Progress report Sea Grant March 2008

Title:
Developing a protocol to use remote sensing as a cost effective tool to monitor contamination of mangrove wetlands

Principle Investigators
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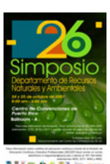
Graduate Students employed:
Ms Marianela Mercado Burgos

Undergraduate students employed:
Mr. Augustine Rodriguez Jan - May 2007
Ms. Angela Perez Jan - May 2007 and Aug – Dec 2007

Other undergraduate students involved
none

Presentations:



"Developing a protocol to use remote sensing as a cost effective tool to monitor contamination of mangrove wetlands: Initial results" XXVI Simposio del Departamento de Recursos Naturales y Ambientales 25 Oct. 2007

Abstract published

2007:Rodriguez, Augustine, Angela Perez, Belyneth Deliz, Yomayra Roman, Almaris Martinez, J.H. Schellekens, F. Gilbes, Remote sensing techniques for mineral exploration used to monitor metal contamination of mangroves: Program and abstracts Sigma Xi XII Posterday, UPRM, Mayagüez, Puerto Rico 26 April 2007, p. 34

2007: Schellekens, J.H., F. Gilbes, A. Rodriguez, B. Deliz, Y. Roman, Exploring remote sensing as a cost effective tool to monitor contamination of mangrove wetlands, XXVI Simposio del Departamento de Recursos Naturales y Ambientales de Puerto Rico, October 2007, San Juan, Puerto Rico.

Unpublished reports:

Schellekens, J.H., Gilbes, G., Rodrigues, A., Deliz, B, and Martinez, A., 2007, Preliminary results of the mangrove reflectance and composition study, unpublished internal report Dept. of Geology UPRM, 22p.

Mercado-Burgos, M. and Veguilla, R. 2007, NDVI and metal content relationship in *Rhizophora Mangle*, southwest of Puerto Rico Island, unpublished report remote sensing Dept. of Geology UPRM 14p.

Narrative:

In January 2007 the project hired two undergraduate students; Augustine Rodriguez, who continued in the project from the previous year and Angela Perez, who was selected from the new applicants. Unfortunately, both parts of the project the reflectance measurements and the chemical analyses became difficult this semester. The GER 1500 Spectroradiometer had to be send back to the manufacturer for service and remained out of service for a large part of the semester. The chemicals ordered needed a person in the UPRM with a license to handle explosives. We were unable to find a person willing and licensed to handle our ordered chemicals with the result that our order was canceled.

The semester was a loss for data collections. The two undergraduate students prepared a poster for the Sigma Xi student poster conference to present their research.

The 1st semester of 2007-2008 the project managed to attract a graduate student, Ms. Marianela Mercado-Burgos, a student with a BA in Natural Sciences from UPR Rio Piedras. She had previous experience with mangrove and coastal research and had experience with Remote Sensing and Geographical Information Systems (GIS). Ms. Angela Perez continued as an undergraduate research student to assist Ms. Mercado. Ms. Mercado reviewed the existing data and compared the use of IKONOS and AVHRR data to discriminate between mangrove species and contaminated and non-contaminated mangroves. She was not able to correlate NDVI with metal contamination in mangrove wetlands with the existing data (Mercado-Burgos & Viguilla, unpublished 2007)

Because no new data were collected during this semester a major effort was made to summarize all the important information of the existing data (Schellekens et al., 2007). A summary of the initial results was given on the 26th Symposium of the Department of Natural and Environmental Resources in San Juan. The presentation was given by Dr. Fernando Gilbes. The most important goal of this presentation was to promote our efforts to potential stake holders in the government.

In December 2007 the Center for Subsurface Sensing and Imaging Systems (CenSSIS) arranged for the first time in Puerto Rico an overflight of the hyperspectral sensor AISA. This sensor has 244 channels and it is operated and distributed by Galileo Group. It operates across the VIS/NIR portion of the spectrum (400-1,000 nm), resolving spectral differences as fine as 2-4 nm. AISA flew over several coastal areas of Puerto Rico, including mangrove sites in Guanica. Dr Fernando Gilbes arranged for an overflight and ground truthing of the Guanica area, which plays an important role in our project as a non-contaminated control area.

