Annual report Sea Grant
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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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Reporting period 22 May 2006 to 1 March 2007

Undergraduate students employed:
Mr. Augustine Rodríguez-Román
Ms. Belyneth Deliz-López
Other undergraduate students involved
Ms. Almaris Martínez-Colón

Presentations:
"Usando Percepción remota como una herramienta para monitorear contaminación de mangles" Sociedad Horticultura del Oeste, San German, PR, 1 October 2006.

"Developing a protocol to use remote sensing as a cost effective tool to monitor contamination of mangrove wetlands" 2nd Annual Symposium for Coastal and Marine Research, UPR Sea Grant College program Mayagüez, PR, 5 October 2006.

"Can we use remote sensing to monitor contamination in mangrove wetlands?" Sociedad Geologica Estudantil, UPRM, Mayagüez, PR, 1 March 2007

Abstract published
2006: Schellekens, J.H., F. Gilbes-Santaella, A. Rodriguez-Roman, Yomayra Roman-Colon, Developing a protocol to use remote sensing as a cost effective tool to monitor contamination of mangrove wetlands: Abstracts of the 2nd Annual Symposium for Coastal and Marine Research, UPR Sea Grant College program October 5, 2006 Mayagüez, Puerto Rico, p. 9.

Unpublished reports:
Martinez-Colon, Almaris, 2006, Distribution of metals and leave reflectance in red mangrove (Rhyzophora mangle). Comparison between Joyuda and Guanica mangrove areas: Unpublished Undergraduate Research report Dept. of Geology, UPRM

Deliz-López, Belyneth and Rodríguez -Román, Augustine, 2006, Monitoring metal contamination of mangroves using remote sensing techniques: Guayanilla: Internal Research report Dept. of Geology, UPRM

Narrative:

In August 2006 we advertised two positions of undergraduate research assistants in the project. Four undergraduate students responded: 2 females and 2 males. We hired Ms. Belyneth Deliz and Mr. Augustine Roman. Both undergraduate students carried out leave reflectance measurements in the field and collected leave and sediment samples for chemical analysis. A third undergraduate student participated as part of her course GEOL 4055 Undergraduate Research II. The three students carried out chemical analyses in the Atomic Absorption Spectrometer (AAS) laboratory of Dr. Arturo Massol under the supervision of Ms. Elba Diaz.

In order to learn more about the movement of metals in the mangroves and the effect of these metals on the leave reflectance, a test was designed where the composition of the soils was compared to the composition and reflectance of leaves at three levels within the tree (lowest, middle and top level). In order to avoid difference due to mangrove species, only leaves of the red mangrove (*rhyzophora mangle*) were used for this test. This semester the leaves were analyzed for Cu, Co, Cd, Ni, and Pb. The AAS laboratory was equipped to do these analyses. The toxic metal As and Hg are planned for next semester after the special chemicals ordered have arrived.

Reflectance measurements were taken by cutting 5 leaves at each level (lowest, middle, and top) (figure 1). From each leave 10 reflectance measurements were taken (figure 2). Giving 5 x 10 x 3= 150 measurements per tree, in each area 3 trees were sampled, giving a total of 450 reflectance measurements per sample area. The leaves of the three levels were collected for chemical analysis. The sample areas selected for these tests were: Joyuda Lagoon (with natural Ni, Co contamination, and reported As contents), Guayanilla (possible industrial contamination, reported Hg), Guanica (probable pristine environment next to Tropical Dry forest reserve, with carbonate rocks and no substantial run-off).

Figure 1. Sampling of mangrove leaves using a pole-pruner

Figure 2. Measuring the reflectance of the leaves using the GER 1500 spectroradiometer.

Initial results

A number of analyses were carried out in the laboratory of Dr. Massol in the department of Geology with the help of Ms. Elba Diaz. Chemical results are listed in the tables 1 to 3.

Table 1. Summary chemical analyses substrates (Rodriguez, 2006) (all points are the average of four samples)

	Ni ppm	Cu ppm	Co ppm	Pb ppm	Cd ppm
Guayanilla	30	128	14	5	0
Guanica	4	70	1	11	0
Arecibo	15	72	5	15	0
Joyuda	141	63	11	5	0

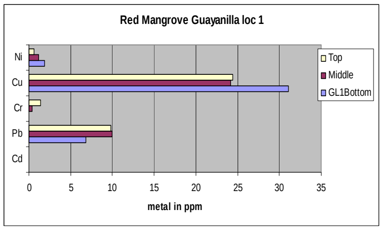
Table 2. Chemical composition leaves of *Rhyzophora mangle* in the Guayanilla area (Rodriguez and Deliz, 2006)

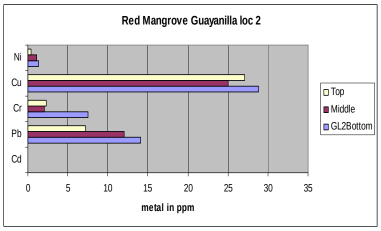
	Cd ppm	Pb ppm	Cr ppm	Cu ppm	Ni ppm
GL1B	0	7	0	31	2
M	0	10	0	24	1
T	0	10	1	24	1
GL2B	0	14	8	29	1
M	0	12	2	25	1
T	0	7	2	27	0
GL3B	0	8	5	34	1
M	0	8	3	52	0
T	0	10	13	69	0

All analyses are the average of two analyses. B, M, and T refers to the level of the leaves in the tree: Bottom, Middle, and Top

Table 3. Chemical composition leaves of *Rhyzophora mangle* in the Joyuda area (Martinez, 2006)

	Cd ppm	Cu ppm	Ni ppm
JO1B	0	53	4
M	0	79	22
T	0	60	4
JO2B	0	65	12
M	0	19	6
T	0	100	4
JO3B	0	10	4
M	0	19	6
T	0	18	1





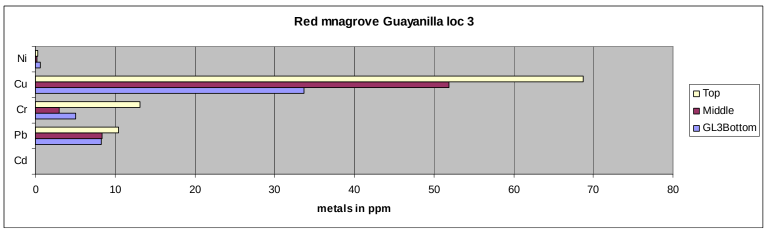


Figure 3. Chemical variation diagrams. Comparison of red mangroves (*Rhyzophora mangle*) of Guayanilla form three locations, separated in top, middle or lower leaves of the canopy.

Discussion of the chemical data

Table 1 shows the chemical analyses available for the substrate from previous undergraduate research projects. The sites were selected for their possible contamination: Joyuda (Acevedo et al, 2000), Guayanilla (Lopez and Teas, 1978), Arecibo or for their pristine nature, Guanica. If the Guanica area is indeed the non-contaminated site as was expected, the metal values may be base-line values for Puerto Rico. The Ni and Co are low as was expected, but the values for Cu (70 ppm) and Pb (11 ppm) are higher than expected. Cu may be always present in this amount, but the Pb is higher than in Guayanilla and Joyuda and may be a result of local pH conditions or contamination.

The high content of Ni and Co in the Joyuda Lagoon was expected next to the Guanajibo Ni-Co laterite deposit (Cram, 1972). The Arecibo area was selected because it formed part of the drainage basin of the porphyry copper deposits (Plaza-Toledo, 2005). Surprisingly the values for both Pb and Cu are comparable to the supposedly pristine Guanica area. Guayanilla, for which Hg contamination was reported (Lopez and Teas, 1978) shows a fairly high content in Ni and Co, also the Cu is twice as high as the other analyzed areas.

