STUDY OF AQUATIC VEGETATION IN TUCURUÍ RESERVOIR (BRAZIL) USING AIRBORNE SAR-C MULTIPOLARIZATION DATA.

Mauricio Almeida Noernberg
Oceanographer
National Institute of Space Research - INPE
Brazil

Commission VII, Working Group 5

KEY WORDS: Aquatic Vegetation, Multipolarimetric SAR-C, SAREX 92, Biophysical Indices.

ABSTRACT:

Aquatic vegetation communities are among the most productive in the world. In recent years the use of radar data have increased significantly, and have been used to estimate biomass trough empirical models. In this study the discrimination capability of two important aquatic vegetation genera (*Eichhornia sp.* and *Scirpus sp.*) was studied. These genera are present in Tucuruí reservoir, Brazil. Airborne SAR C multipolarization data was used. Three biophysical indices were calculated in order to study the type of interaction between microwave radiation and canopy.

1. INTRODUCTION

Aquatic vegetation communities are among the most productive in the world. However, their rapid and uncontrolled growth can result in a number of undesirable problems such as: obstruction of water flow, changes in water quality, decrease in oxygen levels, and increase in human health hazards (Junk and Howard-Williams, 1984; Barrow, 1987). Aquatic vegetation communities also play an important role in the carbon cycle, sequestering CO_2 from the atmosphere through photosynthesis and releasing it through respiration. They are also an important source of methane (CH_4) to the atmosphere (Wetzel and Grace, 1983; Morrissey et al., 1994).

The use of remote sensing data in ecological models has increased during the last years. A series of empirical models were developed to estimate biomass from remote sensing radar images (Le Toan et al., 1992). Most of these models are based on the relationship between radar backscatter and biomass, it is though important to ensure that the radar backscatter information is reliable.

The objective of the experiment was to investigate the effect of polarization on the discrimination of different aquatic vegetation genera using airborne multipolarization C band SAR data.

2. STUDY AREA

The test site for this study is the Tucuruí reservoir, located 300 Km south from Belém, Pará State, Brazil limited by the coordinates of 3°43'S; 49°12'W and 5°15'S; 50°00'W. It is the largest reservoir in operation in the Amazon region. The water reservoir surface is estimated to be around 2700 km². The area covered by aquatic vegetation during the dry season represents 20% of the reservoir's surface (Abdon and Meyer, 1990). The specific test site is the Pucuruí inlet (Figure 1).

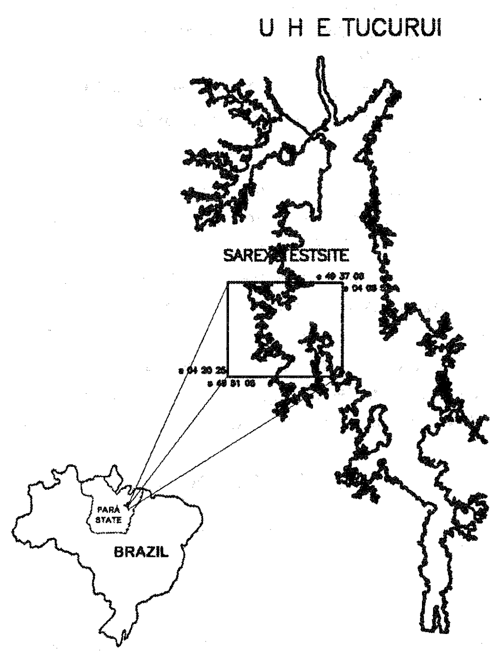
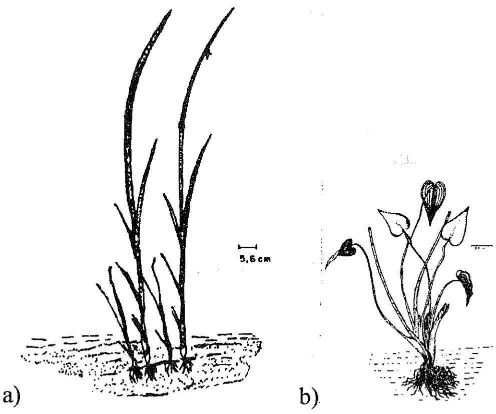


Figure 1. Study area.

