CHAPTER 4

SPECTRAL STUDIES ON MANGROVES

4.1 INTRODUCTION

The sensor systems currently used in optical remote sensing of the Earth's surface can be classified in different ways. This classification is based on the mode of operation of the sensors, their spectral characteristics, and/or the platform on which the sensor is deployed. There is a wide variety of ground-based radiometers with different bandpass filters that mimic the operational airborne and spaceborne radiometers and scanners. Most of these sensors operate basically on the same principles, except that they measure the reflected or emitted energy from the surface over different wavelength regions of the electromagnetic spectrum (Asrar, 1989). The intensive field measurement programs of the 1970s and early 1980s were fruitful and contributed much to satellite data processing and thematic information capability development for example ‘signature-extendable technology’ for Global space-based crop recognition. But they yielded less than expected in the way of fundamental understanding of the physical relationships between electromagnetic radiation and surface variables and processes. Much of the earlier field work was limited to scene classification verification. Recently, increased Global awareness on the need to
repetitively measure and model the Earth, its components and processes, as a single system has ushered in a new era of auspicious Global monitoring and study approach which is opportunely coupled with the prospects for more advanced, multiple sensor Earth Observing Satellite (EOS) systems for the 1990s (Deering, 1989). Imaging spectrometry has also been used for vegetation mapping. The concentration of chlorophyll and water in vegetation canopies have been estimated using imaging spectrometry data. Because of the strong link between chlorophyll concentration, water concentration and the leaf area index (LAI) of the canopy, it has been proved possible to use imaging spectrometry to estimate canopy LAI. More details about imaging spectrometry could be obtained from Curran and Kupiec (1995).

Field measurements using radiometers have been used to calibrate and also validate the information derived from remote sensing data and this process is called ‘ground truth’. In most instances, the purpose of the ground truth data is to standardize the satellite or aircraft remote sensing data and to remove atmospheric effects, to define the surface context and to determine the relation between the spectral signature and the object of inquiry.

The use of ground-based measurements is to evolve the potential for the application of remote sensing using different spectral bands for a specific task and also this could be used for fundamental studies. Well designed ground-based measurement studies will continue to play an important role to understand spectral reflectance properties of objects such as plant canopy level and wholescene level and also checking the accuracy of remote sensing
data (Deering, 1989). More importantly, the spectral information could be used for spectral classification of a scene so as to separate various spectral classes. This kind of approach must be based upon spectral data from actual field situations rather than the idealized spectral data obtained from plants in a laboratory setting (Sliva, 1978).

4.2 SPECTRAL SENSING - SOME FUNDAMENTAL CONSIDERATIONS

In Earth resources remote sensing, spectral radiances that are reflected from the surface and received by the sensor are a function of many factors such as continuously varying incident solar irradiance, for example, geometry and spectral distribution, atmospheric conditions (includes water vapor, aerosols etc.), meteorological conditions (temperature, wind, dew etc.), reflectance properties of the surface like spatial, spectral and biophysical conditions and the sensor viewing conditions (geometry, time of observation). In the specific case of vegetation remote sensing, there are basically four factors that determine canopy reflectance: (i) incoming solar flux, (ii) spectral properties of the vegetation elements (especially leaves), (iii) canopy structure, leaf angle, leaf pattern and Leaf Area Index (LAI) and, (iv) the scattering from surface soil (background surface). Also the variations in bidirectional reflectance of agricultural targets varies with different field of views, changes in solar zenith angles and azimuth angles and this has been evidenced by Pinter et al. (1990). Perfect lossless Lambertian surfaces for use in computing spectral reflectance is very difficult to achieve in practice. Kimes and Kirchner (1982) discovered laboratory goniometer made
up of spray-painted barium sulfate (BaSO₄) panel as reference surface for spectral reflectance study in laboratory conditions.