Leave analyses were carried out in order to determine the movement of metal in the trees. Did the metal move from the substrate into the plant and did the metal move to the top of

the canopy, where it satellite based detectors would be able to see influence of the metal on the chlorophyll production and hence on the reflectance pattern.
The most complete set of data at this moment are the chemical analyses of a red mangrove (*rhyzophora mangle*) in the Guayanilla Mangrove area. Cd and Ni are low and Cu and Pb show a considerable content. It is not clear yet how significant the difference between the lower, middle and top leaves is. Statistical analyses are planned to investigate this. The presence of Cu and Pb in the leaves probably reflects the presence of these metals in the substrate. Analyses for Hg and As will be carried out this semester. Chemical have been purchased to be able to do these analyses.

The data presented for Joyuda look suspect. The substrate contains considerable amounts of Ni and Co (Table 1). The Cu in the leaves may be a reflection of the Cu in the substrate, but previous analyses showed a high content of Ni, so there is a possibility of mix up of the analytical data. This possibility will be further investigated.

Reflectance measurements

The reflectance of the red mangrove leaves was measured using the GER 1500 radiospectrometer.

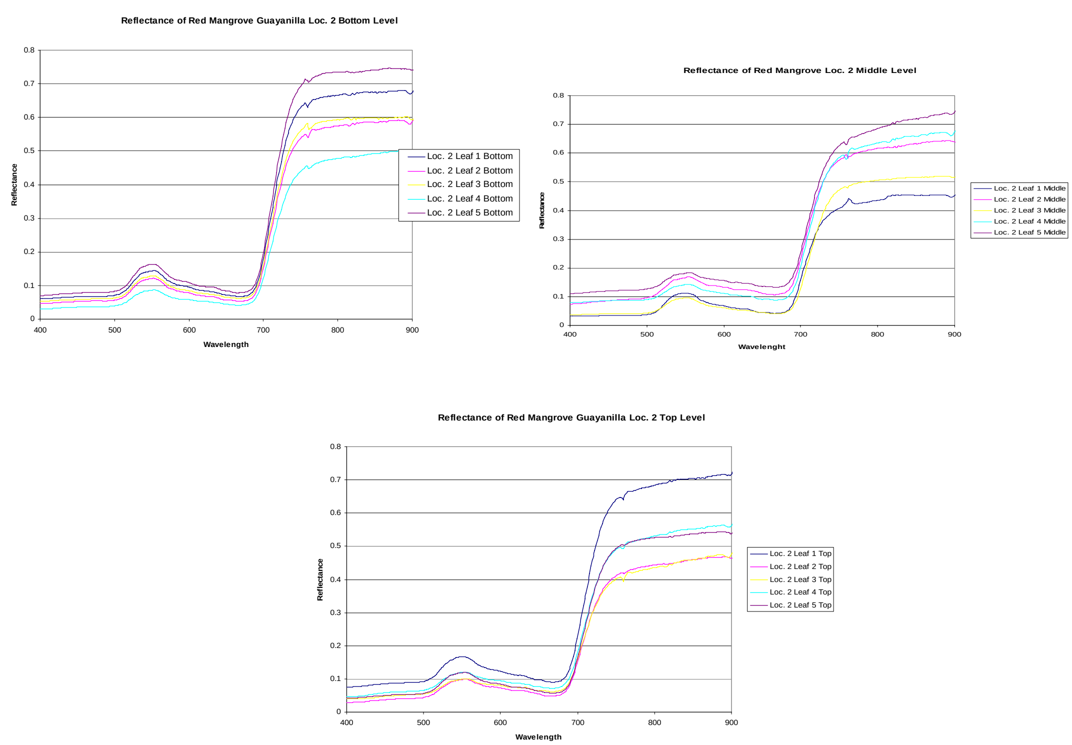


Figure 4 Reflectance patterns of Red mangrove (Rhyzophora mangle) of Guayanilla location 2. The three subfigures are the reflectance patterns of the lower, middle and top leaves of the tree.

Discussion of the reflectance patterns

An example of the reflectance patterns is given in figure 4. As is clear the variation between the reflectance patterns within one level of the tree is just as large as the variation between the different levels. Not all reflectance patterns collected have been corrected. In addition to a close look at the patterns to eliminate incorrect results, staitical analyses of the variation in patterns should be made. Metal content tends to affect chlorophyll production and as a result the location of the IR shoulder. This will be analyzed using the derivative of the curves

Future plans:

- A large amount of data is now available and the next step is to carry out quality control on the reflectance data. Many reflectance curves show anomalous values that will have to be checked and possibly eliminated.
- Statistical analysis of the reflectance patterns and the chemical data will be carried out in order to study the significance of the variation. The first derivative of the pattersn will be compared to the chemical composition in order to detect any correlation.
- Several areas will added to the study: Arecibo with possible Cu and Pb contamination, Ponce where DNRA reports contamination, Punta Verraco, where neighbors claim chemical test where carried out.
- Satellite images will be selected and purchased.
- Presently the project only employs undergraduate students. Graduate student will be recruited to continue and expand the research to fulfill the plans of the proposal.

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Acevedo, D., Rodriguez-Sierra, C.J., Reyes, D.R., and Jimenez, B.D., 2000, Heavy metals in sediments and water from San José and Joyuda Lagoons in Puerto Rico, in: J.A. Centeno et al. Editors, *Metal Ions in Biology and Medicine, volume 6,* p. 169-172.

Cram, C.M., 1972, Estudio preliminar de geología económica del yacimiento niquelífero Barrio Guanajibo: Comisión de Minería, Depto. De Recursos Naturales de Puerto Rico.

Lopez, J.M. and Teas, H.J., 1978, Trace element cycling in magroves: *Symposium on Physiology of Plants in Coastal Ecosystems with emphasis on trace metal cycling, Blacksburg VA.*

Stary, S.J. and Lopez, J.M., 1979. A study of the mercury concentrations of the red mangroves of the south and west coasts of Puerto Rico: *Center for Energy and Environmental Research* M-43.

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

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Project number: R-21-1-06.

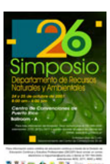
Reporting period 1 March, 2007 to 28 February 2008

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.

