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# REMOTE SENSING IN MANGROVE RESEARCH - RELATIONSHIP BETWEEN VEGETATION INDICES AND DENDROMETRIC PARAMETERS: A CASE FOR CORINGA, EAST COAST OF INDIA

B. Satyanarayana [1], B. Thierry [2], D. Lo Seen [2*], A.V. Raman [1], G. Muthusankar [2]

[1] Marine Biology Laboratory, Department of Zoology, Andhra University, Visakhapatnam - 530 003, India

[2] Geomatics Laboratory, French Institute of Pondicherry, 11 Saint Louis Street, Pondicherry - 605 001, India
tel: +91 413 334 168, fax: +91 413 339 534

[*] corresponding author's email address: danny.loseen@ifpindia.org

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## ABSTRACT

The mangrove forest of the Godavari estuary, Andhra Pradesh, represents the second largest area of such vegetation formations along the East Coast of India, next to the Sunderbans (West-Bengal). Although declared as Wildlife Sanctuary since 1972, this rich but fragile ecosystem has undergone serious alterations largely induced by human activities. Continuous efficient retrieval of reliable information from the mangroves is therefore necessary for conservation purposes. Satellite remote sensing is a useful source of information as it provides timely and complete coverage of the study area, complementing field surveys of higher information content but which are more difficult to carry out, especially in mangroves. The purpose of the present study is 1) to map the mangrove formations and its surroundings based on a supervised classification of remote-sensing data and 2) to analyse the potential relationships between mangrove dendrometric parameters and spectral indices extracted from satellite data. The supervised classification was carried out with an IRS-1C LISS3 image of March 1999 and was trained from ground truth data and field knowledge. Among the resulting 14 classes, 3 correspond to different mangrove signatures. The ground truth includes 128 sampling locations for which mangrove vegetation parameters like basal area and tree density have been estimated using the Point Centred Quarter Method (PCQM) on transect lines of at least 100 m. In a second stage, Vegetation Indices (VI) have been calculated at locations for which mangrove parameters were obtained from field surveys. Various statistical tools, among which scatter-plots and analyses of variance (ANOVA), have been used in order to explore the relationships that may exist between VI and mangrove parameters. The first results show that a relationship exists between VI and basal area whereas this is not the case with density. Furthermore, when spectral indices and mangrove parameters are considered altogether, it appears that only two classes of mangrove can be discriminated.

## 1. INTRODUCTION

Mangroves represent a specific ecosystem found in the intertidal zone along tropical and subtropical coastlines, and are often located near estuaries and deltas (Spalding et al., 1997). Being highly productive ecosystems and harbouring a large diversity of species adapted to these particular habitats, they are considered of utmost ecological importance. Moreover, they provide a number of direct and indirect services, ranging from protection against coastal erosion (Pearce, 1999) to the multiple forest products usage by local population (Blasco, 1975). For the past decades however, the situation of mangrove forests has been continuously deteriorating due to an increasing human pressure resulting in conversion to agricultural lands, renovation of brackish water fisheries, prawn and shrimp farms, salt pans, urban and industrial pollution, etc. (Clough, 1982).

The mangrove forest of the Godavari estuary, Andhra Pradesh, is the second largest area of such vegetation formations along the East Coast of India, next to the Sunderbans (West-Bengal) and counts about fifteen mangrove species, among which *Avicennia marina*, *A. officinalis* and *Excoecaria agallocha* are the most dominant ones. Although declared as Wildlife Sanctuary since 1972, this rich but fragile ecosystem has undergone serious alterations largely induced by human activities. Continuous efficient retrieval of reliable information from the mangroves is therefore necessary for conservation purposes.

Satellite remote sensing is a useful source of information as it provides timely and complete coverage of the study area, complementing field surveys of higher information content but which are more difficult to carry out, especially in mangroves. For these reasons, studies have been carried out on mangrove ecosystems using aerial photography (e.g. Dahdouh-Guebas et al. 2000), optical (e.g. Rasolofoharinoro et al., 1998), and radar (e.g. Mougin et al., 1999) remote sensing data, or a combination of them (e.g. Pasqualini et al., 1999). However, the objectives of the studies differ according to what can be expected from the different types of remote sensing data. For example, mapping mangroves at the species level can be attempted with high-resolution aerial photography, whereas mapping the landscape level environmental indicators of a coastal area can generally be carried out using optical satellite images from sensors like Landsat TM, SPOT HRV or IRS LISS (Klemas, 2001, Ramachandran et al., 1998). For the estimation of mangrove forest parameters like basal area or biomass, radar remote sensing seems most promising (Mougin et al., 1999, Proisy et al., 2000), although appropriate configurations of frequency, polarisation and spatial resolution are currently not available on orbiting radar satellites.

