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SPECTRAL CHARACTERIZATION OF MANGROVE LEAVES IN THE BRAZILIAN AMAZONIAN COAST: TURIAÇU BAY, MARANHÃO STATE.

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ABSTRACT

Mangrove communities are tropical systems which have fewer species than tropical forests, especially in Latin America and display a single architecture, usually lacking the various strata commonly found in other forest ecosystems. The identification of mangrove communities by orbital data is not a difficult task but the most interesting challenge is to identify themselves by the dominant species. The first step toward that floristic identification is the spectral characterization of detached leaves. Leaves from four species of mangrove trees were spectrally characterized considering the Directional Hemispherical Reflectance Factor (DHRF) determined through radiometric measurements using an integrating sphere LICOR 1800 attached to a spectroradiometer SPECTRON SE-590. In the visible bands (0.45-0.69 μm) the button-shaped mangrove *Conocarpus erectus* was brighter and the red mangrove *Rhizophora mangle* was darker than the other two species which shows very close DHRF values. Otherwise the black mangrove *Avicennia germinans* and the white mangrove *Laguncularia racemosa* can be distinguished from one another in the Near Infra Red (NIR) region (0.76-0.90 μm) and in this region of the spectrum the DHRF of *C. erectus* and *R. mangle* become very close.

Key words*: mangroves, leaf reflectance, spectral characterization of leaves, Maranhão, Brazil.*

INTRODUCTION

Mangroves are valuable coastal systems (Cintrón and Schaeffer-Novelli, 1992, Robertson, 1992, Lacerda *et al.*, 1993). They are known to protect the environment against erosion and flooding, to process pollutants and waste discharge contaminated with heavy metals (Silva *et al.*, 1990), to export organic matter to estuarine areas and thereby increasing fisheries yield (Cintrón and Schaeffer-Novelli, 1983, Twilley, 1985), as to shelter threatened species (Rebelo-Mochel *et al.*, 1991, Rebelo-Mochel, 1993).

The Amazonian coast, comprised by the Brazilian states of Maranhão, Pará and Amapá, contains the largest mangrove system in the world, measuring 8,900 km2 (Kjerfve et al. (2002). The state of Maranhão is located in the north coast of Brazil and it contains about 750,000 ha of mangroves (Sant'Anna and Whately, 1981, Kjerfve and Lacerda, 1993,). The macro-tidal coast of Maranhão contains 500,000 ha of these mangroves, more than 30% of the total for all Brazil. Biomass may reach 280 ton/ha or more, with trees taller than 40 m in some places (Cintrón and Schaeffer-Novelli, 1983, Lacerda and Schaeffer-Novelli, 1992, Kjerfve and Lacerda, 1993, Rebelo-Mochel, 1995). Mangrove species in this region are three species of red mangroves *Rhizophora mangle*, *Rhizophora racemosa*, *Rhizophora harrisonii*, two species of black mangroves *Avicennia germinans*, *Avicennia schaueriana*, the white mangrove *Laguncularia racemosa* and the buttom-shaped mangrove *Conocarpus erectus* (Santos, 1986, Rebelo-Mochel *et al* 1991).

The west coast of Maranhão is sharply cut by rivers, streams and tidal channels filled with clay and silt which foster the development of mangroves. The mouth of Turiaçu River is one of the largest entrances of the region with a surface area of 900 km^2. Satellite remote sensing might be the most cost-effective technique for evaluating mangrove distribution and biomass. Long and Skewes (1996) described a technique using Thematic Mapper (TM) satellite images to inventory Australian mangroves. The use of Multispectral Scanner (MSS) and TM satellite

images to identify mangrove areas along the Brazil coast has previously been accomplished by Herz *et al.* (1984), Herz and Jaskow (1985), Herz (1985), Pires (1986), Pires and Herz (1987, 1988) and Herz (1991). Indeed, delimitation of mangrove occurrences using multispectral data is not a hard task considering the spectral contrast between this morphological unit and other land cover types. The problem however is set when it is necessary to identify different mangrove types, especially species composition, due to the existence of mixed stands and the characteristics of coastal land forms. But the potential advantage in that identification procedure through remote sensing technology is the fact that there are few species on mangrove environments compared with other tropical rain forests. Indeed, the Atlantic coast of Americas has 3 species of *Rhizophora*, 2 of *Avicennia*, 1 of *Conocarpus* and 1 of *Laguncularia*.

