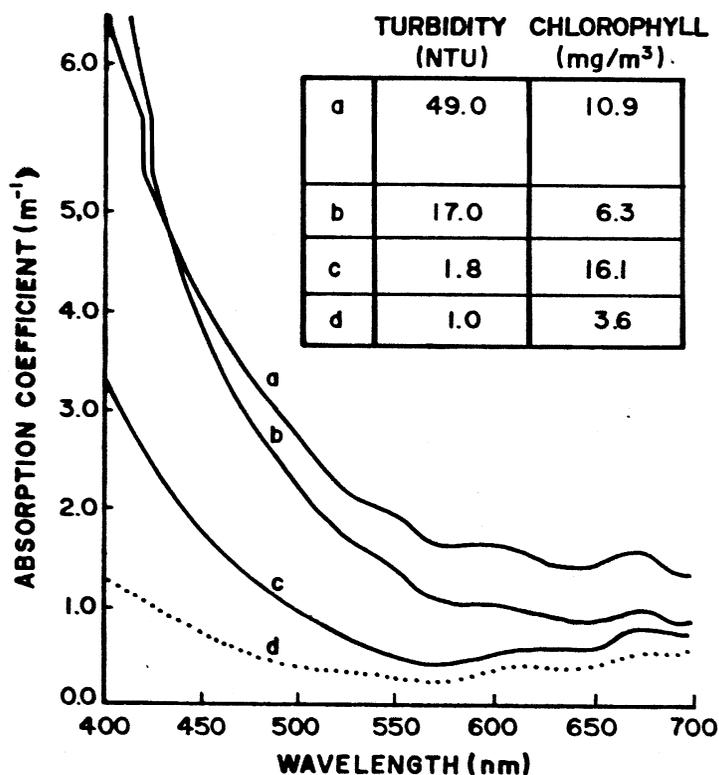|	TURBIDITY (NTU)	CHLOROPHYLL (mg/m³)
a	49.0	10.9
b	17.0	6.3
c	1.8	16.1
d	1.0	3.6

Fig. 5 _ Total absorption spectra of various natural waters in southeastern Australia. The values of turbidity (NTU) and total chlorophyll content (mg m-3) for each curve are listed beside. Adapted from Kirk (1983), p.65.

Another important aspect to explain the inverse correlation coefficient is then the presence of other water components affecting the turbidity. Those components can overcome the effect of chlorophyll absorption on the water spectra.

The effect of the attenuation coefficient over the water column actually sensed by TM system was also assessed by ratioing the chlorophyll and TSS concentrations to the Secchi depth (Braga, 1988). Results in Table 3 shows a decrease in the correlation between chlorophyll and remotely sensed reflectance when ratioed data is used and an increase for TSS case. These diferences between ratioed and raw data can indicate the chlorophyll and TSS distributions in the water column. Chlorophyll tends to be concentrated in the euphotic remotely sensed depth, while TSS is varying within the whole water column.

TABLE 3

CORRELATION COEFFICIENT BETWEEN NORMALIZED WATER VARIABLE
AND REMOTELY SENSED REFLECTANCE

	CLSECCHI	TSECCHI
B1	-0.362	-0.311
B2	-0.624	-0.547
B3	-0.603	-0.566
B4	-0.221	-0.289

where:
      CLSECCHI= Normalized total chlorophyll pigment
concentration
      TSECCHI= Normalized total suspended solids

2- The Chlorophyll Model

Based upon the correlation analysis one could identify Chlorophyll as the major measured parameter to control water reflectance. By inverting the physical model (Curran and Hay, 1986), Chlorophyll concentration could be estimated by using remotely sensed reflectance as independent varibles to run a step-wise regression algorithm. The resulting model is described on Table 4.

TABLE 4

STEP-WISE SELECTION FOR CHLOROPHYLL

Variables in the model	Regression Coefficient	Adjusted R squared	Standard Error of Estimate
B2	-0.431		
B4	1.324	0.861	0.296
CONST	8.294		

As one can observe the model for estimating Chlorophyll concentration included band TM4 which originally presented the lowesest correlation. The model accounts for the colinearity among the independent variables (Wonnacott and Wonnacott, 1977).

The model accounts for 86% of the Chlorophyll variation producing a standard error of 0.296 μg/l . In the range of variation in the Clorophyll concentration (3.96 ~ 6.15 μg/l) it represents a 6% error in relation to the average of the variable distribution.

The model was then implemented into the digital processing system producing the spatial distribution of the chlorophyll concentration in the Barra Bohita reservoir (Figure 6).

Four concentration classes were defined in order to fit the Kratzer and Brezonik (1981) Trophic Index Classification. According to their classification, oligotrophic aquatic systems present a Trophic State Index ranging from 21 to 40, which corresponds to Chlorophyll concentrations up to 2.6 μg/l ; mesotrophic systems correspond to concentration around 6.4 μg/l and eutrophic systems to concentration over that value.