4.3 SPECTRAL SENSING APPLICATIONS - A REVIEW

The spectral reflectance characteristics of vegetation were studied by various researchers, for example, the hemispherical reflectance of a *Rhododendron* leaf by Jenson and Hodgson (1983); reflectance in correlation with chlorophyll by Wittingham (1974) and Curran and Milton (1983); Oak and Poplar leaves by Brakke et al. (1993); plant foliage by Williams (1991); different landscape components from coastal rainforest to high desert interior by Goward et al. (1994) and many others. The applications of spectral sensing of vegetation varies from the development of biospheric models to geobotanical studies. The roles of biospheric models and measurements in developing a practical technique for remote sensing of vegetation are discussed extensively by Colwell (1974), and Goel and Norman (1992). A number of numerical models have been developed which evaluate anisotropic radiative interactions with vegetation canopies (for example, Suits, 1972; Verhoef, 1984; Goel, 1987). An assessment using some of the models was carried out to examine relations between the normalized difference vegetation index (NDVI) and absorbed photosynthetically active radiation (APAR) in a herbaceous vegetation canopy (Goward and Huemmrich, 1992) and also the angular characteristics of canopy reflectance (Simmer and Gerstl, 1985). Extensive field observations over agricultural crops and grasses and radiative transfer simulations for homogenous leaf canopies have provided a fairly good understanding of the factors
The reflected spectral radiance is the basis for remote sensing of vegetation in the 'reflective' (0.3-2.5 μm) region of the spectrum. The biological and optical properties of plant leaves largely determine plant canopy spectral reflectance. For in-situ targets, however, the background spectra must also be considered. Seven principal regions have been reported in the 0.4-2.5 μm region where different properties of green plant canopies control the in-situ spectral reflectance from that surface (Tucker, 1978). Temporal and spatial variability of satellite-based surface reflectance from Landsat TM and NOAA AVHRR and in-situ spectral reflectance measurements were carried out to monitor degradation of desert ecosystems and also to compare the spectral reflectance from different satellite data of arid and semi-arid environments (Frank et al., 1994). Ground-based measurements are required for the study on forest decline. The color information of leaves due to forest decline, which is quantitatively assessed by the spectral reflectance, becomes even more important when remote sensing is involved, because there is less information due to reduced spatial resolution, compared with ground-based study (Hoque et al., 1988). The canopy middle-infrared response provides valuable information on crop discrimination biomass and plant water content (Ungar and Goward, 1983; Ripple 1986; Goward and Huemmrich, 1992). Spectral reflectance of some sclerophyllous Mediterranean species has been investigated by Casacchia et al. (1994). The quantity of energy reflected in the near and middle infrared regions by vegetation canopy depends on the leaf cellular structure, relative water content of the leaf and the plant geometry. It was already proved that
the reflectance spectra of green vegetation in the 1.0 - 2.5 μm region are controlled by both the dominant liquid water and the dry leaf components, such as lignin and cellulose (Gao and Goetz, 1994). When green trees or shrubs are present in sufficient density, they are easily distinguished in remote sensing data by their characteristic reflectance signature in the visible/near-infrared (Salisbury and D'Aria, 1994). Different vegetation characteristics like chlorophyll content or water content of leaves and woody stem area index exert dominance in different spectral regions (Bowman, 1989; Choudhury, 1992). Increase in Leaf Area Index (LAI) causes an increase in the radiance in the near-infrared region, and decrease in the visible region. Various studies on spectral sensing indicate the clear-cut relationship between reflectance and leaf water content, leaf position, changes in cellular characteristics of leaves, leaf chlorophyll content etc. (Tucker, 1978; Sellers, 1985; Boyer et al., 1988). Both ground-based and at-satellite data spectral reflectance measurements are found to be useful to assess water stress symptoms in vegetation because water stress is one of the most common limiting factor of primary productivity in both natural and agronomic plants (Knippling, 1970; Olson, 1977; Boyer, 1982; Holben et al., 1983; Ripple, 1986; Boyer et al., 1988; Cohen, 1991 a, b; Penuelas et al., 1993). Crop canopy reflectances were measured using an Exotech radiometer of MSS bands with 15° field of view to derive differences in canopy architecture due to water stress on irrigated Alfalfa (Moran et. al., 1989) and also the plant temperature - canopy reflectance relationships by Cure et al. (1989). Chlorophyll concentration is usually an indicator of nutritional stress, photosynthetic capacity and developmental stage (senescence). One of the best remote sensing descriptors of chlorophyll concentration has been found
to be the red edge. The red edge is the point of maximum slope in vegetation reflectance spectra. It occurs between wavelengths of 680-750 nm, where the reflectance changes from very low in the chlorophyll red absorption region to very high in the near-infrared because of leaf and canopy scattering. The relationship between the red edge and leaf chlorophyll concentration have been demonstrated by Steven et al. (1990), and also biomass, hydric status and nitrogen status by Filella and Penuelas (1994), Penuelas et al. (1994, 1995) and Filella et al. (in preparation). Different spectral responses of vegetation frequently show lithologic types under vegetation cover (Mouat, 1982; Morrissey et al., 1984). Mouat et al. (1994) suggested that vegetation information from remote sensing data may be a useful indicator of underlying geologic condition. The spectral studies on vegetation could be used for geobotanical investigations (Tuchidas et al., 1994). Spectral reflectance study on soybeans (*Glycine max*) and loblolly pines (*Pinus taeda*) using spectroradiometer of 400 - 900 nm range shows significant changes in reflectance due to different levels of arsenic in the soil (Mouat et al., 1994).

### 4.4 MATERIALS AND METHODS

#### 4.4.1 Theoretical Background

The above discussion clearly shows that considerable attempts have been made to study the spectral properties of vegetation and its application on various vegetation parameters, biospheric modeling, geobotanical investigations etc. No such study has been attempted so far to understand the spectral properties of mangrove species. It is also worth to note that the
spectral properties of different forest plant communities as well as crops are nowhere similar. Therefore there is no information about the spectral properties of mangroves available due to the difficulties in accessibility of mangrove areas and also the difficulties in using truck boom or helicopter to study the mangrove canopy reflectance. Some interest have been shown towards the fundamental knowledge about spectral reflectance of single leaf, a part and a whole of tree crown layer of a mangrove stand of mixed species in the northern part of Okinawa island, Japan (Sato et al., 1992). The mean spectral signatures of different mangrove growth conditions in Philippines were studied using Landsat MSS digital data which provided little information about spectral properties of mangroves (Bina et al., 1984). The study carried out in Okinawa island (Sato et al., 1992) concludes that there were similar spectral reflectance properties among three mangrove species viz. *Bruguiera gymnorrhiza*, *Rhizophora stylosa* and *Kandelia candel* studied using spectroradiometer of 400 to 1050 nm wavelength range kept over an iron pipe stand of four meter height. The spectral reflectance curves of two samples for three species were shown in Figure 4.1. The shape of these curves was different, but the tendency of curves was similar among species. However, this study has not covered different dominant mangrove species and also the reflectance properties of same species in different environmental conditions. More importantly the spectral reflectance of mangrove species were not correlated with their ecological parameters.