By the end of the first semester our project advertised to attract undergraduate students as research assistants. Three excellent candidates applied (2 female, 1 male). During the selection process, Ms Mercado, our graduate student, withdrew from the project. No new graduate students were available on such a short notice. Recruiting the undergraduate research assistants then became an inefficient way to use our funds. We decided to freeze the project for a semester and ask for a no-cost extension of the project. Recruit a new graduate student and two undergraduate research assistants for that year is underway.

Websites:
Progress report http://gers.uprm.edu/pdfs/report_mangrove07.pdf

Presentation in the 2nd Annual Symposium for Coastal and Marine Research, UPR Sea Grant College program October 5, 2006 Mayagüez, Puerto Rico:
http://gers.uprm.edu/pdfs/seagrant06.pdf
Presentation in the XXVI Simposio del Departamento de Recursos Naturales y Ambientales de Puerto Rico, October 2007, San Juan, Puerto Rico.
http://gers.uprm.edu/pdfs/pres_dnr07.pdf

Summary of scientific results:

Site descriptions

Guayanilla Bay is a known area of heavy metal contamination. Mercury levels in Guayanilla Bay compared to other locations (Lopez and Teas, 1978) expressed values 10 times higher than of other coastal areas such as the Joyuda Lagoon, Punta Ostiones, Guanica Bay, and the Phosphorescent Bay (Stary and Lopez, 1979). Stary and Lopez (1979) tried to establish a base-line for mercury concentrations in probably non-contaminated mangrove swamps, using leaves, wood, roots and propagules of mangroves.

Guayanilla Bay is located in the Yauco River Valley surrounded by Ponce Limestone, mudstone from the Juana Diaz Formation and alluvial sediments. The Yauco River also brings additional sediments from Upper Cretaceous volcanic derived rocks. Along the Guayanilla Bay, many industries can be observed (Rodriguez, 2006)
In the Guayanilla Bay area known as the Comunidad el Faro, GPS stations 1-3 (N 17º 59.719, W 66º.47475) and stations 4-6 (N 17º 59.726, W 66º.4645) were established. Station 1 and 4 were black mangroves, where soil and leaves were taken. Station 2 and 3 were red mangroves, and station 5 and 6 were white mangroves. Guayanilla Bay pH and water temperature were taken, pH 8.06 and 32.9º C. (Rodriguez, 2006)

Arecibo is located in the northern part of the island and has a substrate that is derived from limestone, and carbonate sediments. The mangroves in the Arecibo area thrive in an enclosed lagoon. In this site was the AAA Sewage Treatment Plant, the lagoon was near an urbanization and the rice plantation *D'Aqui* was located near this vast wetland environment. In the Urbanization Jarielito in Arecibo six stations were established. Stations 1 and 2, black mangroves were sampled. Stations 3 and 4, white mangroves were sampled. Stations 5 and 6, red mangroves were sampled. GPS coordinates were taken in Arecibo, N 18º 28.743, W 66º41.115. The pH and temperature of the water was taken in Arecibo with standards of 7.01- 10.01, two readings were taken, pH 6.94 and 27.3ºC and pH 6.91 and 27.8ºC (Rodriguez, 2006).

Chemical analyses

Chemical compositions of the substrate and leaves are given in Schellekens et al. (2007). These include the chemical compositions of the lower, middle and upper leaves of the red mangrove (*Rhizophora mangle*) of the Guayanilla beach and the Joyuda Lagoon. Chemical composition of the subtrate of the mangroves is available for Joyuda, Arecibo, Guanica and Guayanilla. Due to the natural zoning in mangrove forests, the substrate of red mangroves will be the closest to the water edge, whereas the black and the white will represent increasing landward locations.

