UNDERGRADUATE RESEARCH PROYECT

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Department of Geology

By:

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The use of AVIRIS to monitor the contamination in mangrove wetlands

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Abstract

The combination of spectral data with chemical analyses allows us to monitor natural ecosystems and detect changes that may damage the environment. Sediment and leaves samples were collected in Punta Ballena at Guanica State Forest. The samples were analyzed for reflectance of leaves using a field spectroradiometer. An image collected with the AVIRIS (Airborne Visible/Infrared imagine Spectrometer) sensor was used to calculate the reflectance and the Normalized Difference Vegetation Index (NDVI) for the mangrove vegetation at Punta Ballena. The reflectance values and the NDVI obtained with the image were compared with the results of leaves. Concentration of heavy metals of cobalt, copper and cadmium were calculated by atomic absorption. High concentrations of copper were found in the leaves of red (60.5 mg/L to 114 mg/L) and black mangroves (21.3 mg/L to 170 mg/L). However, cobalt and cadmium were in low concentrations in leaves and soils with a range of 0.16 mg/L-21 mg/L and 0.18 mg/L to 0.72 mg/L respectively.

Keywords: mangroves, AVIRIS, heavy metals, NDVI

Introduction and Statement

Remote sensing techniques applied to the study of mangroves have been a useful resource for the preservation of coastal environments. It is possible to obtain data from sensors and a variety of information based on measurements of electromagnetic radiation emitted by mangrove vegetation. High levels of heavy metals can cause potential reactivity and toxicity in soils (Selim et al., 1997). Concentrations of heavy metals in mangroves can be determined using spectral data obtained by remote sensors. A well known method used to measure the absorption of vegetation is the Normalized Difference Vegetation Index (NDVI). The NDVI can be obtained from reflectance values using satellite images or by the field measurements of leaves.

In this research project a mangrove wetland in Punta Ballena at Guanica State Forest was analyzed using remote sensing, field data, and chemical analyses. As part of the image processing reflectance and vegetation index were determined at three different stations of Punta Ballena. The study compared the changes in reflectance curves between *in situ* reflectance of mangroves leaves with the reflectance acquired from AVIRIS (Airborne Visible/Infrared imagine Spectrometer) sensor. The distribution of mangroves in the area was also determined. The project included chemical analyses for the concentrations of heavy metals in the substrate and mangroves leaves. Heavy metals of Cu, Co and Cd were analyzed by atomic absorption. The selection of the study site was based on their location, human activity and environmental impact.

Literature Review

Many research have proved that remote sensing techniques can be applied to distinguish mangrove vegetation from non-mangrove vegetation (Green et al., 2000). Some of the most common sensors applied to the study of mangrove with more accurate and detailed results are Landsat TM and CASI. The Turks and Caicos Islands were studied using Landsat TM and SPOT XS and CASI data. Discrimination between mangrove and non-mangrove vegetation could be achieved using Landsat TM and CASI with an accuracy of 92 to 96% (Figure 1: Green et al., 2000).

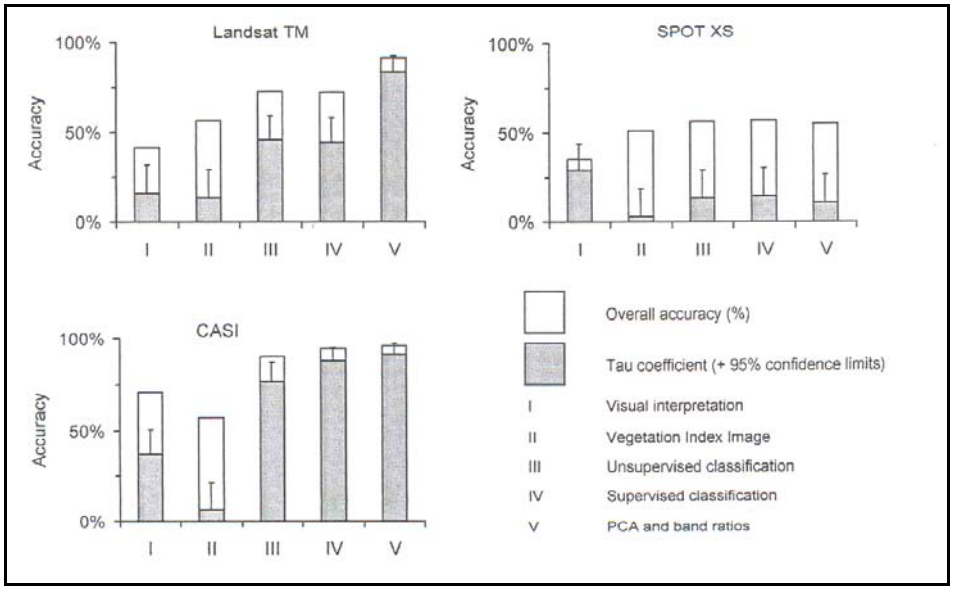

Figure 1: Comparison of the accuracy of mangrove and non mangrove vegetation using Landsat TM, SPOT XS and CASI data (from Green et al., 2000)

Acevedo et al. (2000) studied the concentration of seven heavy metals in the water and sediments of two estuaries of Puerto Rico. The study was focused in monitor two areas with different environmental impacts to determine any variation in the content of metals. The sites were the San José Lagoon characterized as an area of industralization, and the Joyuda Lagoon known as a natural reserve. The San José Lagoon presented more variations in pH and oxygen values attributed to differences in water depth and more input of fresh water. Furthermore, the sediment samples showed higher levels of Cd, Cu, Hg, Pb, Se and Zn in the San José Lagoon whereas in the Joyuda Lagoon the concentration of heavy minerals remained constants.