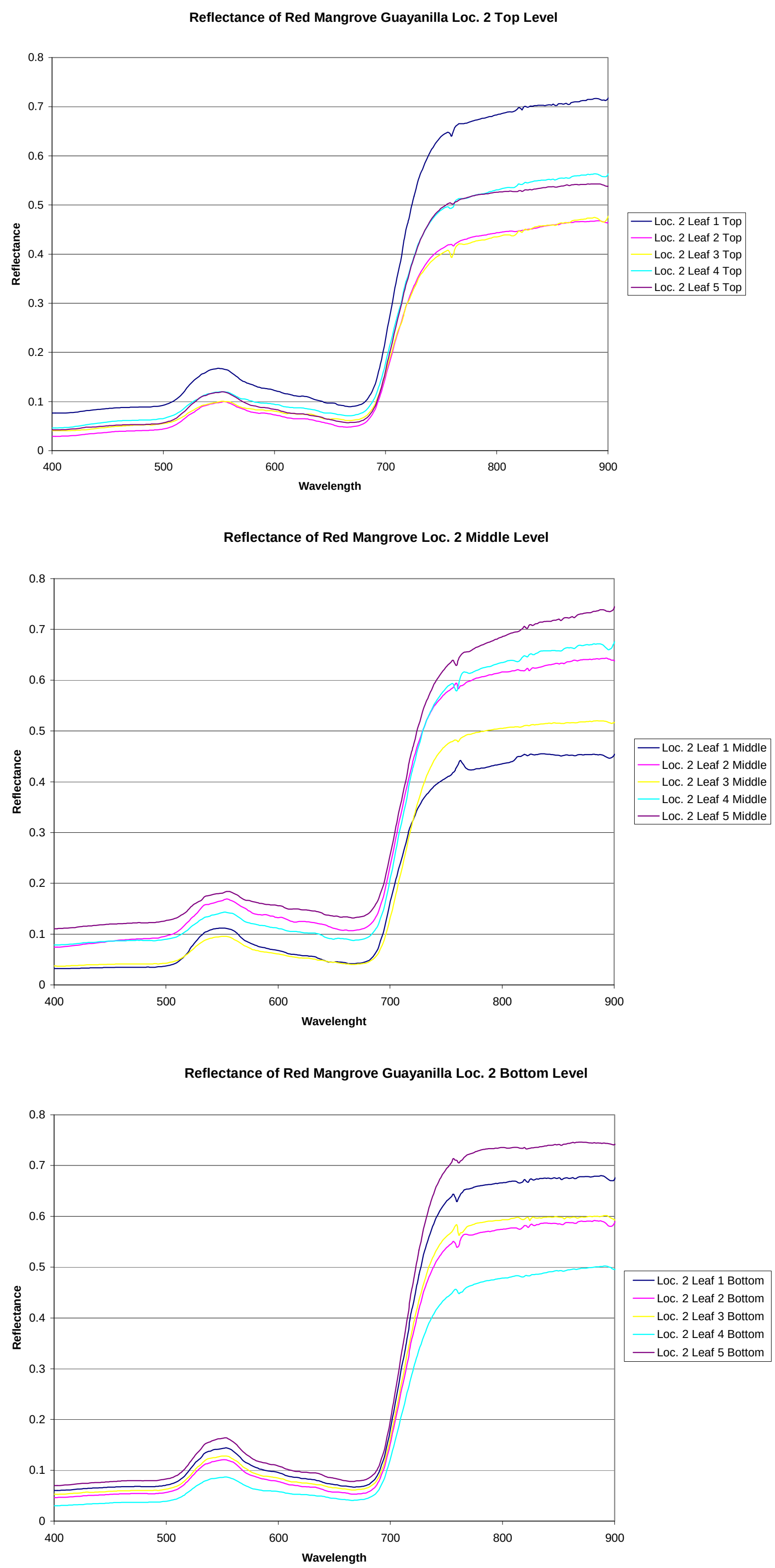


Figure 1. Reflectance patterns of leaves of the red mangrove (*Rhizophora mangle*) at lowest level, middle level and top level in Guayanilla, NDVI values and average NDVI plus standard deviation are given in table 5.

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).

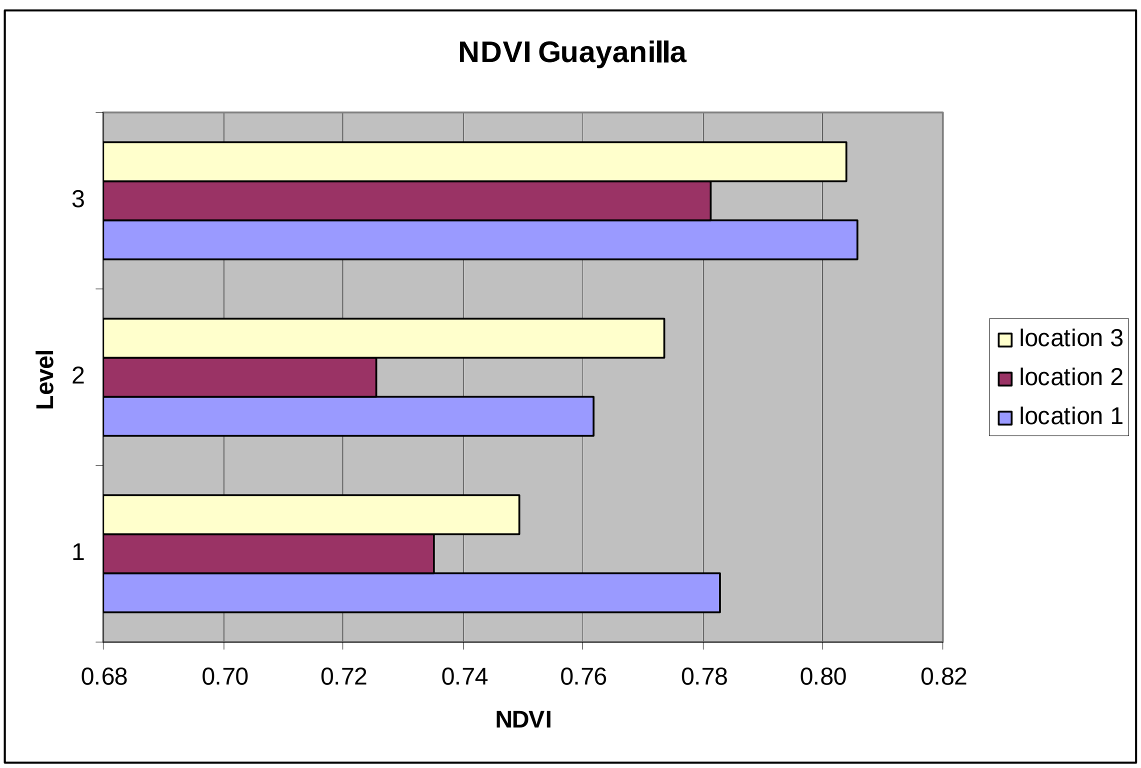


Figure 2. NDVI values for leaves of *Rhizophora mangle* in Guayanilla. Level 1= bottom, level 2 = middle, level 3 = top level of the leaves.

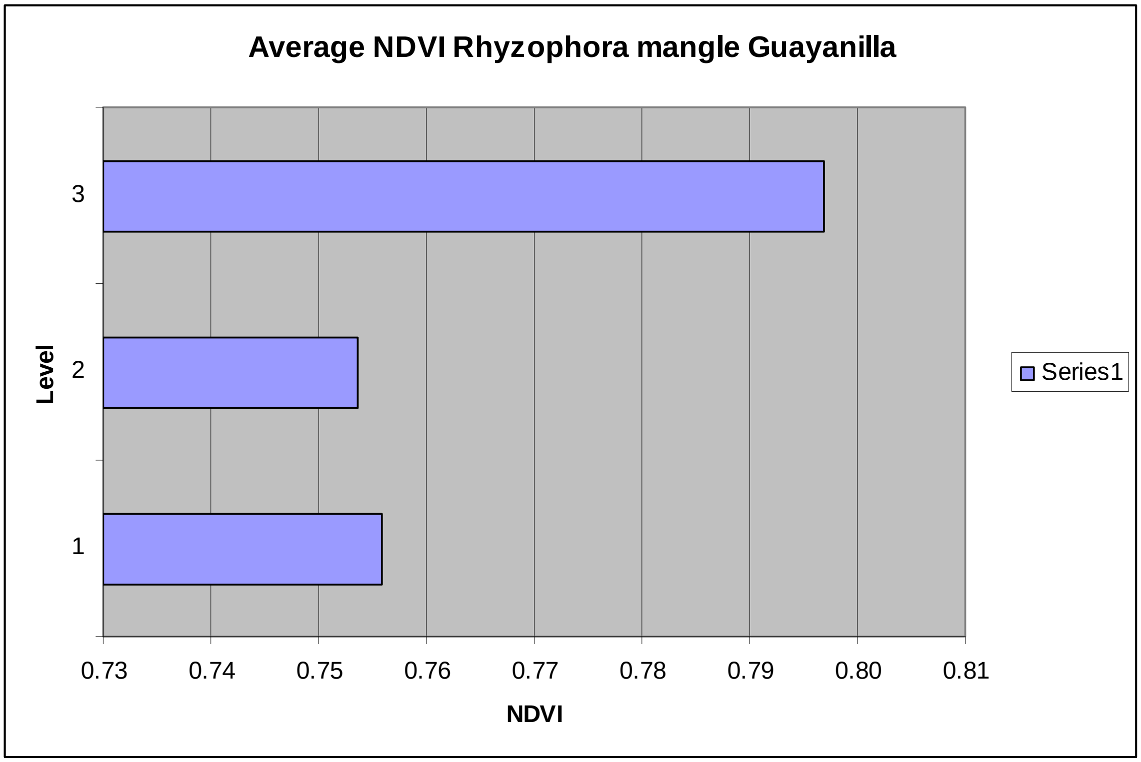


Figure 2. Average NDVI values for Rhizophora mangle in Guayanilla. Level 1= bottom, level 2 = middle, level 3 = top level of the leaves.