Five major genera of aquatic vegetation are usually found in the Tucuruí reservoir. *Eichhornia sp.*, *Salvinia sp.* and *Pistia sp.* (free-floating); *Typha sp.* (emergent); and *Scirpus sp.* (floating leafed). For this study only *Eichhornia sp.* and *Scirpus sp.* will be aimed (Figure 2). The *Eichhornia sp.* has fine roots, produces stolons and viable seeds. Its leaves are 10 to 15 cm long, upright and bright green. The *Scirpus sp.* is the most widespread aquatic plant in the Tucuruí reservoir, with stands that are not homogeneous. Plants grow to a height of 1 to 2 meters and its roots are attached to the dead trees.

The reservoir is surrounded by tropical dense forest. Since the reservoir was filled without removing the forest, large areas are always occupied by dead tree trunks that emerge off the water surface.



a) b)

Figure 2. a) *Scirpus sp.*; b) *Eichhornia sp.*.

3. METHODOLOGY

3.1 Data Acquisition

From April 14 to 16, 1992, the Brazilian National Institute for Space Research (INPE), in co-operation with the European Space Agency (ESA), the Canadian Centre for Remote Sensing (CCRS) and Centrais Elétricas do Norte (ELETRONORTE) carried out an experiment in the Tucuruí reservoir, to assess the feasibility of using SAR data to map aquatic vegetation. The campaign included acquisition of multiviewing and multipolarization data, in the Nadir mode, taken by the Convair 580 SAR C-band System, from CCRS, over the inlets named Pucuruí and Repartimento in the Tucuruí reservoir. The swath width of the Nadir mode is 20 km and the incidence angles are between 20°-74°. Details of the campaign are found in Wooding and Zmuda (1993) and Novo et al. (1995).

The characteristics of SAR data used in this investigation are presented in Table 1. According to Hawkins and Teany (1993), the data acquired during the SAREX 92 mission were submitted to relative calibration. The calibration constants were empirically determined using corner reflectors deployed near Ottawa, Canada. These data were collected just before and soon after the mission, in order to assess the stability of the system. ERS-1 calibration data were then used to adjust the SAREX data.

Frequency	5.3 GHz
Wavelength	5.66 cm
Polarization	HH, VV, HV, VH
Mode	Nadir
Incidence angle of test area	38° - 50°
Pixel size	4m x 4.31m
Resolution	6m x 6m
Number of looks	7

Table 1. SAR characteristics.

The whole calibration equation suggested by Hawkins and Teany (1993). The INPE processed images have as output the amplitude values (A), given by:

$$A = \sqrt{DN^2(ij) - DN_n^{\,2}(j)} + 10^{\left(\frac{Fcal(j) - \overline{Fcal}}{20}\right)} \quad (1)$$

where:

- $DN(ij)$ is the pixel value at row i and column j;
- $DN_n(j)$ is the noise value at column j;
- $Fcal(j)$ is the calibration factor at column j.
- $\overline{Fcal}$ is the mean value of the calibration factor.

The equation used to convert the digital numbers (DN) into backscatter values ($\sigma°_{dB}$) was:

$$\sigma°_{dB} = 10 \log_{10} A^2 + \overline{Fcal} \quad (2)$$

Aerial photographs at the scale of 1:10 000 were acquired concurrently to the SAREX 92 mission and used as ground truth. A digital mosaic of 12 aerial photographs was registered to the SAR image. The mosaic was also used to set the limits of selected samples from different species. The number of samples (n) from each class was proportional to their occurrence in the reservoir. The classes studied are: Open water, Dead tree, Forest, *Eichhornia sp.*, and *Scirpus sp.*. For every sample the mean and the standard deviation of the digital number were computed in the four polarizations. Each mean digital number was converted into $\sigma°_{dB}$ through equation (2). Values of $\overline{Fcal}$ for each polarization are presented in Table 2.

HH = -48.660118	HV = -45.51140
VV = -48.40868	VH = -45.634056

Table 2. $\overline{Fcal}$ values.

The coefficient of variation was calculated for all classes using the digital numbers.