In the present study, we explore the possibility of using spectral indices derived from optical satellite images to give quantitative estimates of mangrove vegetation parameters. The study area, the Coringa Forest, is one of the most closely followed mangroves in India for the last decade. Significant ground data of the area have been acquired during numerous measurement campaigns in the mangrove forests during the last five years. In a first step, the mangrove formations and its surroundings are mapped, based on a supervised classification of an IRS-1C image of March 1999. In a second step, the potential relationships between mangrove dendrometric parameters measured on the ground and spectral indices extracted from the satellite data are analysed and interpreted.

## 2. MATERIALS AND METHODS

### 2.1. Study area

The Godavari is the second longest river of all the Indian sub-continent. It divides into Gautami and Vasista just after the Dowlaiswaram Dam about 60 km before reaching the Bay of Bengal. The mangroves studied are located around the Gautami-Godavari estuary. The study area extends from around 82°05'E to 82°25'E and 16°30'N to 17°05'N and includes Kakinada city, Kakinada Bay, the Coringa Wildlife Sanctuary where the most important stretch of mangrove is found, and also the mangrove forest situated south of Gautami-Godavari River. Several different landscapes compose the area (Figure 1), with paddy fields and coconut tree plantations in the west and south, mangrove forests, aquaculture ponds for shrimp farming spreading into mangrove forests, saltpans, casuarinas plantations along the beach and on Hope Island, villages and urban areas (Kakinada, Yanam).

### 2.2. Ground data collection

The ground data used in the present study were acquired during the period 1998-2000, and consist mainly of mangrove vegetation identification, counting and dendrometry. A regular sampling grid of 1-minute latitude and longitude spacing is first used. Additional sampling points have also been taken, mainly in the mangrove area so that, out of a total of 128 sample plots visited, 83 pertained to the mangrove forest (Figure 1). Each sample plot was accessed with the help of a GPS receiver (model Garmin 45) with an estimated accuracy of 100 m due to the Selective Availability (SA) introduced by the US Department of Defence at that time, *i.e.* before May 2000. When any given grid node could not be reached, the sample plot was installed at the nearest accessible place and the surrounding land-use recorded.

For the mangrove sampling plots, data acquisition was done using the PCQ-Method (Point Centred Quarter Method) (Cintrón and Shaeffer Novelli, 1984). This allows for the measurement of density, basal area, mean diameter and relative composition of forest stands. For each mangrove plot, a transect line of at least 100 m (depending on accessibility) was laid out westwards. Every ten meters along the transect, four quarters were established by drawing a line perpendicular to the transect line. Then, in each quarter, the tree nearest to the node was measured (Figure 2). Following the recommendations of Cintrón and Shaeffer Novelli (1984), diameter at breast height (dbh) was obtained by measuring girth at 1.3 m from the ground in the case of erect tall trees (*Avicennia marina, A. officinalis, A. alba, Bruguiera gymnorrhiza, Excoecaria agallocha, Sonneratia apetala* and *Xylocarpus mekongensis*) and above the highest established prop roots for *Rhizophora* trees. In the case of individuals less than 3 m high (mainly *Aegiceras corniculatum, Bruguiera cylindrica, Ceriops decandra, Lumnitzera racemosa* and some *A. marina*), the girth was measured below the lowest branch point. All the measurements made did not require any sophisticated equipment. For that reason, data like Leaf Area Index (LAI), which could have been interesting for this remote sensing study, were not acquired. The data collected were entered in a spatial database for subsequent spatial queries and analysis.

### 2.3. Satellite data analysis

The multispectral image used in this study is an IRS-1C LISS3 image of March, 8$^{th}$ 1999 with 4 spectral bands (green, red, near infrared (NIR) and short-wave infrared (SWIR)). The spatial resolution (expressed as pixel size) is 23.5 m for the three visible/NIR bands and 70.5 m for the SWIR band. The image has been geocoded in UTM projection based on ground control points obtained by post-SA GPS measurements. The RMS error of the transformation was less than 15 m.