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

<table>
<tr><th>Station</th><th>R= Rhizophora m
B= Avicenna g</th><th>NDVI</th><th>NDVI averaged</th><th>NDVI AVIRIS</th></tr>
<tr><td>1</td><td>B</td><td>0.64</td><td rowspan="6">0.65</td><td rowspan="6">0.80</td></tr>
<tr><td>2</td><td>B</td><td>0.62</td></tr>
<tr><td>3</td><td>B</td><td>0.59</td></tr>
<tr><td>4</td><td>R</td><td>0.78</td></tr>
<tr><td>5</td><td>R</td><td>0.67</td></tr>
<tr><td>6</td><td>R</td><td>0.59</td></tr>
<tr><td>7</td><td>B</td><td>0.75</td><td rowspan="3">0.66</td><td rowspan="3">0.68</td></tr>
<tr><td>8</td><td>B</td><td>(0.15)</td></tr>
<tr><td>9</td><td>B</td><td>0.56</td></tr>
</table>

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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Final Report
Sea Grant March 3, 2009

Executive Summary
Project Title: Developing a protocol to use remote sensing as a cost effective tool to monitor contamination of mangrove wetlands
Date: 3 march 2009
Project Number: R-21-1-06.
Principle Investigators
Johannes H. Schellekens, Ph.D. schellek@uprm.edu
Fernando Gilbes-Santaella, Ph.D. gilbes@cacique.uprm.edu
Department of Geology,
University of Puerto Rico at Mayagüez
Mayagüez, Puerto Rico 00681-9017
Dates covered: 22 May 2006 to 1 March 2008 and extension until March 2009

A. Executive Summary

Summary of Impacts and Contributions

1. Objectives: To apply the remote sensing techniques of mineral exploration to the monitoring of mangrove wetlands for the presence of metal contamination. Similar as in mineral exploration, a cost effective technique that does not require costly field studies, will make an excellent tool for government agencies in charge of monitoring the health of wetlands and the possible contamination of mangrove forests.

   The research involved:

   1) The analyses of substrate and leaves in the top of the canopy of mangroves. The selection of a non-contaminated control area (e.g. Guanica, Punta Ballena, and compare the chemical results, the reflectance spectra of the leaves, the Normalized Difference Vegetation Index (NDVI), and the pH of the seawater, with other possible contaminated sites. For the latter the following sites were selected Joyuda Lagoon with possible Ni, Co contamination next to a Ni-Co laterite, Arecibo Lagoon in the watershed of the porphyry copper deposits and with various industrial sites, and Guayanilla Bay with reported mercury contamination.
   2) Processing of satellite images using differences in reflectance.
   3) Plot data in a Geographical Information System (GIS) for use by agencies in charge of pollution control.

   Objective 1) was partially established. The analyses of some of the heavy metals (e.g. As, Hg) needed chemicals that required an explosive license as ordered by Homeland Security. None of the PIs had this license and efforts to find such a person willing to help us were unsuccessful. Discussions with the Purchasing Department seemed to work, but still the chemicals were never purchased.
   Objective 2) a pilot project using AVIRIS near Punta Ballena did not provide the desired results, due to discrepancies between ground-truthing and the image data.

Objective 3) was never started. The original idea was that the recruited graduate student would carry out this part.

2. Advancement of the Field
   The following discoveries were made and will help future work
   a. Transport of metals from the substrate to the top leaves and the transport of metals within the tree is not the same for all metals.
   b. Transport of metals into, and within the red mangrove (*Rhizophora mangle*) is good to excellent for Cu, Co, Pb, and Cr, whereas the transport of Ni is little and the transport for Cd is none existent. Black mangrove (*Avicennia germinans*) seems to concentrate Cu, Co, and Cd.
   c. In summary red mangrove can be used to monitor for Cu, Co and possibly Pb and Cr, but not for Ni and Cd. Black mangrove can be used to monitor for Cu, Co and Cd.
3. Problems encountered
   A major problem involved the chemical analyses, due to the requirement of having an explosive license to purchase the needed chemicals. We tried unsuccessfully to find a person who could do the purchasing for us, subsequently we explained the Purchasing Dept. we only needed little quantities and they promised to process the order, but no chemicals were ever purchased. We are now discussing with Dr. Massol if we can solve the problem.
4. Research Impacts
   The discovery of the behavior of metals in the various mangroves.
5. Other important impacts or products
   a. List of students supported and otherwise involved

      Graduate Students employed:
      Ms Marianela Mercado Burgos Aug 2007 – Dec 2008
      nela.guayaba@gmail.com
      Ms. Mercado was recruited as graduate student to work in the project. She was supported for one semester. After that she decided to change her research project.

      Undergraduate students employed:
      <u>Mr. Augustine Rodríguez-Román.</u> Aug 2006 - May 2007
      ride_with_stylee@hotmail.com
      Mr. Rodriguez had carried out two undergraduate research projects in preparation of the proposal: Rodríguez-Román, A. (2005 a b)
      Mr. Rodriguez became the most experienced undergraduate student participating in all the steps of the sampling of soil and leaves, determining GPS locations, obtaining pH of water data, and analyzing soil and leaves. He co-authored an internal research report with Ms. Delíz: Delíz and Rodriguez (2007)

Ms. Belyneth Delíz-López Aug 2006 - May 2007
belydel@hotmail.com
Ms. Delíz was recruited as undergraduate research assistant and participated in all the steps of the sampling of soil and leaves, determining GPS locations, obtaining pH of water data, and analyzing soil and leaves. She co-authored an internal research report with Ms. Delíz: Delíz and Rodriguez (2007)

Ms. Angela Perez Jan - May 2007 and Aug – Dec 2007
isabela117@gmail.com
Ms. Perez was recruited as an undergraduate research assistant and carried out sampling of leaves and soils and determined the reflectance of the leaves.

Other undergraduate students involved
Ms. Almaris Martínez-Colón
Ms. Martinez participated as an undergraduate research student in the required course GEOL 4055. She compared the reflection of different levels of red mangrove leaves in Joyuda and Guanica. She produced an undergraduate research report: Martinez-Colon (2006).

Ms. Yomayra Román-Colón
yomayra.roman@gmail.com
Ms. Roman participated as an undergraduate research student in the required class GEOL 4049. She compared reflectance spectra of mangroves in the Punta Ballena area with reflectance data obtained from AVIRIS images. She produced the undergraduate research report: Roman-Colon (2006)

Graduate student research report
Mercado-Burgos and Viguilla, 2007
Undergraduate Research Reports (see full title in bibliography)
Delíz-López and Rodríguez -Román, 2006
Martínez-Colón, 2006
Rodríguez-Román, 2006.
Román-Colón, 2006

6. Sources of matching funds
   No matching funds were obtained. However the Department of Geology provided transportation during the field work.
7. New extra mural funds
   No extra mural funds were obtained
8. Benefits:
   No additional impacts or contributions beyond those described above

B. Final Report Narrative

Brief statement of the problem

Vegetation may take up the metals in their roots, stems, and leaves, and serve as sensors of contamination that integrate pollution over longer time periods, less dependant on daily or seasonal fluctuations. The characteristic that vegetation reacts to the geochemical conditions of the substrate has found a use in the remote sensing techniques applied to mineral exploration, where large areas can be efficiently surveyed without expensive field studies (Goetz et al., 1983). Labovitz et al. (1983) demonstrated that the metal content in the soil changed the leaf reflectance, especially in those parts of the spectrum used for chlorophyll content and water absorption, and that the variation in trace element content was associated with leaf reflectance. Schellekens et al. (2005) studied the application of remote sensing for metal content in the substrate in a diverse tropical forest.

The proposed study tries to apply the remote sensing techniques of mineral exploration to the monitoring of mangrove wetlands for the presence of metal contamination. Mangrove wetlands are specially well-suited for this technique, because the vegetation in mangrove wetlands is not very diverse, four species are known to occur in Puerto Rico, with the red mangrove (*Rhizophora mangle*), the white mangrove (*Laguncularia racemosa*), and the black mangrove (*Avicennia germinans*) as the most abundant. Similar as in mineral exploration, a cost effective technique that does not require costly field studies, will make an excellent tool for government agencies in charge of monitoring the health wetlands and the possible contamination of mangrove forests.