Some attempts have been made to describe mangrove communities by their spectral reflectance in the field. These techniques are generally expensive and laborious, but there are some aspects that become promising in mangrove studies. As mentioned above, mangrove communities have fewer species than tropical forests, especially in Latin America and display a single architecture, usually lacking the various strata commonly found in other forest ecosystems. Besides, mangroves grow in coastal plains with low relief and estuarine waters, forming extensive zones dominated by 1 or 2 species, with relative homogeneous physiography.

Considering leaves as the most important part of a plant in terms of its interaction with the electromagnetic radiation, the spectral reflectance of leaves has great influence on the canopy bidirectional reflectance. Thus, the spectral characterization of leaves can give information about the opportunities and constrains of the canopy identification. These facts reinforce our belief that in mangrove environment it would be possible to find a strong correlation between spectral reflectance of detached leaves and the spectral response of mangroves canopies

measured by an orbital located sensor. One most important aspect to be considered here is related to the real possibility to spectrally characterize leaves of each mangrove species, in other words, if we can segregate mangrove species from their leaves reflectance spectra. The complete understanding of that aspect is the first step to be carried out toward the use of orbital data for discriminating mangrove species.

The main goal of this work is to characterize the reflectance of leaves of four mangrove species that occur in the State of Maranhão, Amazonian coast of Brazil, in order to distinguish them one from another. This spectral characterization can later help the inventory and description of mangroves communities in that region utilizing orbital data.

MATERIAL AND METHODS

Study Area

Turiaçu Bay is located between latitudes S 1º 20' - 1º 45' and longitudes W 45º 10' - 45º 20' in the western coast of Maranhão State, northern Brazil (Figure 1). The extension of the ecosystem, the presence of pure and mixed stands of mangrove species and the low human density and high pristine areas, make this region profitable for regional studies.

[Insert Figure 1 about here]

Turiaçu Bay has a surface area of 900 km^2 and semidiurnal tides range up to 8 m (Department of Navigation DHN). The annual precipitation averages 2,000 mm with maximum of 500 mm in March and minimum of 14 mm in September-November. Mangrove vegetation covers the borders of the bay, mounting tidal channels (*igarapés*) and streams, reaching inland as far as 100 km up the Turiaçu River. The mangrove species that occur in this region are *Rhizophora mangle*, *Avicennia germinans*, *Laguncularia racemosa* and *Conocarpus erectus*, facing

estuarine fringes, basins, hypersaline environments, riverine channels and freshwater wetlands (*varzeas*).

The field work was performed in Bacuri municipality, right side of Turiaçu Bay, during July 1997. There were selected 26 sample plots over 4 mangrove environments: fringe, basin, riverine and hypersaline habitats.

Leaf Sampling and Structural Data

The data collection was carried out inside plots of about 30m x 30m in each of the 26 selected sample plots. Leaves on the top of the canopy were detached from arbitrarily selected trees by climbing and cutting the upper branch exposed to the sun. There were collected about 42 leaves from each mangrove species that were find in each sample plot. The leaves were stocked in plastic bags and carried in ice boxes according to *Sousa et. al* (1996). All the reflectance measurements were performed 8 hours after leaves were detached since *Ponzoni et al.* (1997) didn't find any significant changes in the leaf reflectance measurements up to 10 hours after leaf detaching.

Structural data comprised tree height measured with a Ranging TLR 75 Telemeter and the diameter at the breast height with a calibrated ribbon, for all the trees over 2.5 cm in diameter as stated in *Schaeffer-Novelli et al.* (1986). All the 26 sites were referenced with a Scout GPS Trimble Navigation with an error of less than 90m in the field.

Green leaves were collected and taken to the Laboratory of Botany of the Universidade de Taubaté where their internal structures were examined taking into account the expected differences between species.

Radiometric Measurements

Radiometric measurements were performed with an integrating sphere LICOR 1800 attached to a spectroradiometer SPECTRON SE-590 that runs from 0.4 μm to 1.1 μm, with 0.03 μm of spectral resolution.