Rodríguez-Román, (2005) compared the leave reflectance of various mangroves growing on a possible contaminated substrate in the Joyuda Lagoon and Guanica State Forest. The Joyuda Lagoon receives sediments derived from the nickel-bearing laterites located in the south-west coast of Puerto Rico. In this research project heavy metals of Ni, Cu, Co and Cd were analyzed to determine the concentration of metals in mangrove leaves. The analysis showed high absorbance of Ni, Cu, and Cd in the red mangrove leaves of Joyuda Lagoon and concentrations of Ni, Cu and Co in black mangroves of Guanica State Forest.

Study Area

The Guanica Dry Forest is located in the southwest coast of Puerto Rico and it the largest tropical forest in the world. This forest was designated as an international Biophere Reserve in 1981. It has an extension of 9500 acres and represents the most arid region in the island. This Natural Reserve presents a biodiversity of species including the four dominant species of mangroves: red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), white mangrove (*Laguncularia racemosa*) and the button mangrove (*Conocarpus erectus)*. The study area is located in the south coast of Guanica Dry Forest at Punta Ballena (Figure 2). This region is characterized by a broad distribution of mangrove species in which the most common are the red mangrove and black mangrove. The objective of this project was to monitor the health condition of these mangroves species by measuring the reflectance of leaves and the levels of contaminants in the substrate and leaves.

Figure 2: AVIRIS image of Punta Ballena at Guanica State Forest using bands 30, 20 and 10 (produced by ENVI at GERS Lab.) The red circle indicates the study site.

Methodology

- *Selection and acquisition of images*

The study area was acquired with the AVIRIS (Airborne Visible/Infrared imagine Spectrometer) sensor on August 19, 2004. AVIRIS is an imaging spectrometer that has 224 contiguous channels of approximately 10 nm wide. The image was produced during a flight in which six transects were covered along the coasts of Puerto Rico (Figure 3). The E-F transect was selected because it covered the south coast of Guanica State Forest at Punta Ballena (Figure 2).

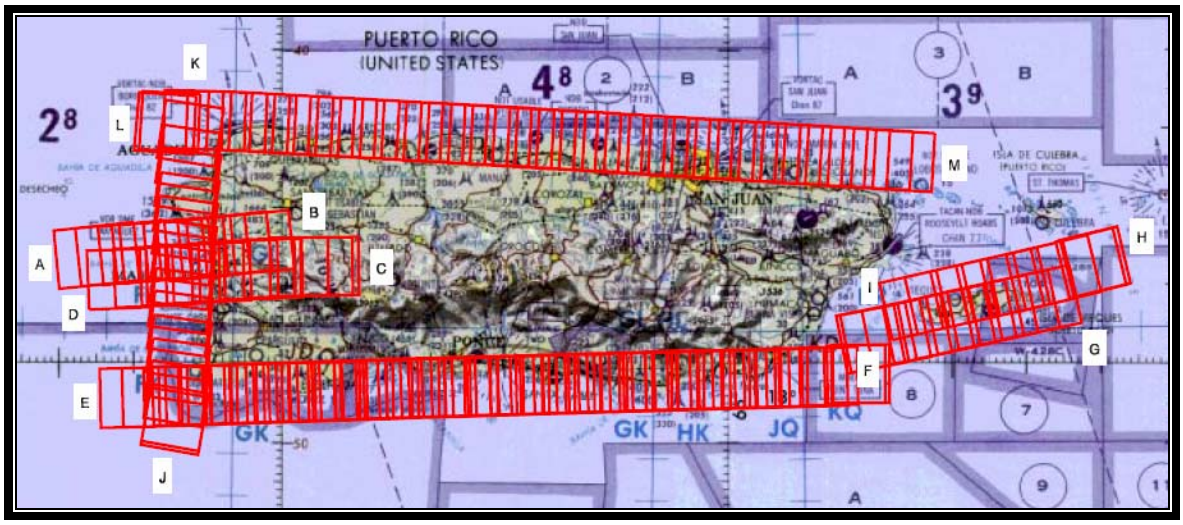

Figure 3: Map of Puerto Rico with six transects produced by AVIRIS sensor in August 19, 2004 (from Flight Summary Report Guild, NASA Research Center, 2004)

- *Image processing*

The image was processed and analyzed considering cloud coverage and atmosphere effects. The atmosphere has a strong influence in the interaction of the electromagnetic radiation creating absorption of energy at specific wavelength intervals (Green et al., 2000). ACORN (Atmospheric COrrection Now) program was used to remove the atmospheric effects (i.e. atmospheric correction). ENVI (Environmental of Visualization Images) software was used to calculate the NDVI and to study the distribution of mangrove habitats. Two regions of interest of 3x3 pixels were selected to create a spectrum profile (reflectance vs. wavelength) and compared with field data registered using a GPS the NAD83 coordinates system.