Similar as in mineral exploration, a cost effective technique that does not require costly field studies, will make an excellent tool for government agencies in charge of monitoring the health wetlands and the possible contamination of mangrove forests.

Methods used

In order to correlate the reflectance pattern with contamination or non-contamination of the substrate, chemical analyses for heavy metals were carried out for sediments in the root system and leaves in the top of the canopy. These high leaves are selected because these are observed by remote sensing techniques. However first the assumption that the metals are transported from the substrate to the highest leaves had to be tested. Therefore as a first experiment in addition the analyses of substrate and top leaves, leaves of the lowest braches and the intermediate branches were analyzed, both for metal content as well as reflectance. The analyses were carried out on an Atomic Absorption Spectrometer, following procedure described by Massol-Deya et al (2005). The reflectance spectra of the leaves were determined in the field using the GER 1500 spectroradiometer. The pH and temperature of the seawater were determined using a Thermo Orion pH meter model 230A.

To obtain the desired results the following pilot project was carried out:

1. Comparison of known heavy metal contaminated mangroves with non-contaminated mangroves
    a. Joyuda lagoon next to the nickel-cobalt laterite (Acevedo et al., 2000)

   b. Guayanilla reported mercury contamination (Lopez and Teas, 1978; Stary and Lopez, 1979)
   c. Arecibo lagoon in watershed with porphyry copper deposits (Bawiec, 2000)
   d. Guanica and Punta Ballena, pristine environments next to the Guanica subtropical dry forest having no run-off. No metal contamination discovered by Massol-Deya et al., 2005)
2. Study of the transport of metals from the substrate to higher levels in the mangrove, and study of the transport of metal within the mangrove tree.
   a. Red mangrove (*Rhizophora mangle)* in Guayanilla and Joyuda.
   b. Black mangrove (*Avicennia germinans*) in Punta Ballena.
3. The use of AVIRIS images in Punta Ballena. Comparison of reflectance patterns in mangroves with reflectance patterns of pixels in the AVIRIS image.

Results and findings

1. Site descriptions
   a. The Joyuda lagoon is situated next to the nickel-cobalt laterite deposit bordering the lagoon on the landward side (Heydenreich and Reynolds, 1959; Cram, 1972). The laterite forms a high and water draining from the laterite end up in the lagoon. As a result Ni and Co are expected to occur in the lagonal sediments.
   b. Guayanilla Bay is a known area of mercury contamination (Lopez and Teas, 1978). 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) 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 to compare these to mercury levels in Guayanilla Bay. Mercury levels in Guayanilla Bay when compared to other locations 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).
   c. Arecibo and 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.
   d. The Guanica and Punta Ballenas sites are located along the shore of the Guanica Subtropical Dry Forest. Substrate of these mangroves consists of limestone fragments derived from the on-land exposures of the limestone in the Guanica area and the carbonates produced by corals and other marine organisms. No surface drainage occurs from the land into the marine environment. In addition Massol-Deya et al. (2005) analyzed the sediments in the bay and did not encounter metal contamination.

Analyses for metal concentrations in the substrate and the leaves of different mangroves are given in Appendix 1 tables 1 to 5

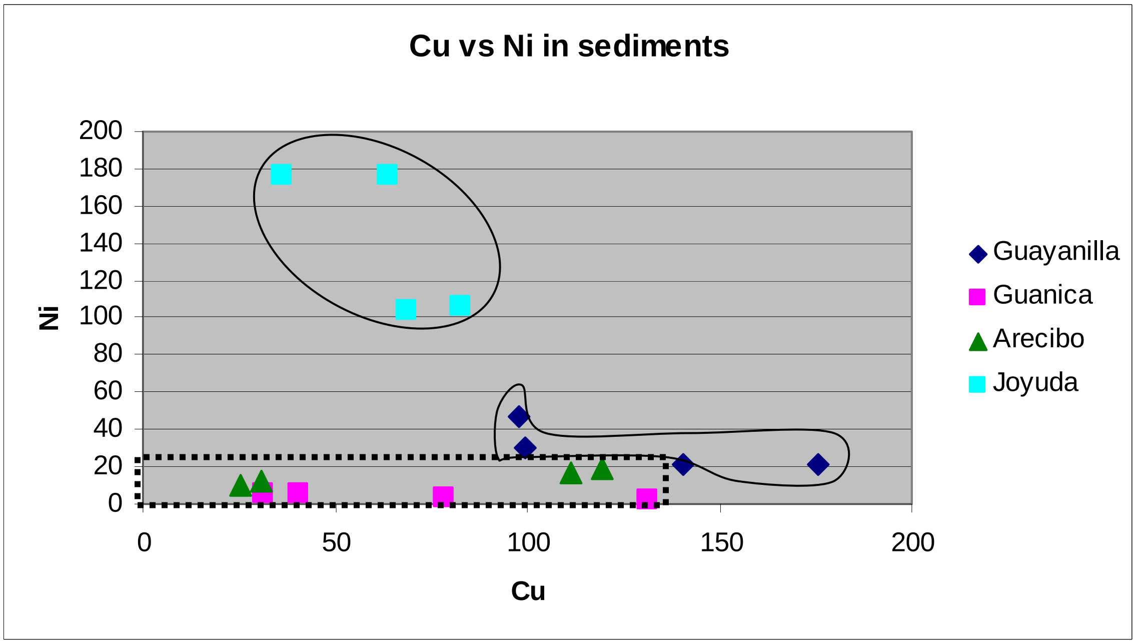


Figure 1 Cu vs Ni in sediments. Guanica is considered the control as a non-contaminated site. The results are found in the dashed lined box in the figure. Notice the high Ni content in sediments of Joyuda lagoon next to the Ni-Co laterite. Guayanilla has slightly higher Cu and Ni than the control.

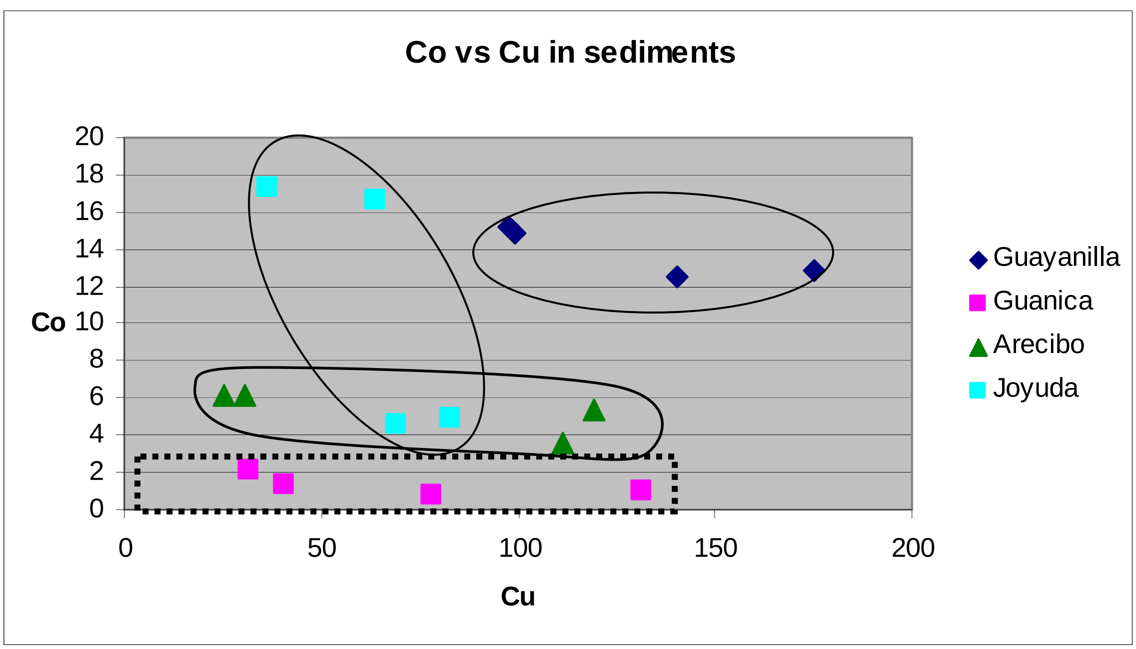


Figure 2 Co vs Cu in sediments. Guanica is considered the control as a non-contaminated site. The results are found in the dashed lined box in the figure. Guayanilla and Joyuda show distinctly higher cobalt contents, whereas Arecibo is less contaminated