Metal Transport in Mangroves

An important factor in the use of mangroves to monitor for heavy metal contamination of the substrate is the ease or ability for the mangroves to transport these elements from the substrate to the tree and within the tree to the top of the canopy. Two areas were selected to investigate the transport abilities, Joyuda and Guayanilla, and in order to limit the variables, only *Rhizophora mangle* (red mangroves) were use in this study. Samples were collected from the substrate, the leaves from the lower branches, leaves from intermediate level branches, and leaves from the top of the canopy (Martínez-Colón, 2006). It should be noted that in Joyuda, no leaves of the top of the canopy were collected, but the 'top' is here represented by the highest leaves that could be reached. Fortunately the data available from Punta Ballena (Roman-Colón, 2006) allows an insight into the transport between substrate and top of canopy for both *Rhizophora mangle* and *Avicenna germinans* for a few elements.

Calculations for transport are given in Tables 1, 2, and 3. Only meaning full calculations are shown. The transport from substrate to top is expressed as the top/substrate ratio, where a ratio > 1 shows concentration of the element with respect to the substrate, and ratios between 0.1 and 0.3 show minor transport, 0.4 and 0.6 observable transport and 0.7 to 1.0 can be classified as well observable transport.

When comparing the metal content of the substrate and the top of the canopy of the *Rhizophora mangle* in Guayanilla it is obvious that the concentration in the leaves is considerably lower than that in the substrate. The highest top/substrate ratio recorded is 0.41 for Cu. A similar pattern is visible in Joyuda where Ni and Co transport from substrate is negligible, whereas Cu shows an enrichment of the leaves with respect to the substrate. In Punta Ballena the Cu transport from substrate to top in *Rhizophora mangle* is minor, whereas the *Avicenna germinans* shows a strong concentration. Similarly, although Co and Cd are below detection in the substrate, they are present in the top of the canopy.

Metal transport within the tree is expressed as the ratio top/bottom, where a ratio of >1 indicates that the tree transports the metal upwards, ratios <1 indicate that the metals lack behind in the lower leaves. Data for this project are only available for *Rhizophora mangle* in Joyuda and Guayanilla. Cu, Co, Cr in Guayanilla show good transport within the tree, the data for Pb are ambiguous but within tree transport well visible. Cu in Joyuda show the same behavior, the other elements were not analyzed in

Joyuda. Ni both in Guayanilla and Joyuda shows only minor transport in the tree, the lower leaves have higher contents.

Discussion

In all studied localities Cu seems to be transported from substrate to the top of the canopy in *Rhizophora mangle*, in some cases, such as in Joyuda and the *Avicenna germinans* in Punta Ballena even concentrated to strongly concentrated. In Guayanilla and Joyuda, Ni and Co are present in the substrate, and Co in Punta Ballena (Ni was not analyzed), but can hardly be detected in the top of the canopy, suggesting only limited transport to the top of the canopy for *Rhizophora mangle*. The same as for Cd in Guayanilla and Punta Ballena. Surprisingly the *Avicenna germinans* in Punta Ballena shows an contrasting behavior: Co and Cd are below detection in the substrate but the top of the canopy has a considerable content of these elements. Judging from the limited transport in the *Rhizophora mangle* of these elements and the very strong concentration of Cu in *Avicenna germinans*, we may conclude that *Avicenna germinans* is an excellent transporter and a concentrator of these elements. The possibility that these elements are not provided by the substrate, but are wind carried is unlikely, because the *Rhizophora mangle* in the same area do not have a high content in their leaves.

Data for transport within the tree are limited. As a first conclusion it shows that Cu, Co, Pb, and Cr are transported within the tree, but that Ni behaves different. Although the Ni content may be high in the substrate, it is only minor transported into the tree and does not easily move higher.