One of the goals of the remote-sensing data analysis was to produce a land-use map of the mangrove forest and its surroundings. This was done in a two-step process. First, a maximum likelihood supervised classification was carried out using training areas chosen according to extensive field knowledge but without any specific reference to the grid sample points. Afterwards, the raw result of the supervised classification was checked during visual interpretation of the satellite image and field visits. Small polygons that were obviously wrong (*e.g.* sediment plumes into the bay were classified as fallow land) have been recoded so as to match the operator's field knowledge (Figure 3).

The second part of the study concerned the analysis of potential relationships between vegetation indices and mangrove dendrometric parameters (namely, density and basal area). Normalised Difference Vegetation Index (NDVI) was calculated from the image as the band ratio (NIR - Red)/(NIR + Red). The transect locations were then entered in the spatial database as rectangles of roughly 150 m x 75 m, which correspond to 18 pixels. This size represents a compromise between the actual dimensions of the field transects and a pixel set large enough to minimise statistical bias due to the spatial variation of pixel value. In the analysis, only sample plots (83) in mangroves were considered. Each transect location on the image was reviewed to account for the 100 m position uncertainty given by the GPS. This prevented overlapping with neighbouring categories of land-use like beach, river and barren land. The mean value of the area thus covered by one transect rectangle was then extracted from the NDVI image and the land-use map. This value was then stored for each mangrove sample plot in the spatial database along with the other available information.