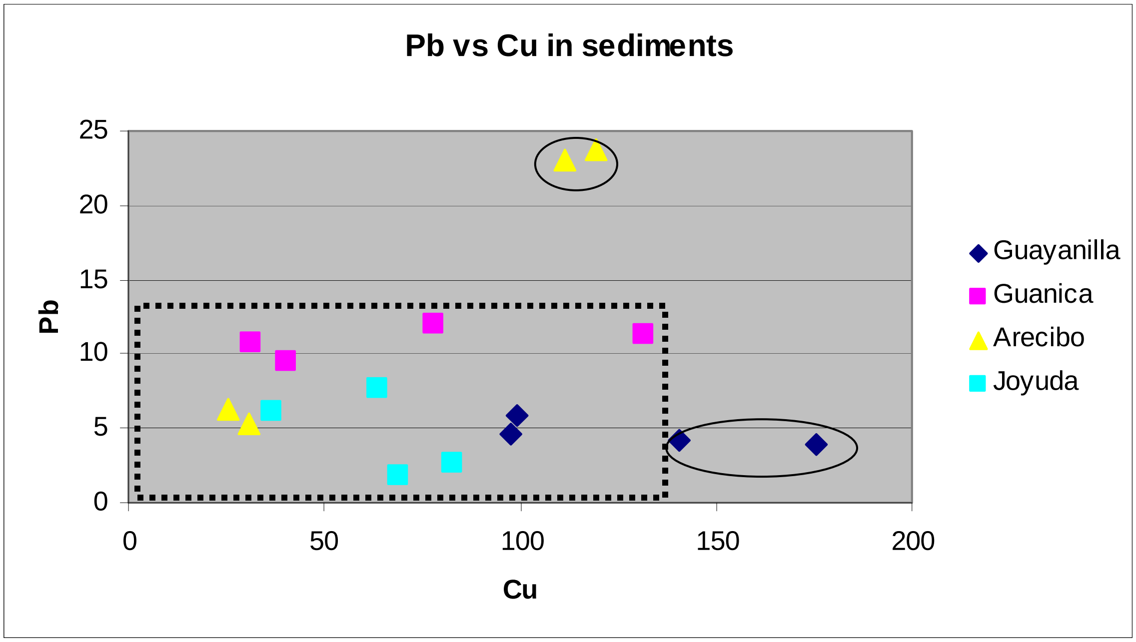


Figure 3 Pb vs Cu in sediments. Guanica is considered the control as a non-contaminated site. The results are found in the dashed lined box in the figure. The Pb concentration of the non-contaminated Guanica site is higher than possible contaminated sites. Two stations in Arecibo show distinct lead contamination.

2. Metal transport from substrate to top of canopy and within the tree.

In order to assess the uptake of metals in the mangrove tree and its transport to the top leaves of the canopy, an enrichment ratio was defined where the metal content of the top leaves was divided by the metal content of the substrate. An example is given in figure 4 for a red mangrove from Guayanilla. In this case the enrichment ratio came out as 0.41 suggesting good transport from substrate to top leaves.

Average substrate	Average bottom leaves	Average middle leaves	Average top leaves	Ratio Top/substrate
98.4	31.2	33.7	40.1	0.41

Figure 4. Example of enrichment ratio for red mangrove (*Rhyzophora mangle*) in Guayanilla.

- **Summary of top/substrate ratios for red mangrove (*Rhizophora mangle)***

– **Cu**			
	• Guayanilla	0.4	observable transport
	• Joyuda	1.2	metal concentration in tree
	• Punta Ballena	0.2	observable
– **Ni**			
	• Guayanilla	0.01	very little uptake
	• Joyuda	0.02	very little uptake
– **Co**			
	• Guayanilla	0.2	observable

In order to assess the transport within the tree an enrichment ratio was defined where the metal content of the top leaves where divided by the metal content of the lower leaves. An example is given for the same red mangrove in Guayanilla. Notice here that the ratio is >1, indicating that the tree concentrates Cu extracted from the soil.

Average substrate	Average bottom leaves	Average middle leaves	Average top leaves	Ratio Top/bottom
98.4	31.2	33.7	40.1	1.3

Figure 5. Example of enrichment ratio within the tree for red mangrove (*Rhyzophora mangle*) in Guayanilla. Notice concentration of Cu in top leaves ratio>1

- **Summary of top/bottom ratios for red mangrove (*Rhizophora mangle)***

– **Cu** Guayanilla		1.3: good transport
	• Joyuda	1.4: good transport
– **Ni** Guayanilla		0.3: little transport
	• Joyuda	0.4: little transport
– **Co** Guayanilla		2.5: very good transport
– **Cd** Guayanilla		0: no transport
– **Pb** Guayanilla		0.9: good transport
– **Cr** Guayanilla		1.3: good transport

- **Summary of top/substrate ratios for black mangrove (*Avicennia germinans*)**

–	**Cu**	Pta Ballena	6.5: concentration
–	**Co**	Pta Ballena	concentration
–	**Cd**	Pta Ballena	concentration

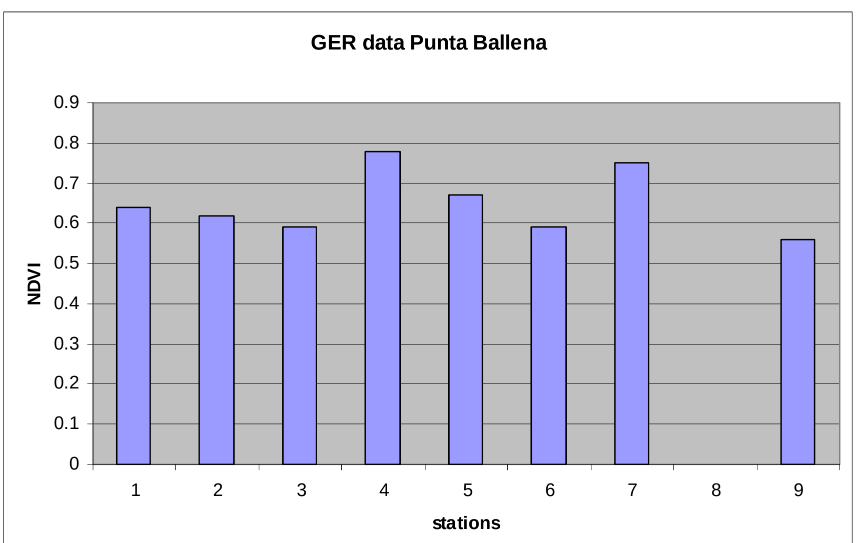
Co and Cd are below detection in the substrate but Co and Cd have an average of 7.6 ppm and 0.3 ppm respectively in the top leaves

In order to use mangrove as a monitor plant using remote sensing, the tree has to take up the metal from the substrate and transport it to the top of the canopy. On the basis of the present data it is suggested that red mangrove (*Rhizophora mangle*) can be used to monitor for Cu, Co, and possibly Pb and Cr, but not for Ni and Cd. The black mangrove (Avicennia germinans) can be used to monitor for Cu, Co, and Cd.

3. Use of AVIRIS (Advanced Visible and InfraRed Imaging Spectrometer)

The AVIRIS has the capability to determine a reflectance spectrum for each pixel and to calculate the Normalized Difference Vegetation Index (NDVI) per pixel. In the Punta Ballena area a pilot project was carried out where the reflectance spectra was measured for mangrove trees using the GER-1500 spectroradiometer. The station was located using a GPS. NDVIs for the tree determined on the ground were compared to NDVIs determined by AVIRIS. Stations 1 to 6 were averaged, and the average NDVI compared to the NDVI determined by AVIRIS for this area. Similarly the average of station 7 and 9 was compared to the NDVI determined by AVIRIS for this area. In both cases the NDVI determined by AVIRIS was too high. This was due to the fact that single trees were smaller than 1 pixel and reflectance from other components of the pixel, like sand, was added to the reflectance of the mangrove.