3.2 Correction Factor

The data presented cross-polarization dB values not compatible with that reported in the literature and neither consistent with radar theory in C band. The cross-polarization backscattering dB values were higher than the like-polarization. Hence, a correction factor (**k**) was computed. It is formulated as follows:

$$\mathbf{k} = \Delta_{VH-VV} + \mathbf{S} \Rightarrow 1.3 + 6.6 = \underline{\mathbf{7.9\ dB}} \quad (3)$$

where,

$$\Delta_{VH-VV} = \frac{\sum_{i=1}^{N} (VH_i + VV_i)}{N} = \underline{\mathbf{1.3\ dB}} \quad (4)$$

were Δ_{VH-VV} is the mean variation in all classes distinguished from SAREX data. This mean variation represents how large are HV data compared to the VV data.

$$\mathbf{S} = \overline{VV} - \overline{HV} = \underline{\mathbf{6.6\ dB}} \quad (5)$$

where $\overline{VV}$ and $\overline{HV}$ are the mean values, in C band, for the following classes: shrubs, short vegetation and grasses, at an

40°-50° incidence angles (Ulaby and Dobson, 1989). The value of **S** was 6.6 dB. This agrees with Freeman and Durben (1996) data, who presented a difference between $\overline{VV}$ and $\overline{HV}$ equal to 6.6 dB. The authors worked with the following classes: Forest, Swamp forest, Flooded forest, Regrowth, Open water, etc., also in C band with incidence angles ranging between 40°-50°.

3.3 Biophysical Indices

Three biophysical indices proposed by Pope et al. (1994) were applied to data in order to improve the interpretation of the vegetation physiognomy. This indices are meaningful only when taken in the context of the type of interaction between microwave radiation and canopy. The indices used are:

- CSI canopy structure index $= \dfrac{VV}{VV + HH}$

- VSI volume scattering index $= \dfrac{CS}{CS + LK}$

- BMI biomass index = LK

where:

- CS $= \dfrac{HV + VH}{2}$, and - LK $= \dfrac{VV + HH}{2}$

CSI is a measure of the relative importance of vertical versus horizontal structure of the vegetation. Ecosystems dominated by nearly vertical trunks or stems will have higher CSI values than will ecosystems dominated by horizontal or near-horizontal branches. It also should be noted that ecosystems with a high percentage of double bounce will have lower CSI values than ecosystems with similar structure but little double bounce interaction.

VSI is a measure of the depolarisation of the linearly polarized incident radar signal. High values of VSI result when the cross-polarized backscattering (CS) is larger than the like-polarized average (LK). Therefore, VSI is an indicator of canopy thickness or density.

BMI is an indicator of above-ground biomass. A critical aspect of BMI is the relationship between the radar wavelength and the size of vegetation components, which determine whether or not a given component acts as a scatterer or absorber. An increase in total, above-ground biomass can cause either an increase or a decrease in BMI, depending upon how this biomass is distributed.

The indices were calculated for all classes, excepting for Open water, using the digital number values.

4. RESULTS AND DISCUSSION

Table 3 presents the number of sample (*n*), the number of pixels, the mean σ° and the standard deviation, for all studied classes. The Table 4 shows the classes dynamic range.

Low dynamic range values denote a smaller σ° variation inside of the class, and a higher homogeneity between the samples. This allows to a better class characterisation (Ahern et al., 1993). Lower dynamic range values were determined for forest in all polarization. In the average the HH polarization presented lower dynamic range values, denoting better classes discrimination possibility.

The variation of the mean σ° values are presented in the Figure 3. The large σ° variation inside the classes are due to radar parameters, like speckle, and variations in the canopy morphologic and structural characteristics.

The aquatic vegetation stands may present variation in the density and homogeneity. This fact may affect the spacing between the leaves and stalks, and consequently the backscattering. Differences in age and height may contribute for the variation in the dynamic range too.

In Figure 3 it is possible to evaluate the polarization behaviour inside the classes. Forest and *Eichhornia sp.* presents VV values bigger than HH. This may be due to the vertical orientation of the branches and stalks, respectively. Ulaby and Dobson (1989) also founded bigger σ° VV values for trees and grasses.

Figure 4 shows the dynamic range in the four polarizations, for each class. Figure 4 indicates small possibility of discrimination among the classes in the four polarizations.

Figure 5a indicates the possibility of discrimination among the classes using de mean σ° values. In VV polarization Forest, *Scirpus sp*, and *Eichhornia sp.* can not be discriminated. The HH polarization seem to present the best discrimination capability for all classes. It is important to point out that only the mean value is been considered, and that the mean σ° values and the coefficient of variation were derived from large samples. This fact bring the mean near to the population mean.

The coefficients of variation of the classes for all polarizations are showed in the Figure 5b. Its analysis show a different behaviour when compared with mean σ° values. There are a smaller variation between the polarization inside the classes, and smaller discrimination possibility between the classes.