As the minimal number of leaves necessary to guarantee confidence to the statistical tests was not known in the beginning of the field work, Directional Hemispherical Radiance was measured for each of 42 detached leaves from each mangrove species in all the 26 sample plots by placing the addaxial (upper) surface of the leaf in the integrating sphere. After each group of 10 leaves, the reference panel ($BaSO_4$) inside the sphere was measured to calculate the Directional Hemispherical Reflectance Factors (DHRF). DHRFs were calculated considering the group of leaves closest (in time terms) to the spectra radiance of the reference panel.

The DHRF is given by the equation:

$$\rho_\lambda = \frac{L_{\lambda leaf}}{L_{\lambda pannel}}$$

Where:

ρ_λ = directional hemispherical reflectance factor (DHRF)
$L_{\lambda leaf}$ = leaf directional hemispherical radiance;
$L_{\lambda pannel}$ = reference panel directional hemispherical radiance ($Ba\ SO_4$).

The data were processed with the software "ESPECTRO" developed by the Radiometry Laboratory of the National Institute for Space Research (LARAD/INPE). At this phase, there were determined 42 DHRFs spectra for each species that had been found in each of the 26 sample plots in the field. From these DHRF spectra it was calculated averages in four different spectral bands: blue (0.45-0.52 μm), green (0.52-0.60 μm), red (0.63-0.69 μm) and near infrared (0.76-0.90 μm). It was determined averages from each of those 42 repetitions, for each species, in each of these four spectral bands. The option of large spectral bands in spite of the fine SPECTRON SE-590 spectral resolution was based on Ponzoni and Gonçalves (1999) that compared the results achieved using large spectral bands and SPECTRON SE-590 fine ones in DHRF of *Eucalyptus saligna* detached leaves. The authors found no differences using both spectral resolutions on an ANOVA statistical procedure. Thematic Mapper bands

were adopted in this study with the aim of checking out possible modeling integrating radiometric data of leaves and Landsat/TM ones, which is the object of another study.

Statistical Analysis

To determine the minimum number of leaves necessary to set confidence to the spectral characterization, it was considered (for each spectral band) the equation:

$$n = \frac{t^2 . CV^2}{d^2}$$

where:

n = minimum number of leaves;
t = 1.83 (for 9 degrees of freedom and 10% of significance);
d = minimum difference to be ratified (in this case, 10%);
CV = coefficient of variation between DHRFs.

Ten spectra from all available ones for each species were randomly selected in order to determine the n values for each band. The minimum number was identified as the higher n value reached in this procedure, independent on the species.

Variance analysis (ANOVA) was applied for the averages of each spectral band to ratify if there were significant differences between the DHRFs for each species in each spectral band. The F value was considered at 10% of significance. After finding significant differences we tested the differences between the averages with Duncan's test also at 10% of significance.

RESULTS AND DISCUSSION

Considering the 26 sample plots, *C.erectus* was found in only one of them, *L.racemosa* in nine, *A.germinans* in nineteen and *R.mangle* in eighteen.

Results for the minimum number of leaves needed to set confidence to the statistical analysis were: 6 leaves for *R. mangle*; 8 for *L. racemosa*; and 33 for *A germinans*. It was acquainted the spectra of 1,848 leaves (total) r considering the 4 mangrove species in the 26 sample plots.

The complete DHRF spectra and the DHRF for each spectral band of mangrove leaves are shown in Figure 2. The DHRFs presented on Figure 2 are average values calculated from all available spectra acquired from the 26 sample plots in the field. Some data were lost in data processing task, thus we decided to consider 39 leaf spectra in each of these sites to perform the statistical analysis for all species.

[Insert Figure 2 about here]

Observing Figure 2 it is possible to notice that in the visible bands (bands 1,2 and 3), *C. erectus* presented higher values of DHRF and *R. mangle* presented the lowest ones, while *A. germinans* and *L. racemosa* presented similar DHRF values themselves. That result could be an indicative that *C. erectus* leaves have lesser photosynthetic pigments than the other species leaves, but this was not confirmed in this paper. In the NIR region (band 4), *A. germinans* presented higher values of DHFR followed by *C. erectus* and *R. mangle* while *L. racemosa* presented the lowest ones, indicating that there are internal leaf structure differences between leaves of the four species themselves. Figure 3 shows a graphic representation of the averages of DHFR and their standard deviation in each spectral band for all species.