A



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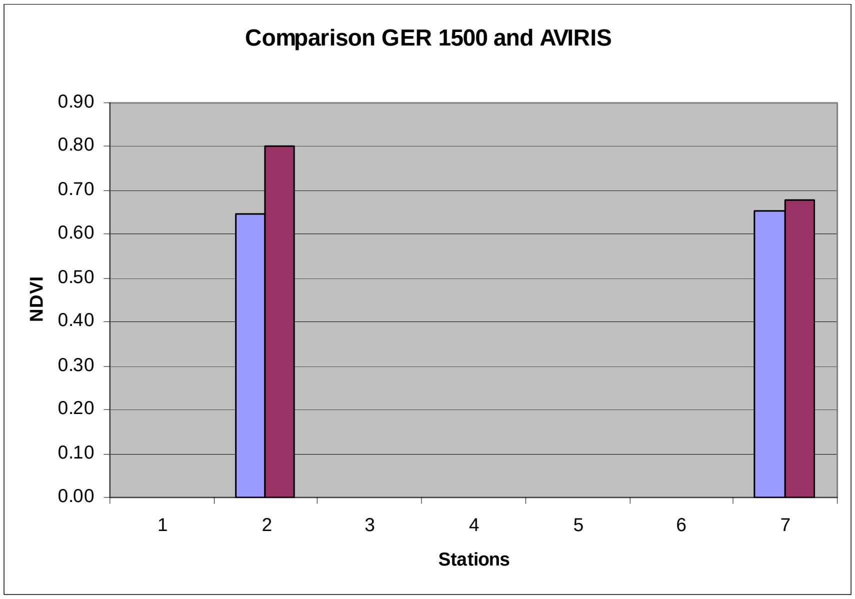


Figure 6. A) NDVIs measured with the handheld spectroradiometer GER 1500 shows a wide spread of reflectance data. B) Comparison of average NDVI of station 1-6 and station 7 to 9 (both blue) with their respective AVIRIS data (red).

Objectives accomplished or not accomplished

Chemical analyses of the substrate and leaves were to be carried out of As, Cd, Cr, Pb, Hg, Ni, Co. This objective was only partly met. Not all elements could be analyzed all the time and the elements As and Hg required chemicals for which we needed a 'explosive license'. Nor the PI or the Co-Pi had such a license and attempts to use a license in the Biology department failed. The Co-PI explained the purchasing department that only a small amount was needed for the analyses. The purchasing department agreed to buy the chemicals but never did. A number of analyses were carried out (see Appendix 1).

Chemical analyses and reflectance spectra from leaves in the top of the canopy. Chemical analyses of the leaves encountered the same problem as the analyses of the substrate. The reflectance spectra were determined from most of the leaves (bottom, middle, and top). However in the last year the radiospectrometer had to be returned to the factory for servicing and calibration. No spectra could be measured in that time.

Compare the reflectance data for contaminated and non-contaminated sites. NDVIs were calculated for red, black, and white mangroves in contaminated and non-contaminated sites. However no statistically valid difference between the two could be discerned.

Process satellite images using the differences in reflectance. Except for a pilot project using AVIRIS this objective was not met. The main reason being that no robust chemical data existed for the various areas and we waited with the purchase of the images until we were certain in which area we could detect contamination.

Discussion of project impacts and products

a. List of students supported and otherwise involved

Graduate Students employed:
Ms Marianela Mercado Burgos Aug 2007 - Dec2008
nela.guayaba@gmail.com
Ms. Mercado was recruited a graduate student to work in the project. She was supported as a graduate student for one semester. She co-authored a report in a Remote sensing class that redid a previous undergraduate research project without contributing new data. (Mercado-Burgos and Veguilla, 2007). After one semester she decided she wanted to change her research project.

Undergraduate students employed:
Mr. Augustine Rodríguez-Román. Aug 2006 - May 2007
ride_with_stylee@hotmail.com
Mr. Rodriguez had carried out two undergraduate research projects in preparation of the proposal:

Augustine Rodríguez-Román: Leaf reflectance of possibly heavy metal contaminated mangroves compared to non-contaminated mangroves: A possible tool to discern heavy metal contamination using remote sensing. [2005]

Augustine Rodríguez-Román: Geo-biological study of heavy metal contamination in coastal areas: Remote sensing techniques applied for mineral exploration [2005]

Mr. Rodriguez became the most experienced undergraduate student, taking samples of both soil and leaves, determining GPS location of sample sites, carrying out measurements of reflectance of leaves, and determining the pH of the water. Mr. Rodriguez also carried out the chemical analyses of the leaves and soil samples. Mr. Rodriguez was an undergraduate research assistant during a large time of the project. He co-authored an internal research report with Ms. Delíz: Delíz and Rodríguez (2007)

Ms. Belyneth Deliz-López Aug 2006 - May 2007
belydel@hotmail.com
Ms. Delíz was recruited as undergraduate research assistant and participated in the collection of samples of both soil and leaves, determining GPS location of sample sites, carrying out measurements of reflectance of leaves, and determining the pH of the water. Ms. Delíz also carried out the chemical analyses of the leaves and soil samples. Together

with Mr. Rodriguez she co-authored an internal report: Delíz and Rodríguez (2007)

Ms. Angela Perez Jan - May 2007 and Aug – Dec 2007
isabela117@gmail.com
Ms. Perez was recruited as an undergraduate research assistant. She carried out sampling of leaves and soils and determined the reflectance of the leaves. Unfortunately during here participation in the project no chemical analyses were carried due to the problems purchasing chemicals, and the GER radiospectrometer had to be send away for servicing.

Other undergraduate students involved
Ms. Almaris Martínez-Colón
Ms. Martinez participated as an undergraduate research student in the required course GEOL 4055. She compared the reflection of different levels of red mangrove leaves in Joyuda and Guanica. She produced an undergraduate research report: Martinez-Colon, Almaris, (2006)

Ms. Yomayra Román-Colón
yomayra.roman@gmail.com
Ms. Roman participated as an undergraduate research student in the required class GEOL 4049. She compared reflectance spectra of mangroves in the Punta Ballena area with reflectance data obtained from AVIRIS images. She produced the undergraduate research report: Román-Colón, Yomayra A. (2006)
http://gers.uprm.edu/pdfs/topico_yomayra1.pdf

Graduate student Research Reports

Mercado Burgos, Marianela and Veguilla, Ricardo, 2007, Relación entre NDVI y contenido de metales en Rhizophora mangle en el suroeste de Puerto Rico: unpublished research paper in GEOL 6225 Advanced geological remote sensing. http://gers.uprm.edu/geol6225/pdfs/mercado_veguilla_2007.pdf

Undergraduate Research Reports

Deliz-López, Belyneth and Rodríguez -Román, Augustine, 2006, Monitoring metal contamination of mangroves using remote sensing techniques: Guayanilla: Internal Research report Dept. of Geology, UPRM

Martínez-Colón, Almaris, 2006, Distribution of metals and leave reflectance in red mangrove (Rhyzophora mangle). Comparison between Joyuda and Guanica mangrove areas: Unpublished Undergraduate Research report Dept. of Geology, UPRM

Rodríguez-Román. Augustine, 2006, Remote sensing techniques for mineral exploration used to monitor metal contamination of

mangroves: The Guayanilla and Arecibo mangroves: Unpublished Undergraduate Research report Dept Geology UPRM, 25p.

Román-Colon, Yomayra A., 2006, The use of AVIRIS to monitor the contamination in mangrove wetlands, Unpublished report undergraduate research Dept Geology UPRM, 15p. http://gers.uprm.edu/pdfs/topico_yomayra1.pdf

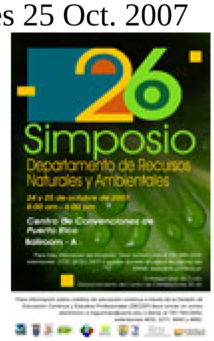
Presentations:

"Usando Percepción remota como una herramienta para monitorear contaminación de mangles" Sociedad Horticultura del Oeste, San German, PR, 1 October 2006.