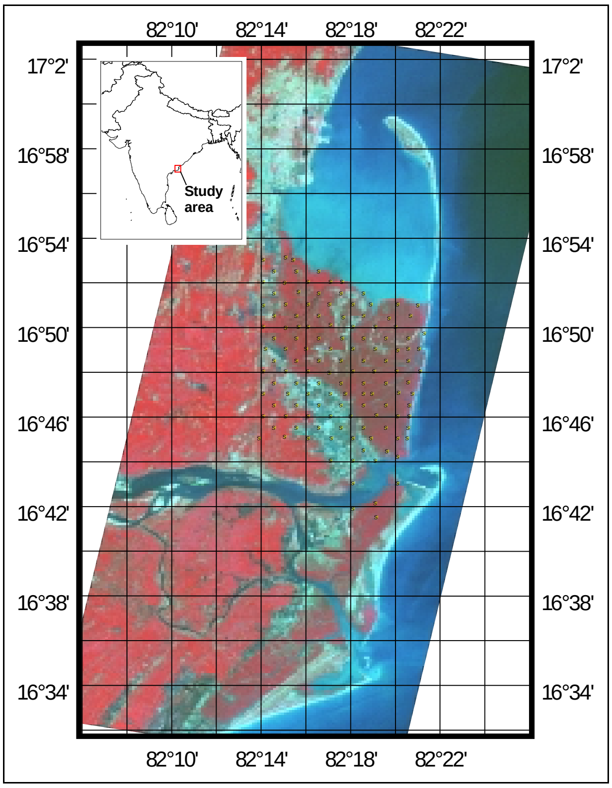


**Figure 1: IRS-1C image of the study area, the 128 sample plots are also represented**

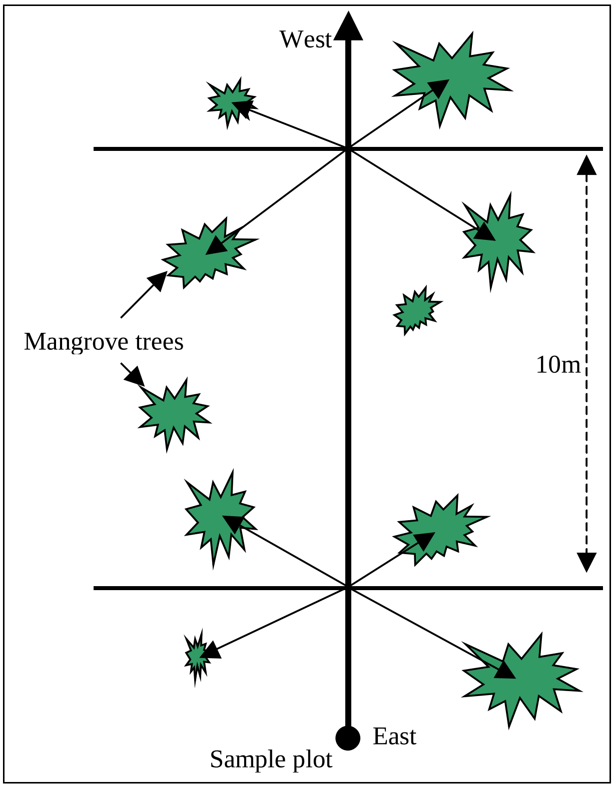


**Figure 2: PCQ-Method example**

## 3. RESULTS AND DISCUSSION

### 3.1. Supervised classification

The land-use map derived from the satellite image is presented in Figure 3. The classification led to 14 classes, among which three were for mangrove forest, *i.e.* dense, medium dense and less dense mangrove. In order to evaluate the accuracy of the land-use map, a confusion matrix was produced (Congalton, 1991) using the 128 ground truth locations. As the classes used for ground truth data were different from those of the land-use map, a non-bijective correspondence had to be set between them. This took the form of a lookup table as presented in Table 1. After overlaying the ground truth locations on the land-use map, the land-use classes corresponding to each of them were noted. Given the relatively small number of locations considered, each individual location was checked both on the image and land-use map to avoid residual misplacement due to SA uncertainty. Plots that fell on or very near boundaries between aquaculture ponds and paddy fields were assigned to the mixed class. The results are given in the confusion matrix shown in Table 2.

| Original class | Matching ground truth class |
|---|---|
| Water | - |
| Sand bar | - |
| Aquaculture | Aquaculture |
| Salt pans | - |
| Unvegetated areas | Barren land |
| Fallow land | Barren land |
| Agriculture | Agriculture |
| Marsh grass | Barren land |
| Coconut | Plantation |
| Casuarina plantations | - |
| Less dense mangrove | Mangrove |
| Medium dense mangrove | Mangrove |
| Dense mangrove | Mangrove |
| Settlements | Settlement |

**Table 1: Lookup table between land-use map classes and ground truth classes**

| | | Supervised classification | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Agriculture | Barren land | Mangrove | Mixed | Plantation | Settlement | Aquaculture | Total | Accuracy |
| Ground truth | Agriculture | 11 | 2 | - | 1 | - | - | - | 14 | 79% |
| | Barren land | - | 5 | - | - | - | - | 2 | 7 | 71% |
| | Mangrove | - | 2 | 81 | - | - | - | - | 83 | 98% |
| | Mixed | - | - | - | 3 | 1 | - | - | 4 | 75% |
| | Plantation | - | - | - | - | - | - | - | 0 | N/A |
| | Settlement | - | - | - | - | - | 1 | - | 1 | 100% |
| | Aquaculture | - | 3 | - | 1 | - | - | 15 | 19 | 79% |
| | Total | 11 | 12 | 81 | 5 | 1 | 1 | 17 | 128 | |
| | Accuracy | 100% | 42% | 100% | 60% | 0% | 100% | 88% | | |

**Table 2: Confusion matrix of supervised classification and ground truth**

The reading of the confusion matrix draws some comments. First of all, it can be noted that mangrove has been very well classified, especially since the three mangrove classes have been merged into one. This is not surprising as it is displayed with a characteristic spectral signature on the satellite image as shown in false colour composite (FCC) in Figure 1. The two points misclassified are found on barren areas within mangroves and are anyhow close to mangrove vegetation. The confusion between Agriculture and Barren land on one hand and Aquaculture (ground truth) and Barren land (supervised classification) on the other hand can be explained by the seasonal cycles of the paddies and ponds. Periodically, aquaculture ponds need to be emptied for maintenance and cleaning (at least once a year) and during that period, the dried ponds have the same spectral signature as barren land. As the image was taken on March 8$^{th}$, 1999 and the fieldwork had been carried out at different periods that spans over 3 years, it is most likely that a number of ponds were empty during the satellite overpass. A similar explanation is also valid for paddy fields: after harvest (which happens once or twice a year), the paddy fields are either left as fallow lands or used for growing leguminous plants (*e.g.* grams). These sparsely vegetated areas tend to have a spectral behaviour very close to that of barren lands, hence the confusion that arises from the time difference between the image acquisition date and the field visits.

### 3.2. Relationship between NDVI and dendrometric parameters

Here, we try to verify whether the three different mangrove classes obtained from the satellite image are substantiated by mangrove vegetation field measurements. In other terms, potential relationships between NDVI and dendrometric factors (*viz.* density and basal area) of mangrove forest are investigated. This has been done through qualitative analysis as well as quantitative – statistical – methods.