4.4.2 Methodology

In the present work it has been decided to study the spectral properties of mangrove species in different environmental conditions using
Figure 4.1 Typical reflectance curves of two samples for three mangrove species at the river mouth of Kesaji river in Okinawa Island

- *Bruguiera gymnorrhiza*, ■: *Rhizophora stylosa*, ▲: *Kandelia candel*

(Sato et. al., 1992)
satellite digital data as well as ground-based spectroradiometers of MSS, TM and IRS bands. The qualitative study on spectral response (grey level variations) of mangrove areas i.e. at-satellite reflectance were analyzed using Landsat TM and IRS LISS-II digital data. For the quantitative spectral study, field instruments were used and the detailed methodology steps of this study are given in Figure 4.2.

4.4.2.1 Experimental setup for Ground-based Spectral studies

A five meters height stand made up of Galvanized iron pipes was fabricated to position the spectroradiometer in a nadir orientation to acquire spectral reflectance measurements (Figures 4.3 and 4.4). The advantages of using five meters height stand is mainly to avoid the spectral radiance or reflectance error due to the presence of nearby objects (e.g., the researcher's body) which may block a portion of the incoming diffuse and ground exitance onto the target (or BaSO₄ reference panel). Also the reflectance measurements were made from positions chosen to ensure that the canopy was adequately sampled, and the species being measured was not shadowed by the radiometer stand. The stand was fabricated suitably to assemble with very simple mechanism and also to disassemble for shifting to different mangrove sites in the field. Reflectance standard measurements (BaSO₄ reference plate) were taken immediately (1 min.) before and after the canopy spectral measurements. The reflectance standard measurement panel (BaSO₄) observations were made under the same ambient conditions as the canopy observations but the reference panel was not calibrated in the field. The spectroradiometer has been conveniently fixed with the cross-bar and there is also a provision to hang some objects like wrench to
Figure 4.2 Spectral studies on Mangroves.

A Spectral response of Mangrove areas

IRS LISS–II and TM digital data

B In-situ studies

SEASONS
May 1994
Feb. 1995

Exotech MGT radiometers

Canopy reflectance

Interpretation of Canopy reflectance

Spectral studies on mangroves

Ground Truth
- Canopy structure
- Leaf pattern
- Leaf chlorophyll and water content
- Leaf abaxial surface morphology
- Background soil reflectance

- Influence of physiological parameters, environmental condition etc.
- Influence of background soil reflectance
- Spectral sensing applications
Figure 4.3 Ground-based spectral measurements at Ennore creek mangroves

Figure 4.4 Nadir orientation of radiometer for canopy reflectance study
properly orient the spectroradiometer to focus on the reference surface (Figure 4.5). The display unit has been connected to the spectroradiometer and for selection of spectral bands as well as changing the instrument gain-set, the stand will be lowered (Figure 4.6). In this experiment the effect of sun elevation on the reflectance of the panel (not perfectly Lambertian) has not been considered. However, the measurements were made between 11 A.M. to 1 P.M. (Indian Standard Time) to minimize the effect of sun elevation angle variations. To record the spectral reflectance of mangrove seedlings, the radiometer was kept hand held.

4.4.2.2 Spectroradiometers

Two types of spectroradiometers available with the National Remote Sensing Agency (NRSA), Hyderabad, were used in this study: (i) Exotech spectroradiometer of MSS bands and (ii) Multiband Ground Truth (MGT) radiometer of TM and IRS bands.

Exotech spectroradiometer is a compact, light weight, internal battery powered instrument for incident or reflected radiation over the wavelength range of 0.40 to 1.1 μm. Four independent channels are interchangeable fitted with filter sets that match the Landsat MSS bands. This radiometer is rugged, self contained and designed for use in the field environment. Adapters are provided for each channel to provide three fields of view. This radiometer has a connector for external power source and for accessing the four simultaneous analysis of output signals. The standard Field Of View (FOV) available are 1° to use for leaf reflectance and also the 15° FOV to use in truck boom, helicopter/aircraft platform. In order to improve the
Figure 4.5 Reference panel (BaSO4) focused by the radiometer

Figure 4.6 Band selection and gain-set adjustment in the radiometer
resolution and readability of the instrument, the facility to measure the final outputs on external digital panel meter is provided. The digital panel meter could be connected to the instrument with BNC cable. The calibration constants were provided in the radiometer calibration report.

Spectral radiance (mw/cm²-Sr-μ) is calculated with the following formula.

\[ L = \left( \frac{O}{P} \right) \times \left( \frac{C_l}{G} \right) \]

Where,
- \( L \) is the spectral radiance (mw/cm² -Sr-μ)
- \( O/P \) is the final output of the instrument (mv)
- \( C_l \) is the calibration constant for specified FOV and spectral band \((( \text{mw/cm}^2 \cdot \text{Sr-μ})/\text{mv})\) and
- \( G \) is the gain indicated by range select switch.