The Normalized Difference Vegetation Index (NDVI) was calculated to compare between mangrove and non-mangrove vegetation. A NDVI image was created with the red band #29 (635.9 nm) and infrared band #51 (825.6 nm) using ENVI (Figure 4).The NDVI values were determined by the following equation:

$$NDVI = \frac{(Near\ IR - Red\ band)}{(Near\ IR + Red\ band)}$$

All image processing was performed at the Geological and Environmental Remote Sensing Laboratory (GERS Lab).

- *Field work*

Nine stations were selected in different areas of Punta Ballena. Every station represented different mangroves trees of ***Rhizophora mangle*** and ***Avicennia germinans***. At each station leaves were collected to measure the reflectance and sediment samples to determine the concentration of heavy metals in the substrate. The reflectance of the leaves was measured in the field using the GER 1500 Portable Spectroradiometer. Leaves samples were also taken to the laboratory for chemical analysis and to determine which elements were transported to the leaf structure.

- *Lab work*

The collected sediments and leaves were analyzed at the microbiology laboratory located in the Biology Department. To determine the concentration of heavy metals in the leaves and sediment samples the process was divided in two parts: calculate the humidity and make the extraction of metals.

- Leaf Analyses

a. Humidity:

The leaves were washed with distilled water, let dry for 10 minutes and cut into small pieces. Crucibles were previously incinerated for two hours in a muffle at 600˚C to eliminate any residue of water. The crucibles were weighed and 3.0 g of sample was weighed with the crucibles. The samples were put in the oven at 70˚C for 18 to 20 hours to calculate the weight of dry samples. The leaves were weighed and put in the oven once again at 585˚C until the next day.

$$\% \text{ Humidity} = \frac{\text{humid weigh of sample} - \text{dry weigh of sample}}{\text{Humid weigh of sample}} \times 100$$

b. Extraction of metals:

After the leaves samples were incinerated they were reduced to ashes and 5 ml of hydrochloric acid 20% was added. The mixture was transferred into a 250 ml beaker and the crucibles were rinsed three times with portions of 5-8 ml of hydrochloric acid 10%. The hydrochloric acid and the ashes are heated on a hot plate, without boiling, until the solution is completely dissolved. The solution was allowed to cool down to room temperature in a covered beaker with a watch glass. The solution was transferred into a 50 ml volumetric flask with a filter. The filter was rinsed three times with hydrochloric acid 10% and it was diluted to the mark and mixed. The concentration of heavy metals was determined by air-acetylene flame detection in an atomic absorption spectrometer. This method examined the concentrations of heavy metals such as Cu, Co, Ni and Cd. The concentrations were calculated and plotted in graphs.

$$\text{Concentration of heavy metal } (\mu g/g) = \frac{\mu g/ml \text{ in the solution} \times 50ml}{\text{weigh of dry sample (g)}}$$

- Sediment Analysis

a. Humidity

Crucibles were incinerated for two hours in a muffle at 600˚C and the sediment samples were put into a desiccator. The crucibles were weighed and 1.5 g of pulverized sediment was transferred into the crucibles and weighed. The sediments were put in the oven at 70˚C for 18 to 20 hours to calculate the weight of dry samples. Then, the samples were incinerated into the oven at 600˚C for two hours and are left to cool down.

b. Extraction of metals

The sediments were transferred into a 600 ml beaker adding 3 ml of concentrated hydrochloric in three portions of 1 ml. Concentrated nitric acid (1 ml) was added into the crucible and transferred to the beaker. Similarly, 15 ml of hydrochloric 10% were added in three portions into the crucible and once again into the beaker. The beaker was covered and heated on a hot plate until the solution was diluted. Finally, 1ml of concentrated nitric acid and 3 ml of concentrated hydrochloric were added and heated once again. The solution was filtered into a 100 ml volumetric flask and it was diluted to the mark.

$$\text{Concentration of heavy metal } (\mu g/g) = \frac{\mu g/ml \text{ in the solution} \times 100 \text{ ml}}{\text{weigh of dry sample}}$$

Results

The values of NDVI (Normalized Difference Vegetation Index) range from 1.0 to -1.0. The NDVI image of Punta Ballena shows high concentrations of green vegetation (Figure 4). The dark-green areas represent the highest values of NDVI. The NDVI values of Punta Ballena are very similar to the values obtained with the spectroradiometer GER 1500 (Table 1).

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Figure 4: NDVI image of Punta Ballena at Guanica State Forest produced in ENVI.

Table 1: Coordinates of the stations in the Guanica State Forest at Punta Ballena and their field NDVI values.