Table 1 Enrichment ratios for *Rhizophora mangle* (red mangrove) in Guayanilla
Contents of 0 or 0.00 means analyzed but below detection limit)

Guayanilla					Ratio top/substrate	ratio top/bottom
Cu	substrate	B	M	T		
	97.6	31.1	24.2	24.4		0.78
	99.2	28.8	25.0	27.1		0.94
		33.7	51.9	68.9		2.04
Average	98.4	31.2	33.7	40.1	0.41	1.29

Ni	substrate	B	M	T		
	46.7	1.9	1.2	0.6		0.32
	29.7	1.3	1.1	0.4		0.31
		0.7	0.2	0.3		0.43
Average	38.2	1.3	0.8	0.4	0.01	0.33

Co	substrate	B	M	T		
	15.2	0.1	0	0		0.00
	14.9	0	0.1	0		
		0.1	0.2	0.5		5.00
Average	15.05	0.07	0.10	0.17	0.01	2.50

Cd	substrate	B	M	T		
	0.00	0.10	0.10	0.00		0.00
	0.00	0.00	0.10	0.00		
		0.00	0.00	0.00		
Average	0.00	0.03	0.07	0.00		0.00

Pb	substrate	B	M	T		
		6.80	10.00	9.80		1.44
		14.10	12.10	7.20		0.51
		8.30	8.40	10.50		1.27
Average	0	9.73	10.17	9.17		0.94

Cr	substrate	B	M	T		
		0.00	0.40	1.40		
		7.60	2.10	2.30		0.30
		5.00	3.00	13.10		2.62
Average	0.00	4.20	1.83	5.60		1.33

Table 2 Enrichment ratios for *Rhizophora mangle* (red mangrove) in Joyuda

Joyuda					Ratio top/substrate	ratio top/bottom
Cu	substrate	B	M	T		
	36.4	53.0	78.8	60.2		1.14
	63.9	65.3	18.9	99.7		1.53
		9.9	19.0	18.1		1.83
Average	50.2	42.7	38.9	59.3	1.18	1.39

Ni	substrate	B	M	T		
	177.0	3.8	22.0	3.8		1.00
	176.5	11.9	6.3	4.4		0.37
		4.1	5.8	0.6		0.15
Average	176.8	6.6	11.4	2.9	0.02	0.44

Table 3 Enrichment ratios for Avicenna germinans (black mangrove) in Punta Ballena

Pta Ballena black						
Cu	substrate	B	M	T		
1	20.5			21.3		
2				94.3		
3				41.1		
7	13.6			170.0		
8	10.4			109.0		
9				144.0		
Average	14.8	0.0	0.0	96.6	6.51	

Co	substrate	B	M	T		
				3.4		
				9.8		
				15		
	0			15.8		
	0			1.4		
	0			0.16		
Average	0.0	0.0	0.0	7.6		

Cd	substrate	B	M	T		
				0.50		
				0.60		
				0.70		
	0.00			0.20		
	0.00			0.00		
	0.00			0.00		
Average	0.0	0.0	0.0	0.3		

Leave reflectance of *Rhizophora mangle* at different levels in the tree

Part of the study of the transport of metals in the tree included the determination of the leave reflectance at these different levels. Five leaves were sampled at the bottom, at the middle and at the highest level, the top of the canopy. Every leave was measured 10 times with the GER 1500 Spectroradiometer. A Spectralon gray card that reflects 50% of the incoming radiation was used as standard in order to calculate the reflectance. Reflectance spectra for location 2 are given in figure 1. Normalized Difference Vegetation Indices (NDVI) were calculated using the formula:

$$NDVI = (Rir - Rr) / (Rir + Rr)$$

In which Rir is the average reflectance of the near infrared band and Rr the average reflectance of the red band. Values for the wavelength were taken from the band 1 and 2 of the NOAA AVHRR satellite, with values of 0.58-0.68 nm and 0.72-1.0 nm respectively. The results for the NDVI values for the Rhizophora mangle in Guayanilla are given in table 4.