Multiband Ground Truth radiometer model 041 manufactured by OPTOMECH ENGG. PVT. LTD, Hyderabad in technical collaboration with Space Applications Center (SAC), Ahmedabad contains 8 channels corresponding to the first 4 spectral bands of Landsat TM and 4 bands of Indian Remote Sensing satellites (IRS-1A & 1B) , and also has 15° ± 1/2° standard FOV. Incoming radiation from the object under study is focused on to the detector with the help of a lens. The spectral selection is achieved with filters, mounted on a filter wheel. Responsivity variations of the detector and optical transmission variations of lens and filters in the entire spectral range are compensated by special electronic circuits to give absolute measurements in the radiometric unit viz. Watts/cm²-Sr-μ. The final output
is displayed on a digital panel meter. All spectral bands are calibrated with a standard tungsten halogen lamp.

4.4.2.3 Study sites and Period of observations

Ground-based experiments were conducted at Ennore, Adyar, Pichavaram and Muthupet mangroves during May 1994 and February 1995. Ennore mangroves are very much influenced by industrial pollution and also the waste disposal from in and around slum areas. Adyar mangroves situated in main part of the Madras city receive lot of sewage. Abnormal height (about 20 m.) of *Avicennia marina* (Forsk) Vierh (grey mangrove) was observed only in this area. Exotech radiometer of MSS bands was used during May '94 at Ennore, Adyar and Pichavaram and the spectral radiance of five major species viz. *Avicennia marina* (Forsk.) Vierh, *Rhizophora apiculata* Blume, *Rhizophora mucronata* Lam., *Rhizophora x lamarckii* Mantrouz and *Suaeda maritima* (L.) Dumort were measured. In the second time during February '95 twelve species Viz. *Acanthus ilicifolius* L., *Aegiceras corniculatum* (L) Blanco, *Avicennia marina* (Forsskal) Vierh., *Bruguiera cylindrica* (L.) Blume, *Ceriops decandra* (Griffith) Ding Hon, *Excoecaria agallocha* L., *Luminitzera racemosa* Willd, *Rhizophora apiculata* Blume, *Rhizophora mucronata* Poiret, *Salicornia brachiata* Roxb, *Sesuvium portulacastrum* (L.) L., and *Suaeda monoica* (Forsskal) J.Gmelin were studied using the Multiband Ground Truth (MGT) radiometer of TM and IRS bands at Ennore, Pichavaram and Muthupet (in the Cauvery delta).
4.5 RESULTS

4.5.1 At-Satellite reflectance

To understand the spectral properties of mangrove areas, and to evaluate the influence of visible and near-infrared radiation, the Landsat TM and IRS LISS-II digital data of Pichavaram were chosen for this study. A qualitative information about spectral reflectance of mangrove areas has been studied by taking a reference scanline which crosses over mangrove area, agricultural land, water bodies, beach sand and sea water. The spectral response profile has been plotted by using DN values as shown in Figure 4.7. The high response profile of mangrove areas can be observed in bands 4, 5 and 7 of TM and also in band 4 of LISS-II. Figure 4.7 also shows that bands 5 and 7 of TM would seem to be useful for separating mangroves from agricultural land. Since the present study is concerned with mangroves and why a mangrove canopy reflects more of certain wavelengths than others, field studies were carried out using ground-based radiometers.

4.5.2 Spectral radiance of mangrove species in MSS bands

Since the major difference among vegetation spectral signatures is the amplitude or magnitude of reflected radiance, the Exotech radiometer of MSS bands with 15° FOV optical element was used to measure the spectral radiance of mangrove species in the first attempt of this study. The instrument height (5 m.) and the time (11.00 A.M. to 1.00 P.M.) was
Figure 4.7 Spectral response profile of Pichavaram Mangrove areas in LISS-II and TM digital data.

- Band 1 (LISS-II)
- Band 2 (LISS-II)
- Band 3 (LISS-II)
- Band 4 (LISS-II)
- Band 5 (TM)
- Band 6 (TM)
- Band 7 (TM)

Key:
- A: Agricultural lands
- M: Mangroves
- B: Beach sand
- S: Sea water
- D: Dunes
maintained throughout the study. Five predominant species viz. *Avicennia marina*, *Rhizophora apiculata*, *R. x lamarckii*, *R. mucronata* and *Suaeda maritima* were selected initially for spectral radiance study. Four scans were averaged together at each observation to plot spectral radiance curves and the average radiance values are given in Table 4.1. All the above mangrove species are showing similar radiance patterns, but variations in intensity of radiance were observed (Figure 4.8). Discussions on this feature will be made at section 4.7.

**Table 4.1** Spectral radiance of mangrove species in Pichavaram

<table>
<thead>
<tr>
<th>Species</th>
<th>Radiance (mw/cm² - Sr - μ) MSS bands</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>band 1</td>
</tr>
<tr>
<td><em>Avicennia marina</em></td>
<td>2.47</td>
</tr>
<tr>
<td><em>Rhizophora apiculata</em></td>
<td>2.88</td>
</tr>
<tr>
<td><em>Rhizophora mucronata</em></td>
<td>4.12</td>
</tr>
<tr>
<td><em>Rhizophora x lamarckii</em></td>
<td>5.35</td>
</tr>
<tr>
<td><em>Suaeda maritima</em></td>
<td>3.29</td>
</tr>
</tbody>
</table>

The highest radiance was observed between 0.7 and 1.1 μm for all mangroves. *R. x lamarckii* showed highest radiance values in the first three bands and *R. apiculata* in the fourth band. *A. marina* showed higher values in band 3 and 4 than *R. mucronata*. The variations in spectral radiance of mangrove species in each band can be obtained from the standard deviation.
Figure 4.8 Spectral radiance of mangrove species in Pichavaram.
values as given in Table 4.2. Much deviations could be observed in bands 1 and 3 for all the species studied.