An efficient statistical method to analyse relationships between a qualitative factor (*e.g.*, mangrove classes) and a quantitative factor (*e.g.*, basal area or density) is analysis of variance (ANOVA). This method investigates, in a set of values organised in several groups, the proportion of variance that can be explained by within-group variability (called *Mean Square Error* or $MS_{err}$) and inter-group variability (called *Mean Square Effect* or $MS_{eff}$). The smaller $MS_{err}$ and higher $MS_{eff}$, the stronger the relationship between the set of values and the groups. Yet, as shown in Figure 4, mean values for basal area of *Less dense mangrove* and *Medium dense mangrove* are not significantly different (respectively, 1.034m$^2$/0.1ha and 1.031m$^2$/0.1ha) to be considered as two groups with respect to basal area. The same observation also holds for density. Consequently, *Less dense mangrove* and *Medium dense mangrove* classes have been merged into one class called *Less/Medium dense mangrove*. With these two groups (*i.e.*, *Less/Medium dense mangrove* and *Dense mangrove*), ANOVA gives $MS_{eff} = 97.4$ and $MS_{err} = 3.3$ for basal area on one hand and $MS_{eff} = 444193.8$ and $MS_{err} = 68895.1$ for density on the other hand. Using the $F$ test, which measures the significance of the ratio of the two variances, we obtain $F = 29.5$ for basal area and $F = 6.4$ for density. Therefore the two mangrove classes can be considered highly related to the basal area and much less pertinent relative to density.