The plot of the four polarizations with the respective coefficient of variation are presented in Figure 6. It's possible to observe well defined groups, mainly in HH polarization. In the other polarizations the classes *Scirpus sp.*, *Eichhornia sp.* and Forest make the groups less evident.

Table 5 presents the biophysical indice values for all classes. Although of the low variation between the indices values it is possible to observe large CSI values for Forest and *Eichhornia sp.*. This confirms the larger influence of the vertical structures in the larger VV backscattering. The Forest presents larger VSI values indicating a larger canopy wave penetration. Probably this fact is due to the small wavelength (5.6 cm) in relation to the forest scatterer size distribution. *Scirpus sp.* have the bigger BMI values, indicating larger biomass. Although of the high forest biomass it is not showed by the BMI index, probably, because the C band wavelength interact only with the upper forest canopy, not been influenced by the trunk biomass.

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ACKNOWLEDGEMENTS

The author thanks the Brazilian National Institute for Space Research, the Canadian Centre for Remote Sensing, the Canadian International Development Agency, and the European Space Agency for supporting this work. Thanks are also due to Centrais Elétricas do Norte for the support during the ground data collection in the Tucuruí reservoir. The author would also like to thank Dra Evlyn M. Novo and Dra Thelma Krug for the support to carry out this study.

Class	Pixels	*n*	HH		HV		VH		VV	
			Mean	s	Mean	s	Mean		Mean	
Water	27583	13	-28.5	1.4	-24.5	2.4	-25.4	2.2	-26.8	1.5
Dead trees	33691	14	-16.4	1.7	-19.6	1.6	-19.7	1.6	-18.8	1.6
Forest	243326	18	-13.3	0.6	-10.9	0.6	-11.0	0.6	-12.8	0.3
Scirpus sp.	155176	39	-12.0	0.9	-10.9	0.9	-10.9	0.9	-13.6	1.2
Eichhornia sp.	14973	8	-15.1	1.5	-13.0	1.4	-13.1	1.4	-14.3	1.7

Table 3. Mean σ^{o}_{dB} and Standard Deviation (s) values for all classes and all polarization.

Class	HH		HV		VH		VV	
	Mean	D.R.	Mean	D.R.	Mean	D.R.	Mean	D.R.
Water	-28.5	4.5	-24.5	7.6	-25.4	6.8	-26.8	4.8
Dead trees	-16.4	5.6	-19.6	5.9	-19.7	5.2	-18.8	5.0
Forest	-13.3	1.4	-10.9	2.2	-11.0	2.1	-12.8	0.8
Scirpus sp.	-12.0	3.5	-10.9	3.9	-10.9	4.1	-13.6	5.4
Eichhornia sp.	-15.1	4.2	-13.0	4.0	-13.1	4.0	-14.3	4.8

Table 4. Mean σ^{o}_{dB} and Dynamic Range (D.R.) values (dB) for all classes and all polarization.