**Table 4.2 Standard deviation of spectral radiance of mangroves in Pichavaram**

<table>
<thead>
<tr>
<th>MSS bands</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0216</td>
</tr>
<tr>
<td>2</td>
<td>0.9916</td>
</tr>
<tr>
<td>3</td>
<td>1.3261</td>
</tr>
<tr>
<td>4</td>
<td>0.3901</td>
</tr>
</tbody>
</table>

Since *A. marina* is the commonly occurring species in all the four mangrove areas of Tamil Nadu, the spectral radiance of *A. marina* from polluted and unpolluted environments were studied for comparison. The spectral radiance of *A. marina* in polluted (Ennore and Adyar) and unpolluted (Pichavaram) environments exhibits considerable variation in intensity of radiance (Figure 4.9). *A. marina* that occurs in polluted environments shows decrease in radiance and especially the species from Adyar location has extremely less radiance. The causes for this phenomena will be discussed in section 4.7.

The spectral radiance of *A. marina* that occurs in Ennore and Pichavaram were studied during May '94 and February '95 using Exotech radiometer (MSS bands) and MGT radiometer (TM & IRS bands). Table 4.3
Figure 4.9 Spectral radiance of \textit{Avicenna marina} in Ennore, Adyar and Pichavaram
shows the radiance values recorded in different seasons using different band sensors.

Table 4.3  Spectral radiance of *A. marina* in May '94 and February '95

<table>
<thead>
<tr>
<th>Location</th>
<th>MSS bands (May '94)</th>
<th>TM bands (February '95)</th>
<th>IRS bands (February '95)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1  2  3  4</td>
<td>1  2  3  4</td>
<td>1  2  3  4</td>
</tr>
<tr>
<td>Ennore</td>
<td>0.27 0.28 0.17 0.87</td>
<td>0.18 0.28 0.24 0.70</td>
<td>0.14 0.30 0.24 0.69</td>
</tr>
<tr>
<td>Pichavaram</td>
<td>0.16 0.28 0.19 0.85</td>
<td>0.11 0.20 0.16 0.56</td>
<td>0.14 0.15 0.13 0.59</td>
</tr>
</tbody>
</table>

Much variations in spectral radiance could be observed in band 4 wavelength of MSS, TM and IRS (Figure 4.10a & b). The error bar plot on seasonal changes in radiance shows that the amplitude of spectral radiance varies in different locations (Figure 4.11a & b). *A. marina* in Pichavaram shows seasonal variations in radiance especially in bands 2 and 4 but the same species in Ennore location shows variations in bands 1 and 4.

4.5.3 Background Soil Spectral Characteristics

At the canopy level, reflectance spectra depend not only on the optical properties of leaves, but also the background soil spectra and the canopy geometry (Jackson and Ezra, 1985; Baret et al., 1988). When plants only partially obscure the soil background, changes in soil reflectance may reduce the value of spectral data in monitoring plant canopies (Tucker and Miller, 1977). Spectral reflectance of barley crop was studied in relation to the spectral properties of soil and leaves in order to evaluate the stability and dynamics of leaf optical properties in seasonal canopy-soil background.
Figure 4.10 Seasonal changes in spectral radiance (May '94 and Feb.'95)
MSS, TM and IRS Bands
Figure 4.11 Seasonal changes in spectral radiance (May 1994 and February 1995).

(a) *Avicennia marina* in Ennore

(b) *Avicennia marina* in Pichavaram

Figure 4.11 Seasonal changes in spectral radiance (May 1994 and February 1995).
reflectance. Because of the similarity between soil reflectance and plant canopy reflectance in the early growth stages, only measurements later in canopy development provide information about the crop (Lorenzen and Jensen, 1991). The role of the soil background on canopy response is critically examined for a range of soil types, surface moisture conditions, vegetation densities, solar zenith angles, and atmospheric conditions by Huete (1989). More information on soil and vegetation interactions can be obtained from a series of controlled experiments that were conducted by Huete et al. (1985). Vegetation may also mask the spectral signatures of underlying rocks, changing their reflectivities and emissivities. The spectral properties and behavior of bare-soil surface are important to understand, since the soil serves as a useful reference from which we attempt to discriminate and measure green-vegetation growth (Huete, 1989). Soil reflectance spectra will mainly vary with soil type, moisture variations, iron content and total organic matter content (Saxena, 1987). In this study an attempt was made to find out the role/influence of soil background on spectral radiance of mangroves. For this purpose the soil background of A. marina in Ennore, Adyar and Pichavaram were studied. Suitable locations were chosen in order to study the spectral radiance of A. marina and soil background consequently. Also the following parameters of background soil were analyzed to correlate with their spectral radiance:

1. soil moisture,
2. soil type,
3. soil surface,
4. iron content, and
5. total organic matter content.
The different soil parameters analyzed are given in Table 4.4. To study the soil type, soil samples were analyzed using the MALVERN particle size analyzer. The graphical representation of particle size distribution are shown in Figure 4.12.