Sample	GPS coordinates Lat/Lon	Species	NDVI values
1	N 17˚56.783′ WO 66˚51.926′	"*Avicennia germinans*"	0.64
2	N 17˚56.777′ WO 66˚51.923′	"*Avicennia germinans*"	0.62
3	N 17˚56.790′ WO 66˚51.931′	"*Avicennia germinans*"	0.59
4	N 17˚56.810′ WO 66˚51.947′	"*Rhizophora mangle*"	0.78
5	N 17˚56.813′ WO 66˚51.950′	"*Rhizophora mangle*"	0.67
6		"*Rhizophora mangle*"	0.59
7	N 17˚56.790′ WO 66˚51.873′	"*Avicennia germinans*"	0.75
8	N 17˚56.782′ WO 66˚51.854′	"*Avicennia germinans*"	0.15
9	N 17˚56.788′ WO 66˚51.832′	"*Avicennia germinans*"	0.56

The leaves samples were analyzed to determine the concentration of heavy metals. The process was divided in two parts: calculate the weight of dry samples and make the extraction of metals to determine the concentration of metals (Table 2).

Table 2: Calculus of leaves samples analysis to determine the weight of sample

Leaf Sample	Weight of crucible	Weight of crucible + humid sample	Weight of humid sample	Weight of crucible + dry sample	Weight of dry sample	%Humidity
1	36.5489 g	39.6362 g	3.0873 g	37.6371 g	1.0882 g	65 %
2	43.4296 g	46.470 g	3.0404 g	44.4469 g	1.0173 g	67 %
3	44.7997 g	47.8815 g	3.0818 g	45.7604 g	0.9607 g	69 %
4	40.8459 g	43.9114 g	3.0655 g	41.9533 g	1.1074 g	64 %
5	43.9415 g	47.0079 g	3.0664 g	44.9567 g	1.0152 g	67 %
6	43.6935 g	47.1388 g	3.4453 g	44.7640 g	1.0705 g	69 %
7	43.1270 g	46.1270 g	3.0000 g	44.2063 g	1.0793 g	63 %
8	36.5418 g	40.0008 g	3.4590 g	37.6537 g	1.1119 g	68 %
9	38.2782 g	41.8785 g	3.6003 g	39.5636 g	1.2854 g	64 %

The heavy metals analyzed in the leaves were cobalt, copper and cadmium. The red mangroves presented higher concentrations of cobalt (samples 4, 5 and 6). The metal with the lowest concentration in red and black mangroves was cadmium with a range of 0.19 µg/g to 073 µg/g. Copper was detected with the highest concentration in black mangroves (samples 7, 8, 9).

Leaf sample	[Co]	[Cu]	[Cd]
1	3.4 µg/g	21.3 µg/g	0.46 µg/g
2	9.8 µg/g	94.3 µg/g	0.59 µg/g
3	15.0 µg/g	41.1 µg/g	0.73 µg/g
4	16.9 µg/g	114.0 µg/g	0.36 µg/g
5	19.6 µg/g	92.5 µg/g	0.34 µg/g
6	21.0 µg/g	60.5 µg/g	0.28 µg/g
7	15.8 µg/g	170.0 µg/g	0.19 µg/g
8	1.4 µg/g	109.0 µg/g	nd
9	0.16 µg/g	144.0 µg/g	nd

nd = not detected

Table 3: Calculus of sediment samples analysis to determine the weight of sample

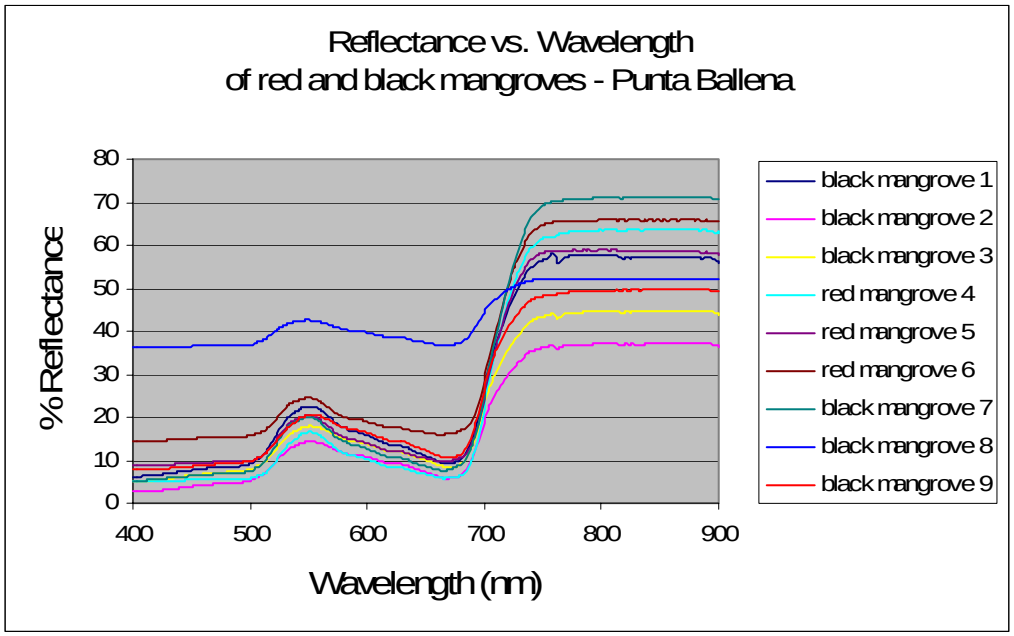
Sediment Sample	Weight of crucible	Weight of crucible + humid sample	Weight of humid sample	Weight of crucible + dry sample	Weight of dry sample	%Humidity
1	43.6641 g	46.2112 g	2.5471 g	46.0404 g	2.3763 g	7 %
4	41.1670 g	44.6703 g	3.5033 g	43.3197 g	2.1527 g	39 %
7	41.3409 g	45.8712 g	4.5303 g	44.3681 g	3.0272 g	33 %
8	44.7968 g	47.3917 g	2.5949 g	46.5285 g	1.7317 g	33 %