[Insert Figure 3 about here]

As expected, in bands 1 and 3 the DHFRs of all species were low due to photosynthetic pigments activity (Ponzoni, 2001) with lower standard deviation values comparing with band 2 results. In band 4 both DHFR and standard deviation were higher than those observed in the visible bands.

A scatter plot composed by DHFR values from band 4 (y axe) and band 3 (x axe) is presented in Figure 4 in order to allow a complementary evaluation of the spectral differences between the leaves of the four species.

[Insert Figure 4 about here]

Considering the places of the DHFR values (four species) in the bi-dimensional scatter plot presented in Figure 4 one can observe that both *L.germinans* and *C.erectus* (even considering only one point for this last one) could be individualized from the others two species, besides being individualized themselves. The DHFR's dispersion for *R.mangle* was lower than those observed for the others, indicating higher homogeneity of DHFR values for this species.

The performance and results of the Analysis of Variance (ANOVA) are shown in Table 1. All F values were considered significant at 10% of significance. It was performed Duncan's test to identify which averages of DHFR were different at the same level (10%). Table 2 presents the results of Duncan's test. All the species presented different DHFR values in band 1. In bands 2 and 3, however, *C. erectus* and *R. mangle* remain with the higher and lower reflectances, while *L. racemosa* and *A. germinans* became closer and having no significant differences between their DHFRs. On the contrary, in the NIR region the DHFR values of *A. germinans* was higher and *L. racemosa* was lower than the other 2 species which spectra became closer. The spectral bands used in this study showed satisfactory results, finer bands, with more wavelengths seem to have little advantage for characterizing leaf spectral reflectance (Ramsey and Jensen, 1996).

[Insert Table 1 about here]

[Insert Table 2 about here]

Radiant energy interacts with the leaf structure by absorption and by scattering (*Gates et al.,*1965). In the visible bands (1,2 and 3) Cardoso and Ponzoni (1997) found similar spectral reflectance between 5 species of terrestrial shrubs, differences appearing in the NIR band 4 probably due to leaf mesophyll influence. Gausman (1974) demonstrated that compacted leaves had lower reflectance than leaves with porous mesophyll or with many cell wall-air space interfaces. The anatomical analysis of the epidermis of mangrove leaves showed all the species are dorsiventral, or in other words with a marked dissimilarity between the upper and the lower halves, and a colorless tissue represented by a thick addaxial hypodermis (Tomlinson, 1986). The white mangrove *L.racemosa* has the most compacted epidermis below the cuticular membrane of all the species examined. It has cuticular membrane and flanges strongly developed besides having a concentration of palisade layers below a very thin lacunal parenchyma. This is coherent with the low brightness explained by the lowest values of DHFR in the NIR bands (Figures 3 and 4). The red mangrove *R.mangle* and the black mangrove *A.schaueriana* have a similar arrangement in the structure of the epidermis but *Avicennia* has far well developed lacunae in the parenchyma between the cuticular membrane and the palisade layers. This may explain the higher reflectance of this species in the NIR region. In this study we were not able to make anatomical analysis of *C.erectus* but Stace (1965) made a review of Combretaceae and reports that C. *erectus* has narrow-walled epidermal cells arranged in a very regular way. The weak arrangement of cells of *C. erectus* could be related to the high brightness of this species in the NIR region.

In the visible bands the spectral response should be explained due to differences on the chemical components (differences), including photosynthetic pigments amount (Ponzoni, 2001). As no chemical analysis were performed, it was impossible to compare chemical differences with radiometric ones. Gitelson and Merzlyak (1996) verified that even a small increase in the chlorophyll content of green leaves lead to a significant decrease in the

reflectance, so it can be possible that in the visible bands the significant differences between DHFR values could be associated to differences on the chlorophyll content (differences). Anyway, the significant differences in DHFR were quite important even at laboratory investigation since they are at least (because at least they are) indicatives that orbital data from visible and NIR spectral regions could also be explored in mangrove species identification.