**Table 4.4 Characteristics of background soil**

<table>
<thead>
<tr>
<th>Sample location</th>
<th>Soil type (particle size distribution below 31.01 μm)</th>
<th>Moisture content (%)</th>
<th>Iron content (ppm)</th>
<th>Total organic matter (per unit weight)</th>
<th>Surface condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adyar</td>
<td>60.01 %</td>
<td>5.86</td>
<td>29.4</td>
<td>0.135818</td>
<td>Smooth</td>
</tr>
<tr>
<td>Ennore</td>
<td>75.79 %</td>
<td>5.62</td>
<td>37.8</td>
<td>0.015596</td>
<td>Smooth</td>
</tr>
<tr>
<td>Pichavaram</td>
<td>91.63%</td>
<td>5.67</td>
<td>20.1</td>
<td>0.005134</td>
<td>Rough</td>
</tr>
</tbody>
</table>

The spectral radiance properties of *A. marina* and the soil background are shown in Figure 4.13a & b. Reflected radiances of *A. marina* and soil background were measured simultaneously in all the four bands of MSS. The standard time (11.00 A.M. to 1.00 P.M.) and instrument height (5m) was maintained to record radiance so as to avoid the other influences like sun elevation angle, atmospheric conditions etc. The overlay of spectral radiance curves of *A. marina* and soil background (Figure 4.13c) reveals the following observations:

1. the variations in reflected radiance of *A. marina* is mainly due to variations in environmental conditions, plant health etc., and
2. the variations in reflected radiance of soil background is mainly due to soil properties.
Figure 4.12 Particle size distribution in soil samples.

(a) Ennore

(b) Adyar

(c) Pichavaram
Figure 4.13 (a) Spectral radiance of *A. marina*
(b) Spectral radiance of background soil
(c) Overlay of figures (a) and (b).
The radiance intensity of soil background is low. The radiance curve is nearly flat showing a slow rise towards shorter wavelengths (Figure 4.13b). The lowest radiance of soil background in Adyar might have been due to high moisture content and total organic matter content, besides smooth surface condition. The overlay of reflected radiance of A. marina and soil shows that there was no correlation existing between them (Figure 4.13c). The spectral radiance curves of A. marina and soil background show that there is no overlap portion in the visible and near-infrared bands. Both the intensity and pattern of radiance curves having dissimilarity except the bands 3 and 4 of A. marina and soil in Adyar location. However this can be justified with the original trend of the radiance curves of soil background since it shows decrease in radiance from band 1 to band 4.

4.5.4 Spectral reflectance of mangrove species in TM and IRS bands

The comparison of spectral radiance of mangrove species provides some information about the variation in intensity of radiance. However the difference in radiance may be due to changes in isolation. The comparison of reflectance of different mangrove species will be more useful to correlate with various related parameters of mangrove vegetation. Since the floral distribution i.e. zonation is more in Pichavaram, twelve species in this area, four species in Muthupet and one species in Ennore were selected for spectral reflectance study during February '95.

From the measurements, reflectance percentage was calculated (as the ratio of the radiometer output over each target to the output over the BaSO₄ panel) at each wave length of TM and IRS bands and the reflectance curves
were drawn for each species as shown in Figures 4.14 and 4.15. The spectral reflectance curves have similar tendency but difference in shape of the curves. Among the twelve species studied, *Avicennia marina* and *Aegiceras corniculatum* (river mangrove) have high reflectance. *Salicornia brachiata* and *Excoecaria agallocha* are characterized by lowest reflectance in both IRS and TM bands.

The spectral reflectance of four species viz. *Avicennia marina, Aegiceras corniculatum, Excoecaria agallocha* and *Acanthus ilicifolius* from Muthupet shows difference in reflectance when compared to the same species in Pichavaram (Figure 4.16). The decrease in reflectance could be observed in band 2 wavelength region. In Pichavaram, the experiment was conducted at two sites, one nearer to seashore area (high saline) and the other in Madavamedu located nearer to Coleroon river mouth where the water is having less salinity. The spectral reflectance of *Luminitzera racemosa* and *Excoecaria agallocha* which occur in saline (Pichavaram) and freshwater influenced areas (Madavamedu) shows considerable variations (Figure 4.17a & b). In Figure 4.17 (M) denotes species in Madavamedu, (P) denotes species in Pichavaram. *Luminitzera racemosa* that occurs in Madavamedu shows less reflectance in all the four bands of IRS and TM but *Excoecaria agallocha* shows high reflectance in band 4 and less in bands 1, 2 and 3.

Normalized reflectance curves were prepared by taking average of reflectance percentage in each band of all mangrove species to understand the cumulative nature of spectral signature of all the mangrove species and also to observe the variations in reflectance using TM and IRS band sensors. Normalized reflectance curves (Figure 4. 18a) have a crest at 0.52 - 0.58 μm
Figure 4.14 Spectral reflectance of mangrove species (Pichavaram). IRS Bands, February '95.
Figure 4.15 Spectral reflectance of mangrove species (Pichavaram). TM Bands, February '95.
Figure 4.16 Spectral reflectance of mangroves species Muthupet in Cauvery Delta
(a) IRS Bands (February 1995)
(b) TM Bands (February 1995)
Figure 4.17 Spectral reflectance of mangrove species in high saline (Pichavaram) and less saline (Madavamedu) areas.
(band 2 in IRS) and 0.52-0.60 μm (band 2 in TM) and followed by a trough at 0.63 - 0.69 μm (band 3 in TM) and 0.62 - 0.69 μm (band 3 in IRS). The steady increase in reflectance starts from 0.69 - 0.9 μm wavelength region. The amplitude of spectral reflectance varies in different mangrove areas. A comparison of spectral reflectance curve of *A. corniculatum* shows high reflectance in Muthupet than to the same species in Pichavaram (Figure 4.18b). An abnormal shift in reflectance peak could be observed in bands 2, 3 and 4 of IRS. The species in Muthupet shows decrease in reflectance in band 2 (0.52 - 0.58 μm) and increase in reflectance in bands 3 (0.62 - 0.68 μm) and 4 (0.77 - 0.86 μm). In Figure 4.18b, the shift in reflectance peak has been marked (down arrows and up arrows).