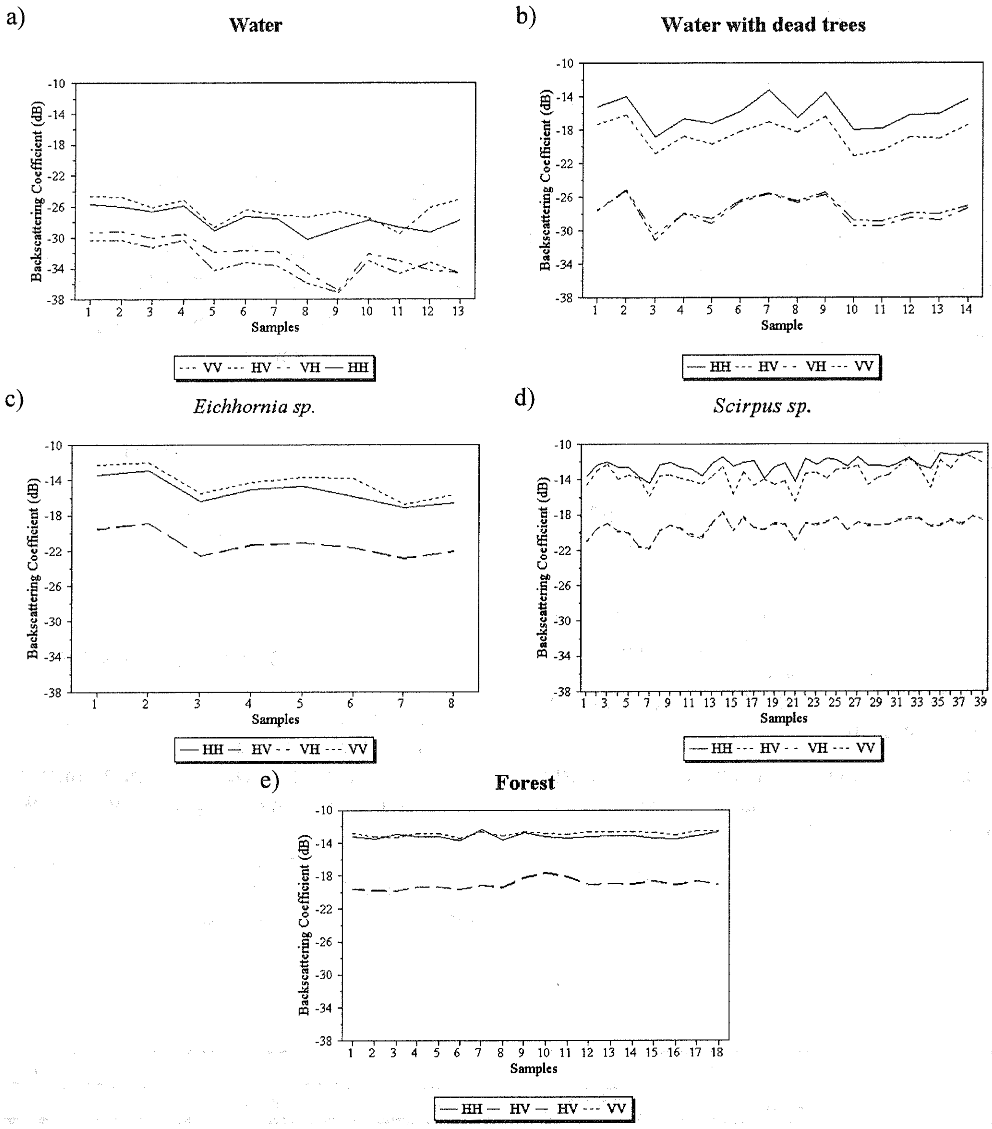

Figure 3. Mean σ° variation for all polarizations for all samples of classes.

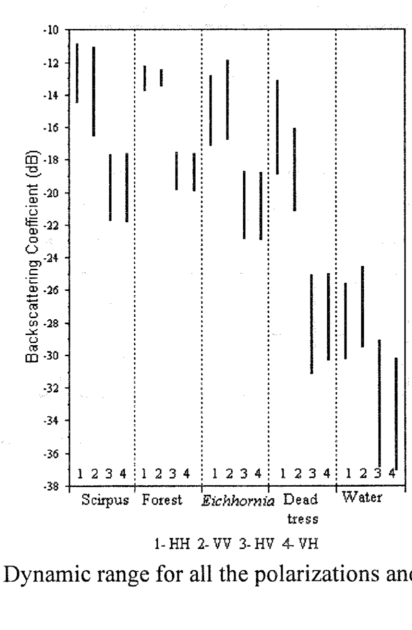

Figure 4. Dynamic range for all the polarizations and all the classes.

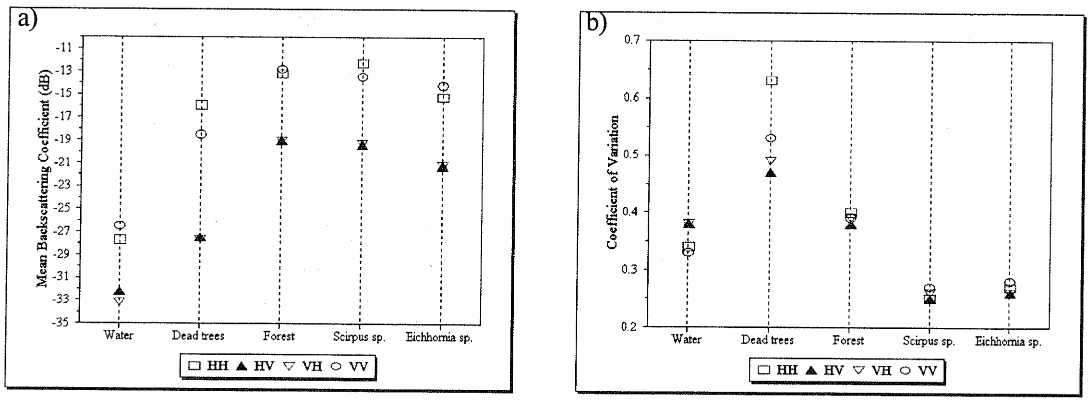

Figure 5. a) Mean $\sigma°$ values for all polarizations to each class. b) Coefficient of variation for all polarizations to each class.