The optical analysis of leaf epidermis showed that *Rhizophora* has far more chloroplasts than the other species although the total amount of chlorophyll was not measured in this study. Photosynthetic and chemical components probably are responsible for the lowest brightness of *Rhizophora mangle* in the visible bands. The reflectance of the leaf water content is measured by the wavelengths of 1.45 - 1.93 μm (Thomas *et al*., 1971) and it was not discussed in this paper.

In spite of Ponzoni and Gonçalves (1999) have recommended the usage of larger spectral bands, it should be interesting to consider the possibility to obtain orbital hyperspectral (Hyperion data, for instance) from mangrove areas. Considering the greater amount of mangroves spectra that could be extracted from the hyperspectral images, statistical procedures like those utilized by Galvão et al. (2004), for example, could be applied in the entire spectral range data in order to identify differences or similarities between mangroves canopies.

CONCLUSIONS

The spectral identification of the 4 mangrove species was possible. All mangrove species were distinguished in band 1. In the visible bands 2 and 3 the spectra of *A germinans* and *L. racemosa* were confused and otherwise in the NIR band 4 the spectra of *C. erectus* and *R. mangle* would be confused.

Considering the mangrove species in this study *Conocarpus erectus* had the highest reflectance and *Rhizophora mangle* had the lowest in the visible bands, while in the NIR

region the leaf reflectance *of Avicennia germinans* was higher and *Laguncularia racemosa* was lower than both of the other 2 species.

Disregarding the aspects related to the architecture of canopies dominated by these species one should expect when using airborne or orbital data high reflectance values in canopies of *C. erectus* in the visible bands. The contrary should be expected for R. mangle canopies. In the visible bands canopies of *A germinans* and *L. racemosa* would be confounded. In the NIR region however canopies of *A germinans* are expected to be brighter while *L. racemosa* should present darker canopies. Both *R. mangle* and *L. racemosa* should be confounded in the NIR region.

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RESUMO

Comunidades de manguezais são sistemas tropicais que apresentam poucas espécies constituintes em relação às florestais tropicais úmidas, especialmente na América Latina. A identificação de manguezais mediante a observação de dados orbitais não é uma tarefa muito complicada, porém um desafio interessante seria a identificação florística dos manguezais. Folhas de quatro espécies arbóreas presentes em mangues tiveram suas folhas caracterizadas espectralmente mediante o uso de esfera integradora acoplada a um espectrorradiômetro SPECTRON SE-590 que permitiram a determinação de Fatores de Reflectância Direcional Hemisférica (DHRF). Na região do visível (0,45 – 0,69 μm), a espécie *Canocarpus erectus* reflete mais intensamente a radiação eletromagnética incidente, enquanto que a espécie *Rhizophora mangle* é a que reflete menos radiação. As espécies *Avicennia germinans* e *Laguncularia racemosa* podem ser distinguidas entre si na região do infravermelho próximo (0,76 – 0,90 μm), enquanto que nessa mesma região espectral as espécies *Conocarpus erectus* e *Rhizophora mangle* apresentaram valores similares de reflexão da radiação incidente.

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Table 1 - Results of ANOVA application on all species and spectral bands.

Table 2 - Duncan's test results for mangrove species, same letters indicate similar reflectance.