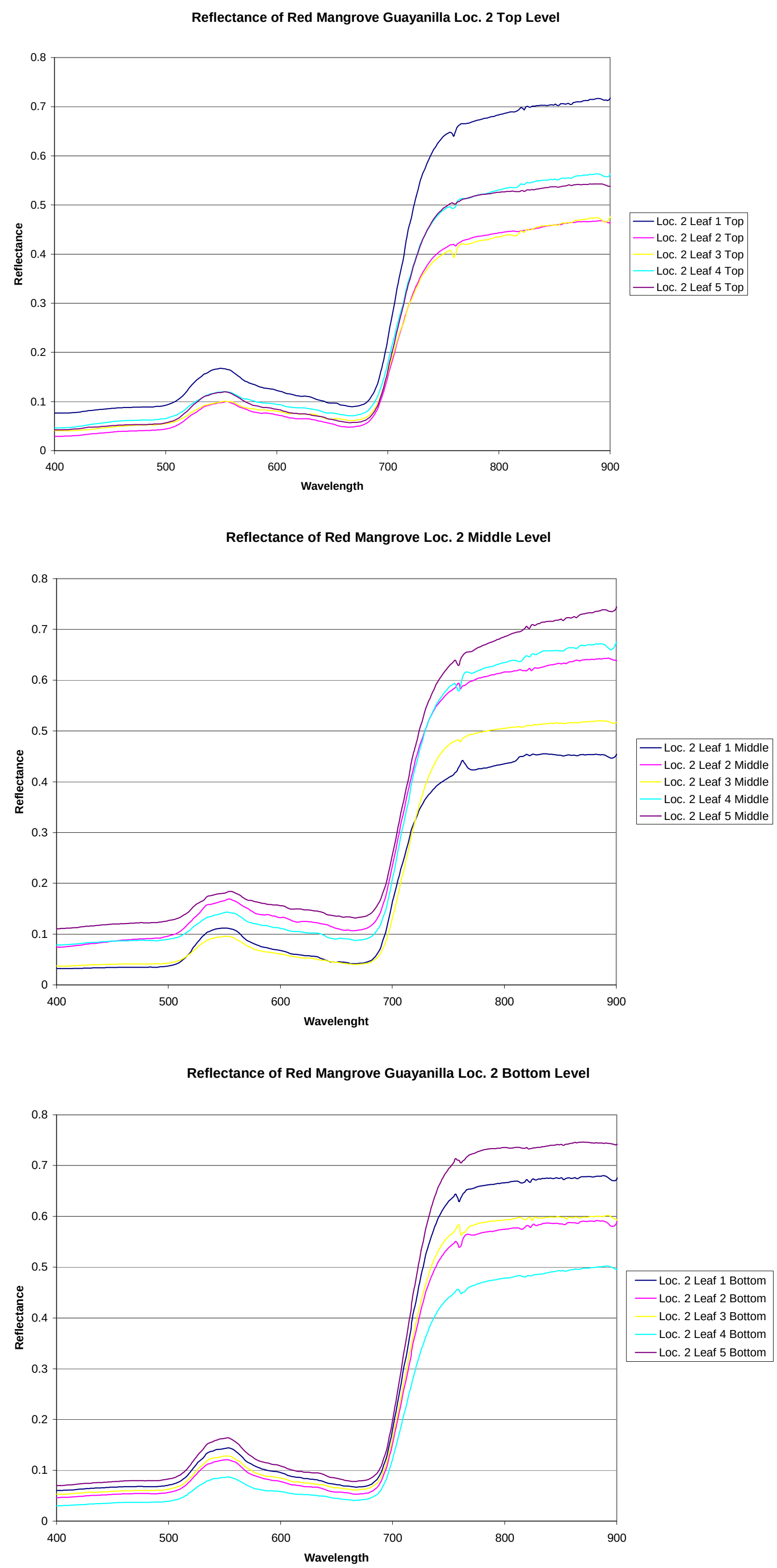


Figure 1. Reflectance patterns of leaves of the red mangrove (*Rhizophora mangle*) at lowest level, middle level and top level in Guayanilla, NDVI values and average NDVI plus standard deviation are given in table 5.