To understand the influence of local environmental conditions (pollution and salinity) on spectral reflectance, *A. marina* was chosen from Ennore, Pichavaram and Madavamedu. *A. marina* in Pichavaram has high reflectance but the reflectance of *A. marina* in polluted (Ennore) and less saline areas (Madavamedu) are having much similarity in reflectance as shown in Figure 4.19.

Seedlings of *Rhizophora mucronata* and *Ceriops decandra* were studied on a building terrace at the Center for Advanced Study in Marine Biology in Parangipettai near Pichavaram. The seedlings were less than 1 m. in height and were nearly 1 year old. The spectral measurements were taken in similar timing and in cloudless condition, however the instrument height was not maintained as studied in the field. The spectral reflectance of *R. mucronata* and *C. decandra* seedlings shows higher reflectance in the first 3 bands of IRS and TM when compared to matured species in the field (Figures 4.20 a & b).
Figure 4.18 (a) Normalized spectral reflectance curves
(b) Spectral reflectance changes in different locations
Figure 4.19 Spectral reflectance of *A. marina* in Ennore, Pichavaram and Madavamedu.
(a) TM Bands, Feb 1995.
(b) IRS Bands, Feb 1995.
Figure 4.20 Spectral reflectance of seedlings and matured species.

(a) *Rhizophora mucronata*

(b) *Ceriops decandra*
In Figure 4.20a & b, (L) denotes the seedlings studied in laboratory, (M) and (P) denote Madavamedu and Pichavaram respectively. The spectral reflectance of *R. mucronata* was studied in the laboratory and in Pichavaram, whereas that of *C. decandra* was studied in the laboratory and in Pichavaram and Madavamedu. The error bar plot indicates the amplitude of variations in reflectance of seedlings and matured species (Figure 4.21a & b). The variations in reflectance could be observed more in *C. decandra* in all the four bands of IRS and TM (Figures 4.22a & b).

4.6 GROUND TRUTH

4.6.1 Some Physiological Measurements on Mangroves

To understand the variations in spectral reflectance of mangrove species, the following parameters were studied during the ground truth:

- leaf chlorophyll and water content,
- leaf pattern and canopy structure, and
- leaf morphology.

Fresh mangrove leaves were collected from study sites and these were analyzed at the Center for Advanced Study in Marine Biology, Parangipetattai. Scanning Electron Microscope (SEM) studies were carried out on leaf adaxial morphology at the School of Biological Sciences, Madurai Kamaraj University. The results of the above analysis are discussed below.
Figure 4.21 Spectral reflectance variations of *Rhizophora mucronata* seedling and matured species.

(a) Error bar plot for IRS bands
(b) Error bar plot for TM bands
Figure 4.22 Spectral reflectance variations of *Ceriops decandra* seedling and matured species.

(a) Error bar plot for IRS bands

(b) Error bar plot for TM bands
4.6.2 Leaf chlorophyll and water content

Generally, leaves under shade contain slightly less chlorophyll per unit area than leaves exposed to sunlight (Boto and Boto, 1979; Cheeseman et al., 1991; Lovelock and Clough, 1992; Lovelock et al., 1992). Also, the study on photoinhibition and recovery in tropical plant species revealed decrease in the chlorophyll from shade-grown plants (Lovelock et al., 1994). The leaf chlorophyll content estimated for different mangrove species (in mg/g fresh weight) during February 1995 at Pichavaram, Madavamedu and Muthupet are given in Table 4.5.

Table 4.5 Leaf chlorophyll content (total chlorophyll in mg/g fresh weight) in different mangrove species