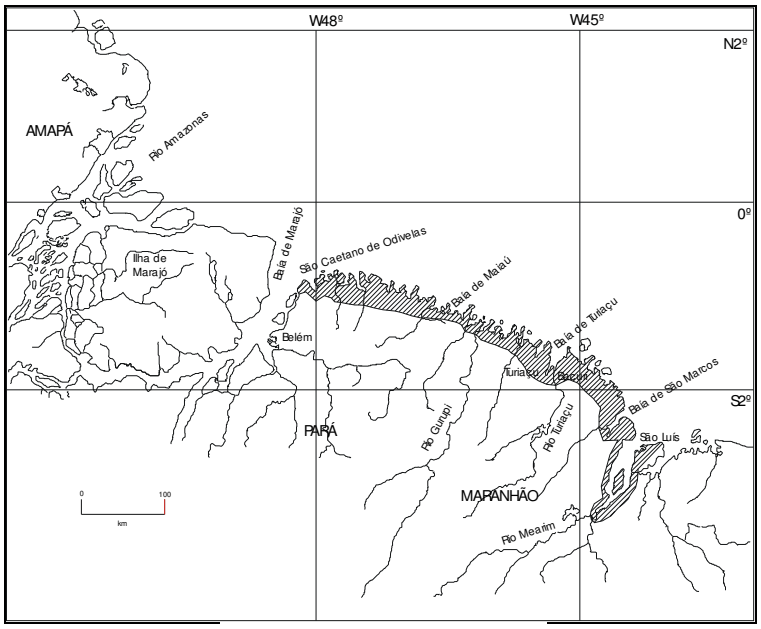
W48º
W45º
N2º
0º
S2º
AMAPÁ
Rio Amazonas
Ilha de Marajó
Baía de Marajó
São Caetano de Odivelas
Baía de Maiaú
Baía de Turiaçu
Belém
Turiaçu
Baía de São Marcos
São Luís
PARÁ
Rio Gurupi
Rio Turiaçu
MARANHÃO
Rio Mearim
0
100
km
Mangrove

Figure 1

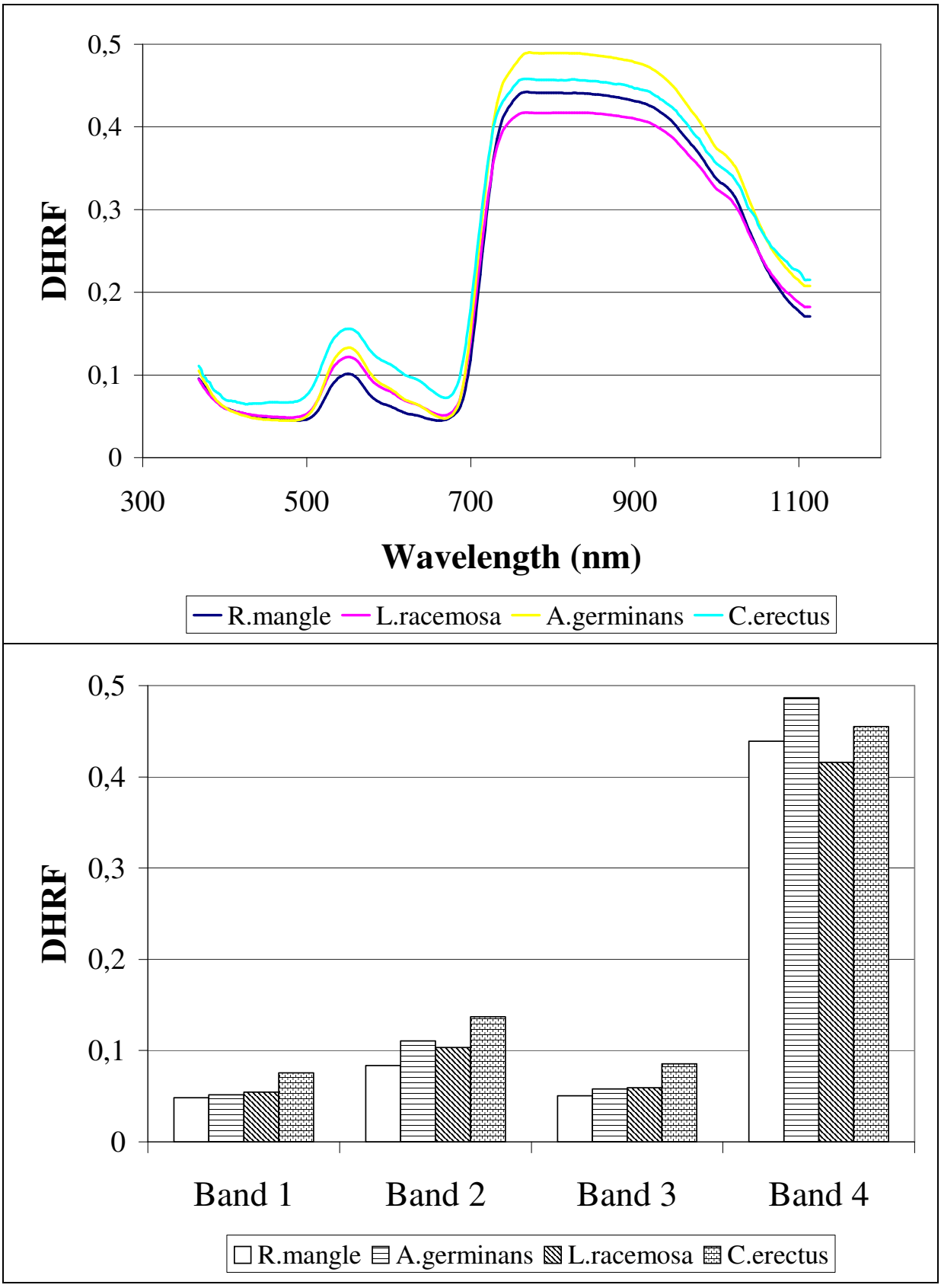
0,5
0,4
0,3
0,2
0,1
0
DHRF
300
500
700
900
1100
Wavelength (nm)
R.mangle
L.racemosa
A.germinans
C.erectus
0,5
0,4
0,3
0,2
0,1
0
DHRF
Band 1
Band 2
Band 3
Band 4
R.mangle
A.germinans
L.racemosa
C.erectus