Table 4 NDVI values for Rhizophora mangle in Guayanilla (Rodríguez & Deliz, 2006)

Location 1	1	2	3	4	5	Average NDVI	St Dev
Top	0.78	0.77	0.78	0.82	0.76	0.78	0.02
Middle	0.75	0.73	0.76	0.78	0.79	0.76	0.02
Bottom	0.79	0.78	0.83	0.83	0.80	0.81	0.02
Location 2	1	2	3	4	5		
Top	0.73	0.75	0.72	0.72	0.75	0.74	0.02
Middle	0.77	0.67	0.81	0.72	0.65	0.73	0.07
Bottom	0.77	0.79	0.77	0.81	0.77	0.78	0.02
Location 3	1	2.00	3	4	5		
Top	0.71	0.76	0.74	0.75	0.79	0.75	0.03
Middle	0.81	0.82	0.78	0.71	0.76	0.77	0.04
Bottom	0.81	0.75	0.83	0.82	0.81	0.80	0.03

The reflectance measurements for each leave are an average of 10 measurements. The NDVI was calculated for every leave using the wavelength of band 1 and 2 of the NOAA AVHRR satellite (resp. 0.58-0.68 nm for red, and 0.72-1.0 nm for NIR).

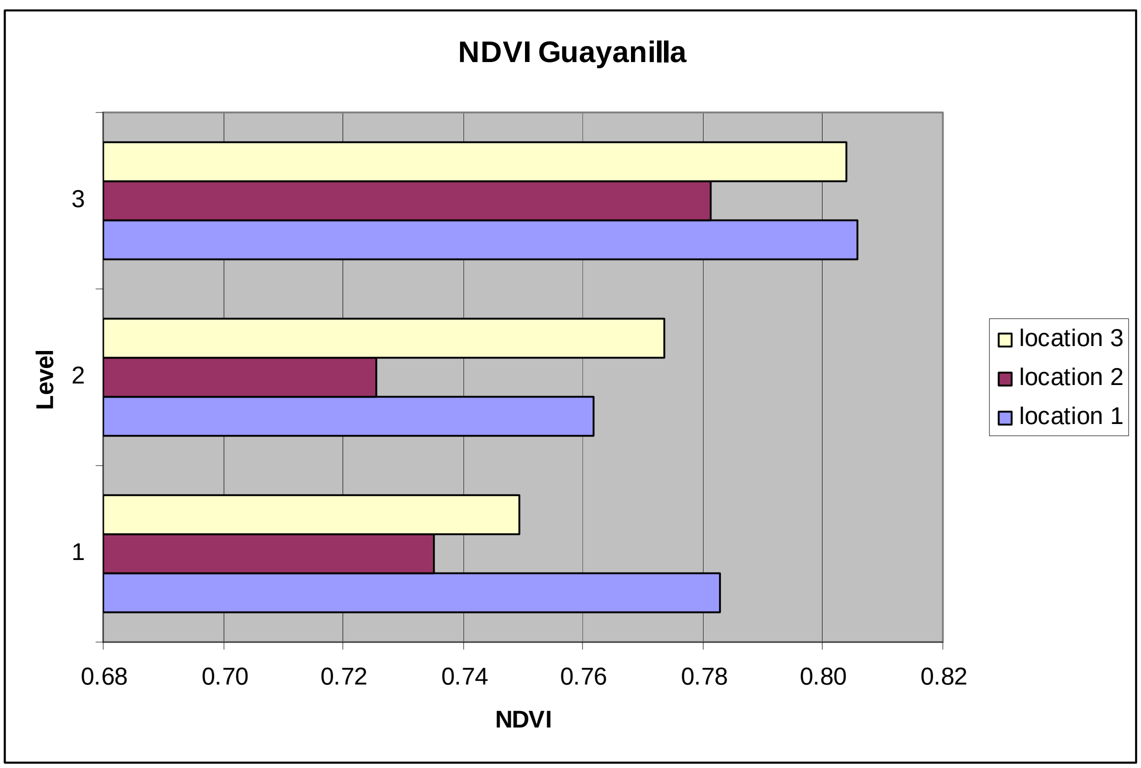


Figure 2. NDVI values for leaves of *Rhizophora mangle* in Guayanilla. Level 1= bottom, level 2 = middle, level 3 = top level of the leaves.