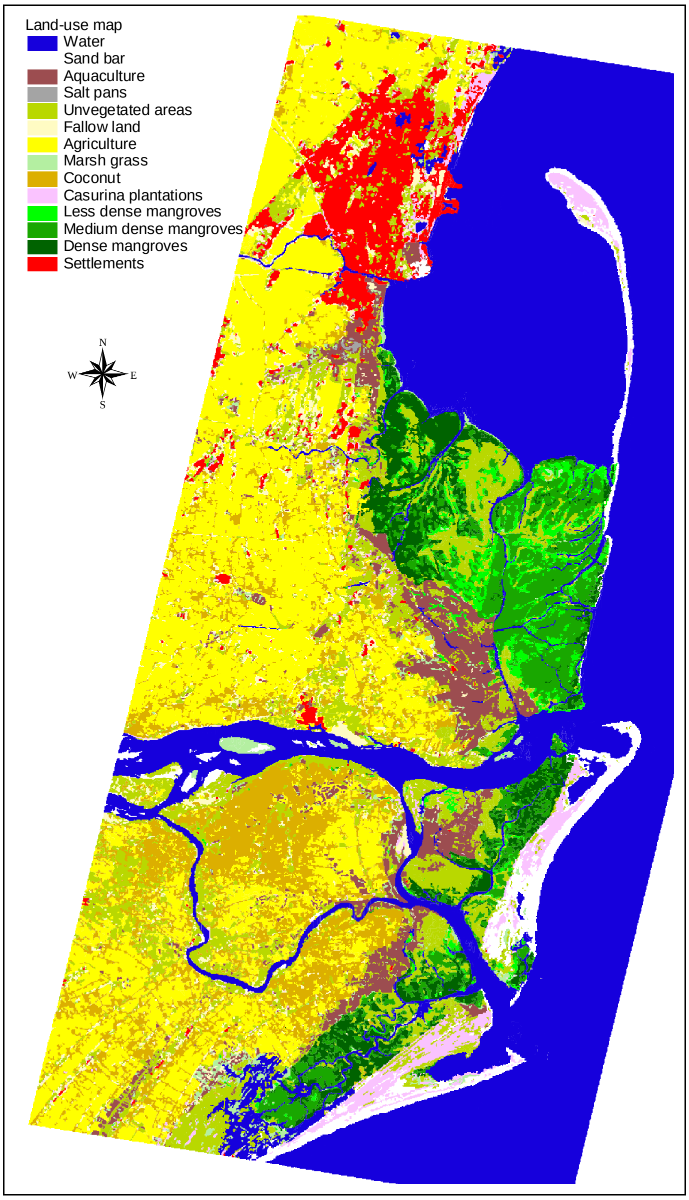


**Figure 3: Land-use map**

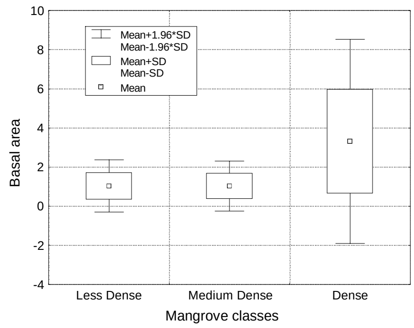


**Figure 4: Comparison of basal area mean for the three mangrove classes**

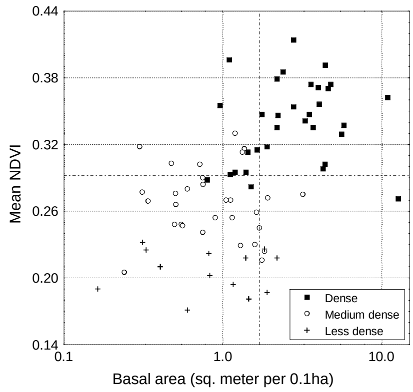


**Figure 5: Basal area vs. NDVI for the three mangrove classes**

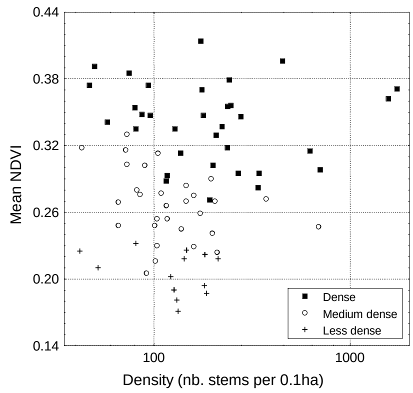


**Figure 6: Density vs. NDVI for the three mangrove classes**

These results are clearly illustrated on Figure 5 and Figure 6. The two scatter plots show the relationships between NDVI and basal area (Figure 5) and between NDVI and density (Figure 6) for the three classes, *viz. Less*, *Medium dense* and *Dense mangrove*. In both figures, *Less*, *Medium dense* and *Dense mangroves* are displayed in correct order, that is, with increasing mean NDVI from *Less dense* to *Dense mangrove*. This is as expected because both NDVI and the classification were derived from the same data source (satellite image). When NDVI is plotted against basal area, two zones can easily be identified along the main diagonal, one in the lower left quarter, and the other in the upper right quarter of the graph, which indicates that a relationship exists between basal area and NDVI. However, when NDVI is plotted against density, no relationship is found. This is not quite surprising because density expressed as number of individuals per unit area is not a good indicator of the ‘amount’ of vegetation as seen in the satellite image, as the sizes of the individuals can be very different (height up to 10 m, dbh up to 60 cm). In comparison, basal area is shown to be a better indicator of vegetation ‘amount’ such that *Less/Medium dense mangrove* may stand for lower basal area and *Dense mangrove* for higher basal area. These preliminary results show that at least a broad estimate of the basal area of mangrove forest can be obtained from optical satellite imagery. In fact, the relationship is more between classes of NDVI and basal area than between NDVI and basal area directly. This relationship is therefore considered not significant enough to allow basal area mapping of the mangrove forest.

## 4. CONCLUSION

A land-use map of the Godavari estuary area was made from supervised classification of an IRS-1C LISS 3 satellite image of March 8, 1999. A difficulty faced while carrying out this classification was to correctly identify some aquaculture ponds and agricultural fields while they were seen as barren lands on the day of the satellite overpass. This type of errors can however be reduced/eliminated using multi-date classification of images taken at different seasons. The mangrove areas have been presented in three classes in the land-use map corresponding to *Less dense*, *Medium dense* and *Dense* mangroves, according to differences in spectral characteristics revealed during the classification procedure. When compared with ground data, these differences were consistent with differences in basal area only after merging *Less dense* and *Medium dense* classes, as the basal area measurements for these two classes were not significantly different. In that way, *Less/Medium dense* mangroves were found to correspond to mangroves with lower basal area, and *Dense* mangroves, to those with higher basal area. However, no such relationship was found with measured 'density'. This observation can be understood by the fact that the term 'density' has different meanings in the classification and in ground measurements. In the classification, density stands for the 'amount' of vegetation seen by the sensor or by a person walking in the mangroves, whereas the measurements are expressed in number of individual trees per unit surface area. These mangroves being neither mono-specific nor even-aged, it is normal that a same number of trees will correspond to different 'amount' of vegetation. In that sense, basal area has a definition closer to the density used in the classification, which explains the relationship between density classes and classes of basal area. The direct relationship between spectral indices and basal area is however not considered significant enough to allow basal area mapping. A possible explanation is that spectral indices integrate variabilities in optical characteristics, amount and spatial organisation of leaves due to species and edaphic conditions that are only partially expressed in basal area. Conversely, a similar study aiming at species identification would be hampered by variabilities in vegetation densities that are not related to species composition. Nevertheless, recent and future sensors with increased spatial and spectral resolutions are bringing new hope to obtain timely and precise information necessary for managing mangrove ecosystem conservation.

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