Figure 2

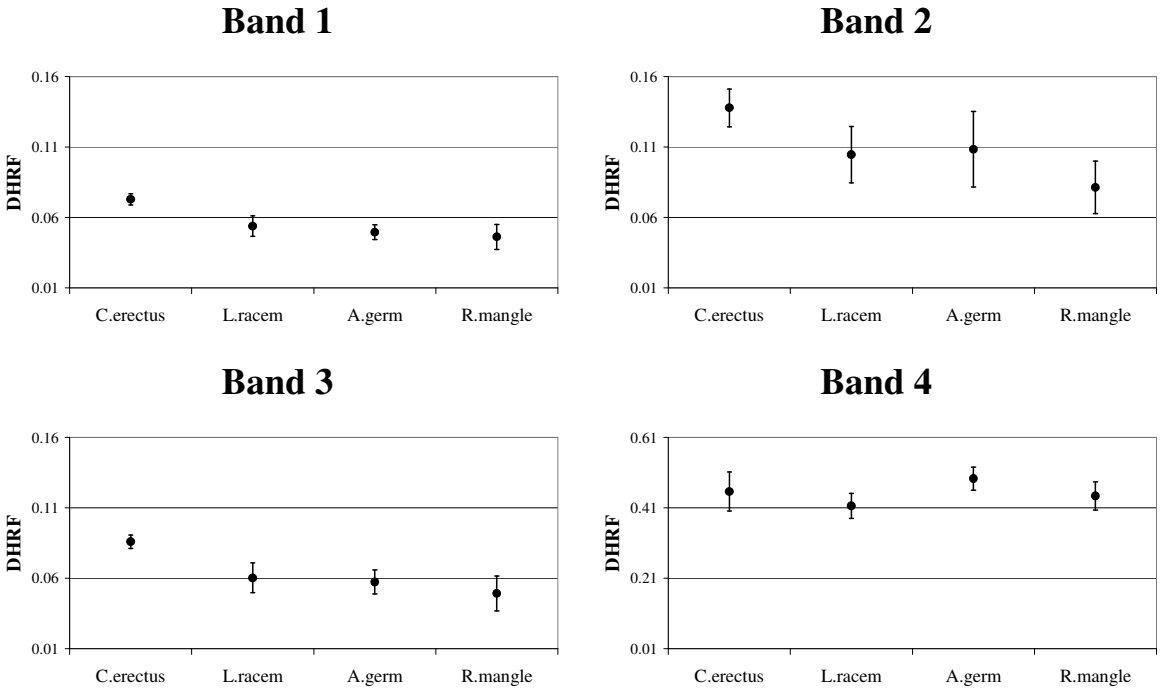
Band 1
Band 2
Band 3
Band 4
DHRF
0.16
0.11
0.06
0.01
0.61
0.41
0.21
C.erectus
L.racem
A.germ
R.mangle