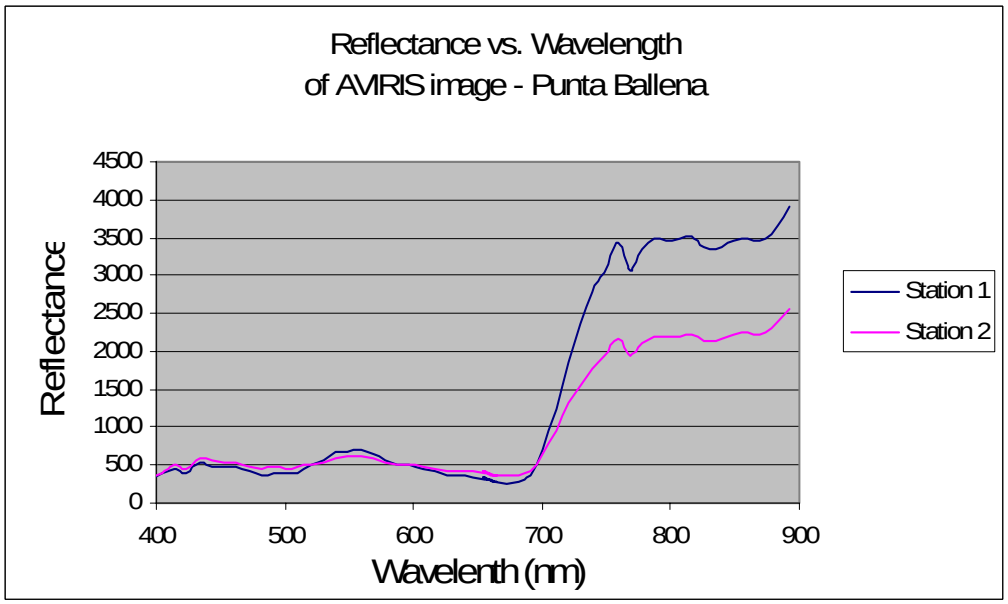
Four sediment sample were analyzed obtaining low concentration of copper whereas cobalt and cadmium were not detected.

Sediment Sample	[Co]	[Cu]	[Cd]
1	nd	20.5 µg/g	nd
4	nd	12.1 µg/g	nd
7	nd	13.6 µg/g	nd
8	nd	10.4 µg/g	nd