Using chlorophyll distribution as an indicator of the reservoir trophic state one can observe that during the satellite overpass most of the water presented mesotrophic conditions with patchs of eutrophic water concentrated in the Piracicaba river. Based on this information areas of pollutant discharges can be better identified and controlled by the environmental protection agencies.

Conclusion

These preliminary results were applied to optimize data collection of the ongoing research, since it is a long term project carried out through scientifical cooperation between the National Institute for Space Research and the Centre for Hidric Resources and Applied Ecology (CRHEA), Brazil. The chlorophyll distribution map is in agreement with the existing results obtained through conventional limnological studies performed by CRHEA during the last 10 years, giving to them the missing synoptic view.
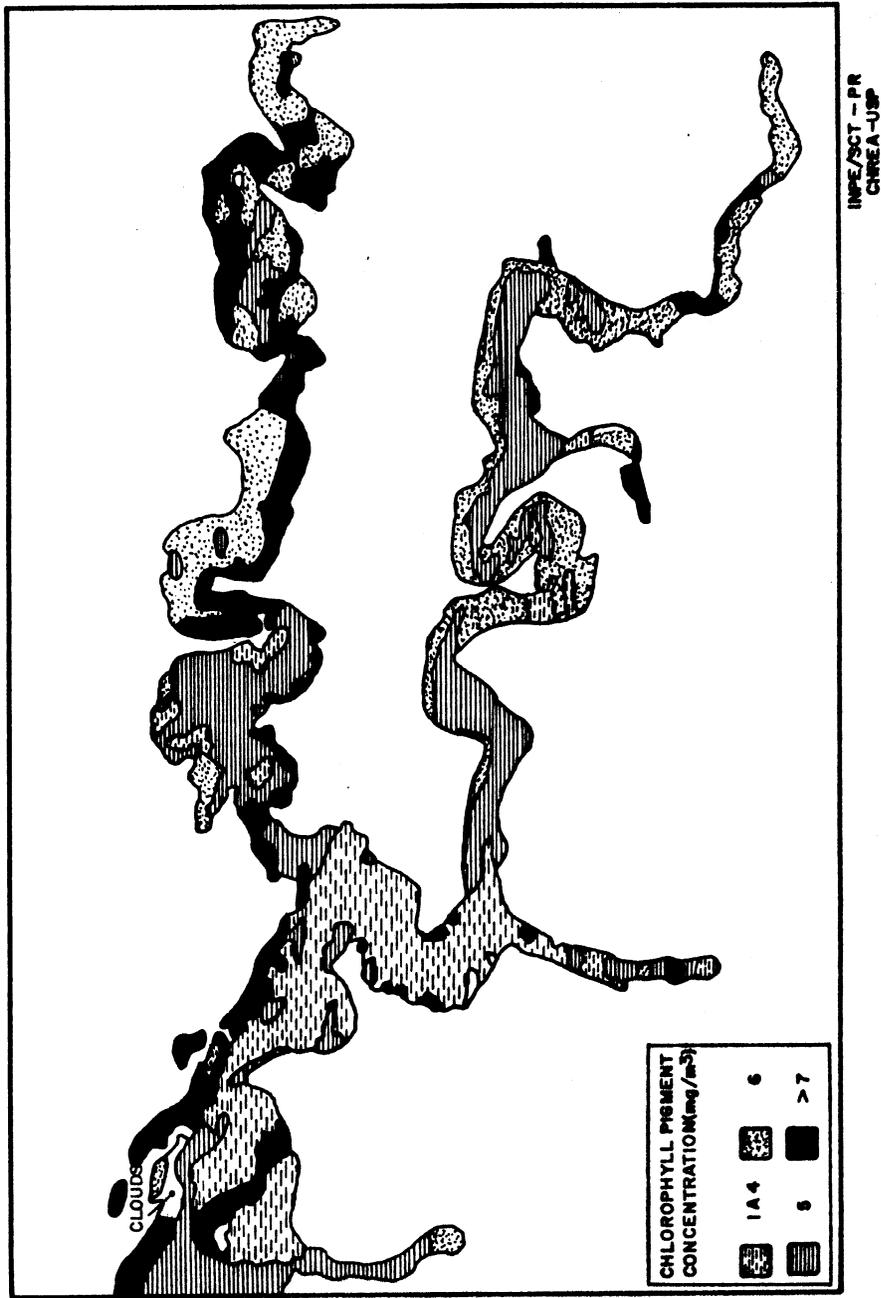
Fig. 6 - Chlorophyll pigment distribution in
Barra Bonita Reservoir

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