Figure 3

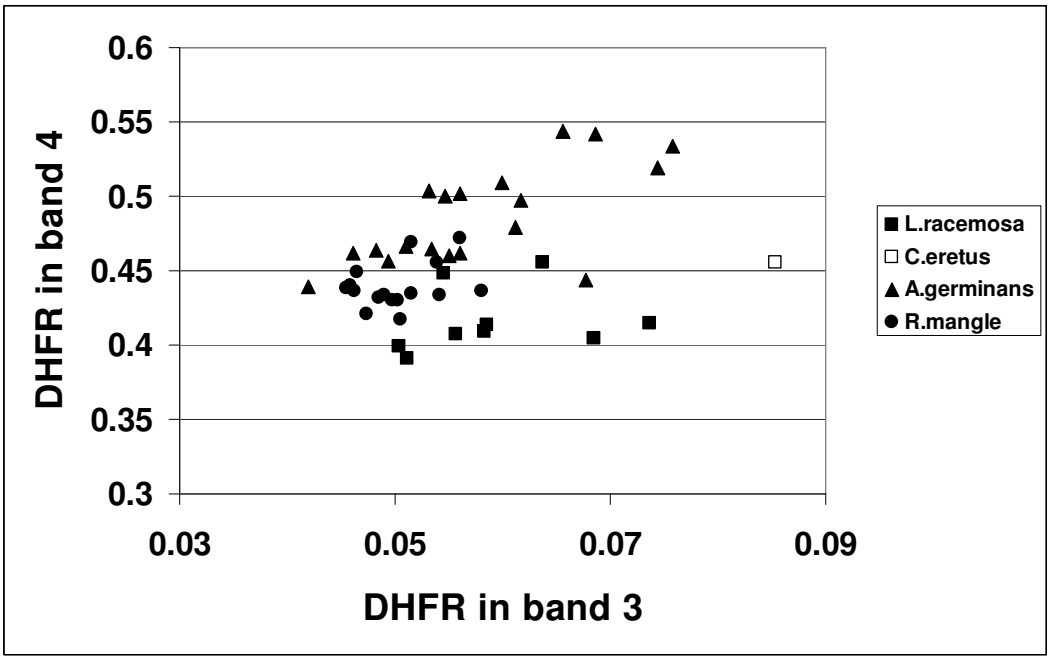
0.6
0.55
0.5
0.45
0.4
0.35
0.3
DHFR in band 4
0.03
0.05
0.07
0.09
DHFR in band 3
L.racemosa
C.eretus
A.germinans
R.mangle

Figure 4

Band 1	***Square Sum***	***Degrees of Freedon***	***Mean Square***	***F***	***P-value***	***F-crit***
Species	0.0164939	3	0.005498	121.94*	2.90E-40	2.120
Residual	0.0068529	152	4.508E-05			
Total	0.0233468	155				
Band 2	***Square Sum***	***Degrees of Freedon***	***Mean Square***	***F***	***P-value***	***F-crit***
Species	0.0627871	3	0.020929	49.681*	1.95E-22	2.120
Residual	0.0640332	152	0.0004213			
Total	0.1268203	155				
Band 3	***Square Sum***	***Degrees of Freedon***	***Mean Square***	***F***	***P-value***	***F-crit***
Species	0.0294241	3	0.009808	106.966*	2.82E-37	2.120
Residual	0.0139374	152	9.169E-05			
Total	0.0433615	155				
Band 4	***Square Sum***	***Degrees of Freedon***	***Mean Square***	***F***	***P-value***	***F-crit***
Species	0.1216148	3	0.0405383	22.614*	3.68E-12	2.120
Residual	0.2724773	152	0.0017926			
Total	0.3940922	155				

* Significative at 10% level of significance.

Table 1

	Band 1	**Band 2**	**Band 3**	**Band 4**
C.erectus.	a	a	a	b
L.racemosa.	b	b	b	c
A.germinans.	c	b	b	a
R.mangle.	d	c	c	b

Table 2