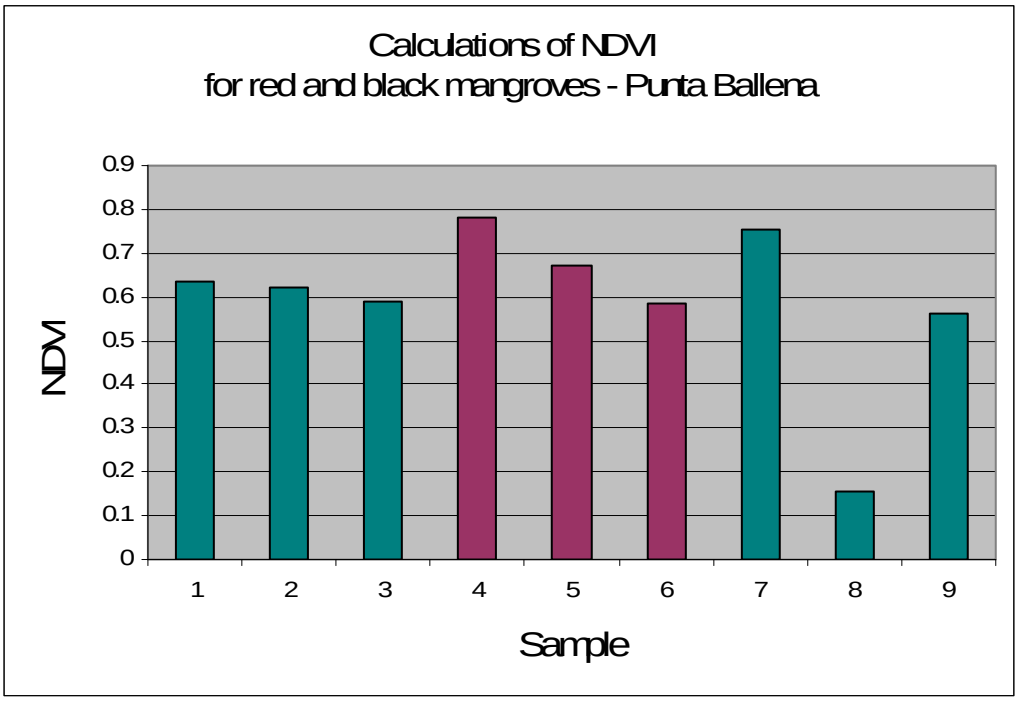
nd= not detected

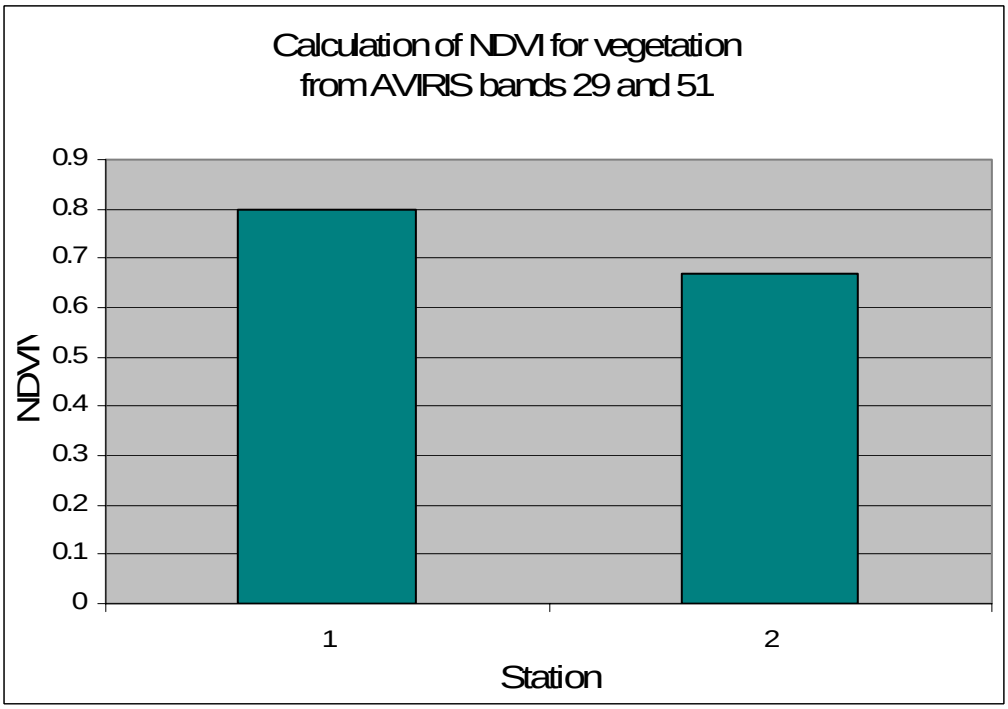
Graphs

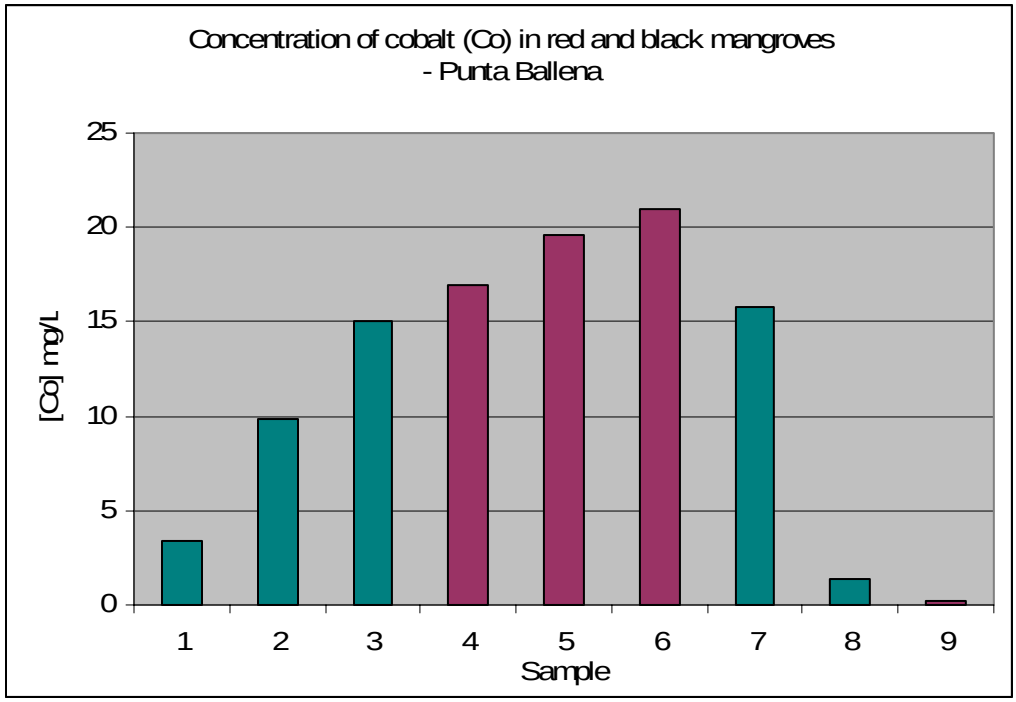

Reflectance vs. Wavelength
of red and black mangroves - Punta Ballena
% Reflectance
Wavelength (nm)
0
10
20
30
40
50
60
70
80
400
500
600
700
800
900
black mangrove 1
black mangrove 2
black mangrove 3
red mangrove 4
red mangrove 5
red mangrove 6
black mangrove 7
black mangrove 8
black mangrove 9