"Developing a protocol to use remote sensing as a cost effective tool to monitor contamination of mangrove wetlands" 2nd Annual Symposium for Coastal and Marine Research, UPR Sea Grant College program Mayagüez, PR, 5 October 2006.

"Can we use remote sensing to monitor contamination in mangrove wetlands?" Sociedad Geologica Estudantil, UPRM, Mayagüez, PR, 1 March 2007

"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



Abstracts published (students in bold)

Rodríguez-Román, Augustine and J.H. Schellekens, 2006, Leaf reflectance comparison between possibly heavy metal contaminated mangroves and non-contaminated mangroves: A possible tool to discern heavy metal contamination using remote sensing: Abstracts Sigma Xi student poster day Mayagüez, PR April 6, 2006

Schellekens, J.H., F. Gilbes-Santaella, **A. Rodríguez-Román, Yomayra Román -Colon,** 2006, Developing a protocol to use remote sensing as a cost effective tool to monitor contamination of mangrove wetlands: Abstracts of the 2nd Annual Symposium for Coastal and Marine Research, UPR Sea Grant College program October 5, 2006 Mayagüez, Puerto Rico, p. 9.

Rodriguez, Augustine, Angela Perez, Belyneth Delíz, Yomayra Román, Almaris Martínez, J.H. Schellekens, F. Gilbes, 2007, 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 2006, p. 34

Schellekens, J.H., F. Gilbes, **A. Rodríguez, B. Deliz,** and **Y. Roman,** 2007, 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., **Rodríguez, A., Deliz, B., and Martínez, A**., 2007, Preliminary results of the mangrove reflectance and composition study, 11p.

Annual reports for Sea Grant are available at:
For 2008: http://gers.uprm.edu/pdfs/report_mangrove08.pdf
For 2007: http://gers.uprm.edu/pdfs/report_mangrove07.pdf

The project has obtained valuable data that can be applied in further research on the topic, such as the transport of certain metals in either red or black mangroves and hence which mangroves can be used for the monitoring of certain metals and which not..
Unfortunately the research project was delayed by various factors, including the problems with purchasing chemicals, the loss of the graduate student, and the sabbatical leave of one of the PIs.
In summary the following conclusions can be drawn from the research:

a. The substrate of mangroves does contain considerable amounts of metals
b. Not all metals are taken up by the mangroves:
   Cu, Co, Pb, Cr are taken up by red mangrove (*Rhizophora mangle*) but Ni and Cd are not.
   Cu, Co, and Cd are taken up and even concentrated by black mangrove (*Avicennia germinans*)
c. The reflectance spectra and NDVI of mangroves when measured on the ground yield a wide range of values. Averaging the data seem to yield consistent results, however with the limited amount of data obtained, no statistically valid differences could be observed between contaminated and non-contaminated mangrove forests.
d. AVIRIS images can be used, but ground truthing has to take into account the larger pixel size (~32m) as compared to IKONOS (2m)

Recommendations

In order to close this research project with publishable results it is recommended to spend a few extra months to carry out the following steps

1. Sampling and analyses of black mangrove at other sites, to establish whether the black mangrove indeed concentrates certain heavy metals. It would make the black mangrove a candidate to be used to clean up contaminated coastal areas.
2. Concentrate on one contaminated area (either Joyuda or Arecibo) to compare the satellite images with the non-contaminated control area in Guanica-Punta Ballena.

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Appendix 1

Table 1 Guayanilla: Heavy metal concentrations Rhyzophora mangle

Cu in ppm

Site	substrate	Bottom	Middle	Top
GL1	97.6	31.1	24.2	24.4
GL2	Average 98.4	28.8	25.0	27.1
GL3	99.2	33.7	51.9	68.9

Ni in ppm

Site	substrate	Bottom	Middle	Top
GL1	46.7	1.9	1.2	0.6
GL2	Average 38.2	1.3	1.1	0.4
GL3	29.7	0.7	0.2	0.3

Co in ppm

Site	substrate	Bottom	Middle	Top
GL1	15.2	0.1	nd	nd
GL2	Average 15.1	nd	0.1	0
GL3	14.9	0.1	0.2	0.5

Cd in ppm

Site	substrate	Bottom	Middle	Top
GL1	Nd	0.1	0.1	0
GL2	Average nd	nd	0.1	0
GL3	Nd	0	nd	nd

Pb in ppm

Site	Substrate	Bottom	Middle	Top
GL1		6.8	10.0	9.8
GL2		14.1	12.1	7.2
GL3		8.3	8.4	10.5

Cr in ppm

Site	substrate	Bottom	Middle	Top
GL1		Nd	0.4	1.4
GL2		7.6	2.1	2.3
GL3		5.0	3.0	13.1

All results are the average of two analyses. When no reading was obtained the result is reported as non detected (nd)

Table 2 Joyuda: Heavy metal concentrations Rhyzophora mangle

Cu in ppm

Site	substrate	Bottom	Middle	Top
JO1	36.4	53.0	78.8	60.2
JO2	Average 50.1	65.3	18.9	99.7
JO3	63.9	9.9	19	18.1

Ni in ppm

Site	substrate	Bottom	Middle	Top
JO1	177.0	3.8	22.0	3.8
JO2	Average 176.5	11.9	6.3	4.4
JO3	176.0	4.1	5.8	0.6

Co in ppm

Site	substrate	Bottom	Middle	Top
JO1	17.3			
JO2	Average 16.9			
JO3	16.6			

Cd in ppm

Site	substrate	Bottom	Middle	Top
JO1	Nd	0.4	nd	nd
JO2		nd	nd	nd
JO3	Nd	nd	nd	nd

Table 3 Heavy metal concentrations in ppm for Rhyzophora mangle

	Guanica substrate			**Guayanilla substrate**			**Arecibo substrate**			**Joyuda substrate**		
Cu	131.6	78.2		97.6	99.2		119.4	111.4		36.4	63.9	
Ni	1.9	3.2		46.7	29.7		19.6	16.3		177.0	176.0	
Co	1.0	0.8		15.2	14.9		5.4	3.6		17.3	16.4	
Cd	0.0	Nd		Nd	nd		0.1	0.1		Nd	nd	
Pb												
Cr												

	Punta Ballena substrate			**leave**									
	4	**5**	**6**	**4**									
Cu	114.0	92.5	60.5	20.5									
Ni													
Co	16.9	19.6	21.0	nd									
Cd	0.36	0.34	0.28	nd									

Pb												
Cr												

Table 4 Heavy metal concentrations in ppm for Avicenna germinans

	Guanica substrate			**Guayanilla substrate**			**Arecibo substrate**			**Joyuda substrate**		
Cu										**82.7**	**68.9**	
Ni										**105.7**	**104.3**	
Co										**4.9**	**4.6**	
Cd										**Nd**	**nd**	
Pb												
Cr												

	Punta Ballena substrate				**Punta Ballena leaves**					
	1	7	8	9	1	2	3	7	8	9
Cu	20.5	13.6	10.4		21.3	94.3	41.1	170.0	109.0	144.0
Ni										
Co	nd	nd	nd		3.4	9.8	15.0	15.8	1.4	0.16
Cd	nd	nd	nd		0.5	0.6	0.7	0.2	nd	nd
Pb										
Cr										

Table 5 Heavy metal concentrations in ppm for Laguncularia racemosa

	Guanica substrate			**Guayanilla substrate**			**Arecibo substrate**			**Joyuda substrate**		
Cu	**40.5**	**31.4**		**140.4**	**175.4**		**25.4**	**30.9**		**-**	**-**	
Ni	**5.2**	**5.6**		**21.1**	**20.1**		**10.0**	**12.7**		**-**	**-**	
Co	**1.4**	**2.1**		**12.5**	**12.9**		**6.1**	**6.2**		**-**	**-**	
Cd	**0.1**	**Nd**		**Nd**	**nd**		**Nd**	**Nd**		**-**	**-**	
Pb												
Cr												