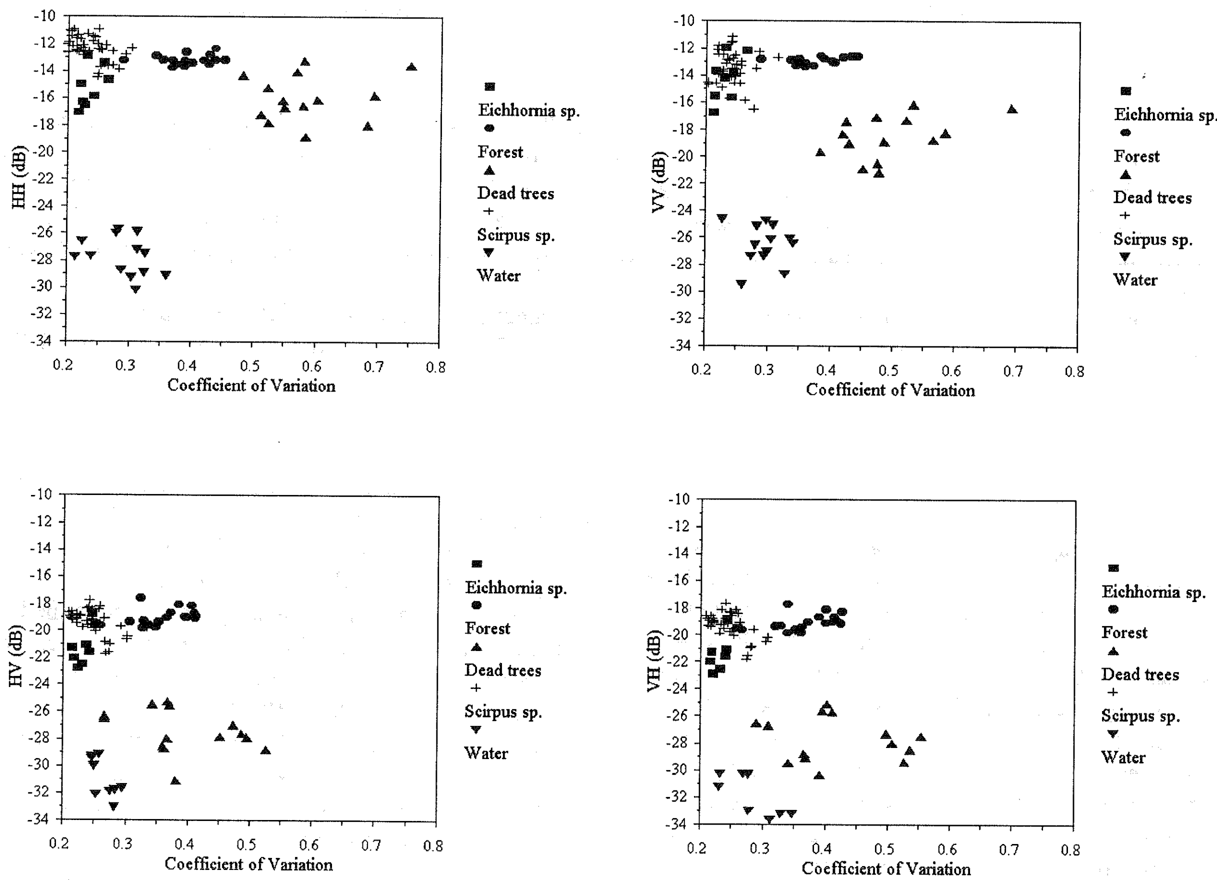

Figure 6. Coefficient of variation and the four polarizations plot for all samples of the classes.

Class	VSI		CSI		BMI	
	Mean	s	Mean	s	Mean	s
Dead trees	0.19	0.06	0.44	0.09	35.5	19.6
Forest	0.27	0.05	0.50	0.07	59.4	21.9
Scirpus sp.	0.25	0.05	0.46	0.08	63.5	13.0
Eichhornia sp.	0.25	0.05	0.51	0.07	49.0	11.7

Table 6. Biophysical indices mean values and standard deviation (s) for all classes.