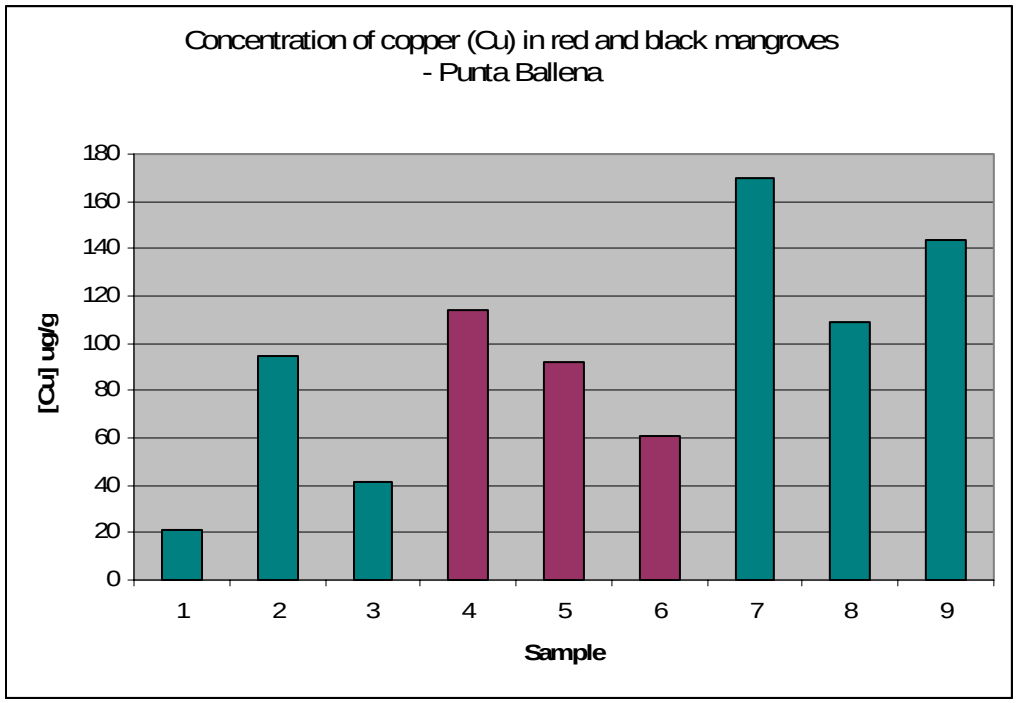

Reflectance vs. Wavelength
of AVIRIS image - Punta Ballena
Reflectance
Wavelenth (nm)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
400
500
600
700
800
900
Station 1
Station 2

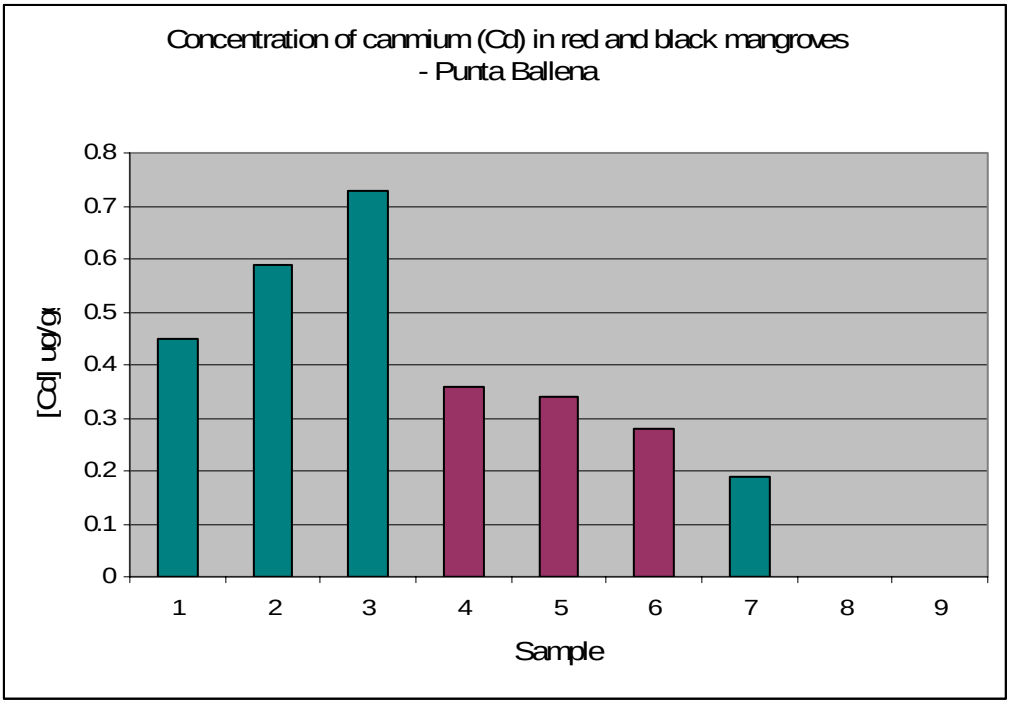
Graph: Comparison of the NDVI values obtained by the GER 1500 with the NDVI of the AVIRIS image.