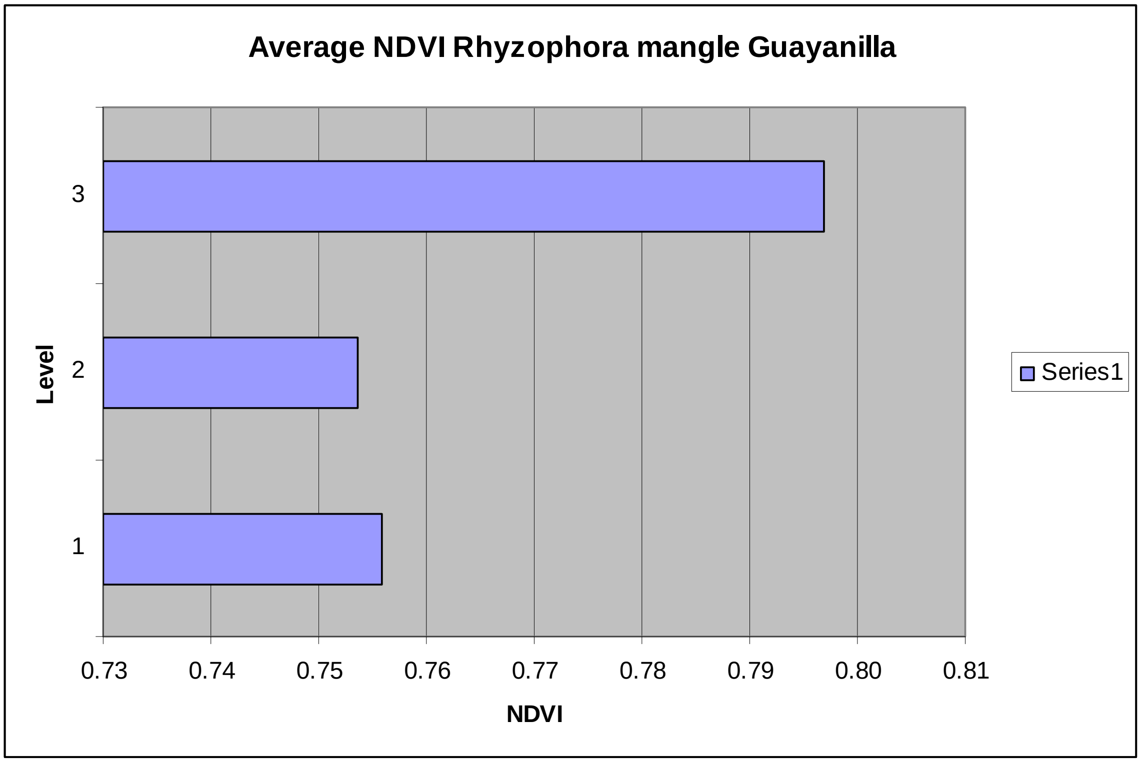


Figure 2. Average NDVI values for Rhizophora mangle in Guayanilla. Level 1= bottom, level 2 = middle, level 3 = top level of the leaves.

Comparison between NDVI measured on the ground and in an AVIRIS image

The Punta Ballena area became a test ground for comparing the reflectance measured with the GER1500 radiospectrometer and the reflectance measured using the bands in AVIRIS images (Roman, 2006).

Table 5 NDVI data Roman-Colon (2006) for mangroves and AVIRIS in Punta Ballena area

Station	R= Rhizophora m B= Avicenna g	NDVI	NDVI averaged	NDVI AVIRIS
1	B	0.64	0.65	0.80
2	B	0.62		
3	B	0.59		
4	R	0.78		
5	R	0.67		
6	R	0.59		
7	B	0.75	0.66	0.68
8	B	(0.15)		
9	B	0.56		

Table 5 lists the NDVI values determined by Roman-Colon (2006) using the GER-1500 spectroradiometer for 9 stations. In the right hand column the NDVI as measured with AVIRIS images and determined using ENVI is listed. The top number is the average of stations 1 to 6 and the lower number is the average of stations 7 to 9. In the column to the left the averages of the GER measured values was calculated for the same stations. The result for station 8 was ignored as being probably erroneous. No good correlation is visible for the stations 1 to 6. The most likely explanation being that these stations involved single trees standing on a beach, these trees were smaller than one AVIRIS pixel (30m) and the reflectance includes reflectance of the beach sand.

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