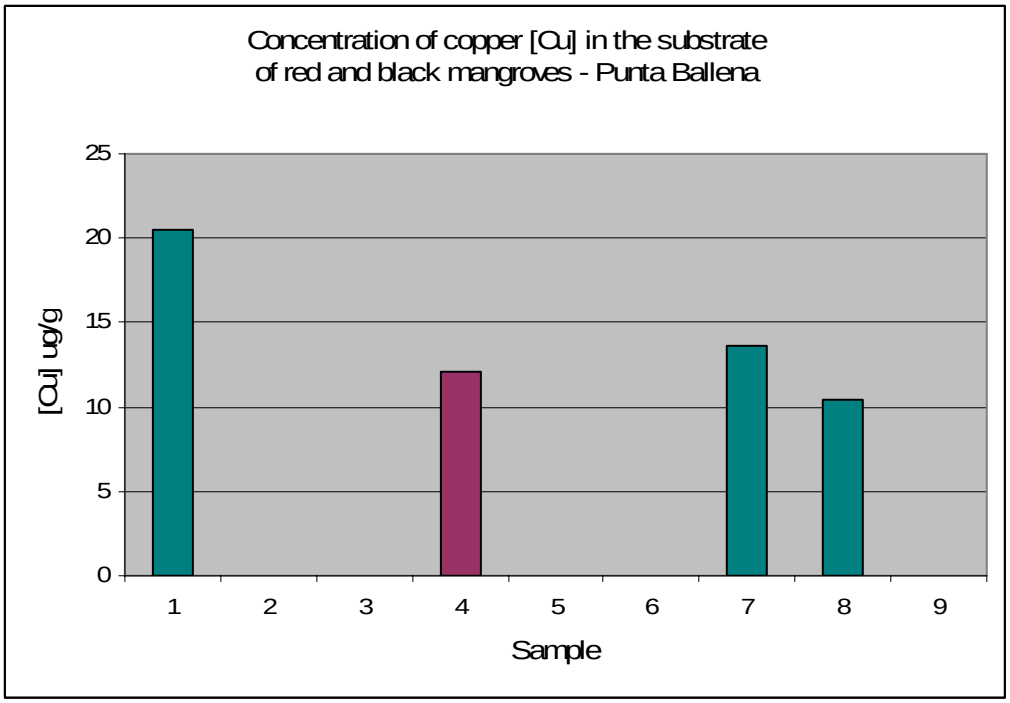





Concentration of cobalt (Co) in red and black mangroves
- Punta Ballena
[Co] mg/L
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
Sample


Concentration of copper (Cu) in red and black mangroves
- Punta Ballena
[Cu] ug/g
180
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
Sample


Concentration of cannmium (Cd) in red and black mangroves
- Punta Ballena
[Cd] ug/g
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
Sample


Concentration of copper [Cu] in the substrate
of red and black mangroves - Punta Ballena
[Cu] ug/g
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
Sample

Discussion and Interpretation

The AVIRIS image produced the reflectance curves and the vegetation index (NDVI) for the two stations. The reflectance in the AVIRIS image was very similar to the reflectance that was taken in the field although the values were a little lower at some points of the graph. On the other hand, the path in the reflectance of leaves took by the GER 1500 showed normal patterns (400-900nm) in which the areas of high reflectance were in the red and infrared wavelengths typically of vegetation areas. The values of NDVI were obtained using specific wavelength of the GER 1500 that were similar to the wavelengths of red and infrared bands of the AVIRIS image. In this part, the index in both methods indicated a high concentration of green vegetation range in both from 0.6-0.8.

The concentrations of heavy metals of Punta Ballena were determined by atomic absorption. Cobalt, cooper and cadmium were the heavy metals analyzed in the spectrometer. The leaves samples obtained low concentrations of cobalt in a range of 0.16 μg/g-21 μg/g whereas in the sediment sample the heavy metal was not found. On the other hand, the concentration of cooper was higher in the leaves of mangroves showing an absorbance of 21.3 μg/g to 170 μg/g in the black mangroves, and 60.5 μg/g to 114 μg/g in the red mangroves. The four sediment samples had lower values of 20.5, 12.1 μg/g, 13.6 μg/g, 10.4 μg/g respectively. The level in the concentration of cadmium was low in the leaves samples with a range of 0.18 μg/g to 0.72 μg/g. However, in sediment samples the concentration of cadmium was not detected.

The methods of remote sensing to calculate the reflectance and the vegetation index can provide multiple possibilities to study the health condition of the mangroves at Punta Ballena. The concentration of heavy metals can affect the vegetation in the way that light is absorb by the leaf structure and reflected. The high percentage of reflectance can be attributed to a healthy mangrove. The concentration of cobalt, and cadmium extracted from the leaves and substrate do not represent any danger to the stability of the mangrove area.

Conclusion

Monitoring of natural reserves is very important for the preservation of our environment. Initially the study was focused in the comparison two areas: a contaminated and non contaminated mangrove. Unfortunately, the microbiology lab was only available for graduate students and the faculty of the Biology Department. For a better understanding in the dynamic process of mangroves and how metal content could affect the spectral signals of satellite images, more advanced projects for graduate students are recommended. Supervised classification of the images is also suggested for a better understanding of the land use and land cover of the area.

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