<table>
<thead>
<tr>
<th>Species</th>
<th>Pichavaram</th>
<th>Madavamedu</th>
<th>Muthupet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acanthus ilicifolius L.</td>
<td>0.14</td>
<td>-</td>
<td>0.16</td>
</tr>
<tr>
<td>Aegiceras corniculatum (L.) Blanco</td>
<td>0.20</td>
<td>-</td>
<td>0.33</td>
</tr>
<tr>
<td>Avicennia marina (Frosskal) Vierh</td>
<td>0.06</td>
<td>0.16</td>
<td>0.22</td>
</tr>
<tr>
<td>Bruguiera cylindrica (L.) Blume</td>
<td>0.07</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ceriops decandra (Griffith) Ding Hou</td>
<td>0.08</td>
<td>0.15</td>
<td>-</td>
</tr>
<tr>
<td>Excoecaria agallocha L.</td>
<td>0.06</td>
<td>0.21</td>
<td>0.39</td>
</tr>
<tr>
<td>Luminitzera racemosa Willd</td>
<td>0.17</td>
<td>0.17</td>
<td>-</td>
</tr>
<tr>
<td>Rhizophora apiculata Blume</td>
<td>0.11</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Rhizophora mucronata Poiret</td>
<td>0.06</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Salicornia brachiata Roxb</td>
<td>0.06</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sesuvium portulacastrum (L.) L.</td>
<td>0.06</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Suaeda maritima (L.) Dumort</td>
<td>0.07</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Suaeda monoica (Forsskales) J.Gmelin</td>
<td>0.06</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Leaf chlorophyll shows variations both in species wise and also in location wise. All the mangrove species in freshwater influenced less saline areas (Madavamedu) and also in Muthupet (in Cauvery delta) are having high chlorophyll than the species in Pichavaram (Table 4.5). Observations were made on the chlorophyll content of different mangrove leaves collected in the morning time (around 9 hrs.) and the leaves collected in the afternoon (around 12 hrs.). It was also observed that diurnal changes in leaf chlorophyll content from different mangrove species in Pichavaram (Figure 4.23a). In Figure 4.23a the variations in leaf chlorophyll content could be clearly observed and the chlorophyll content increases from the morning (M) to the afternoon (A). The leaves collected in the morning are having less chlorophyll when compared with the leaves collected in the afternoon. Considerable changes in the chlorophyll content was observed for A. marina, R. apiculata and R. mucronata during different seasons (Figure 4.23b) and all the three species were having high chlorophyll in summer season (May). It was also confirmed by the earlier study on pigments in mangrove species of Pichavaram that the pigments attained their maximum peak during summer months and minimum during postmonsoon. Again the species like E. agallocha, R. mucronata and C. decandra are having high chlorophyll content than other species (Oswin and Kathiresan, 1994). Lovelock et al. (1992) studied the leaf compounds absorbing UV radiation in tropical mangrove leaves. The above study illustrates the effects of UV radiation on mangroves such as the increased production and accumulation of UV absorbing compounds, increased concentration of carotenoids, and change in leaf morphology. In the present study it was observed that leaf disease causes decrease in leaf chlorophyll especially in A. marina in Adyar rather than the
other causes like industrial pollution in Ennore, for example, *A. marina* in Adyar is having less chlorophyll (0.05 mg/g) when compared with the same species in Ennore (0.53 mg/g). Leaf chlorophyll of *C. decandra* and *R. mucronata* seedlings show less content (0.02 mg/g) than the leaves from matured plants. The water status (water content and water potential) of forest trees depends on species, soil water availability, rooting characteristics, topography and environmental conditions. Water status will vary with daily and seasonal time scales. The water content of tree leaves varies with time of day having a maximum in the night or often near dawn and a minimum in early afternoon as transpiration draws water out of the leaves (Gates, 1991). All the species leaves studied for chlorophyll content were also used for leaf water content estimation (Figure 4.23c). Comparison of Figures 4.23a & c shows that leaf chlorophyll is having negative relationship with leaf water content, i.e., increase in chlorophyll with decrease in leaf water content. High leaf water content could be observed especially in the species like *Salicornia brachiata* Roxb, *Sesuvium portulacastrum* (L.)L and *Suaeda maritima* (L.) Dumort when compared to other species. It was also observed that leaf water content is less in the leaf samples collected in the afternoon (Figure 4.23c).

4.6.3 Leaf pattern and Canopy structure

Leaf pattern in mangrove species constitute the variations in leaf angle, leaf pigments content, leaf water content and Leaf Area Index (LAI). Mangrove canopy structure/geometry varies due to the variations in leaf pattern, leaf thickness and LAI. The stand characteristics of different mangrove species are prepared based on ground truth (Table 4.6).
Figure 4.23 Leaf chlorophyll and Water content
(a) Diurnal changes in leaf chlorophyll
(b) Seasonal changes in leaf chlorophyll
(c) Diurnal changes in leaf water content.
### Table 4.6 Mangrove stand characteristics in Tamil Nadu

<table>
<thead>
<tr>
<th>Species</th>
<th>Habit</th>
<th>Height maxi. (m)</th>
<th>Leaf and canopy structure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. ilicifolius</strong></td>
<td>Shrub</td>
<td>1.0</td>
<td>Thin and spiny leaves and stems. Less dense canopy.</td>
</tr>
<tr>
<td><strong>A. corniculatum</strong></td>
<td>Shrub</td>
<td>1.5</td>
<td>Thick, ovate and non fleshy leaves with extended glandular dots. Leaves alternate and spirally arranged. Canopy without aerial roots.</td>
</tr>
<tr>
<td>✓ <strong>A. marina</strong></td>
<td>Shrub &amp; Tree</td>
<td>3.5</td>
<td>Thin and less dense leaves, leaf base grooves and aerial roots as pointed pneumatophores. Closed canopy.</td>
</tr>
<tr>
<td><strong>C. decandra</strong></td>
<td>Tree</td>
<td>3.0</td>
<td>Moderately thick leaves. Stilt roots in sapling stage.</td>
</tr>
<tr>
<td><strong>E. agallocha</strong></td>
<td>Tree</td>
<td>3.0</td>
<td>Moderately thick and spirally arranged leaves, milky latex leaking from cut surface. Leaf margin slightly notched. Palisade like layers on each surface of leaves. Without aerial roots. Grows intermittently and irregularly. Briefly deciduous in dry seasons.</td>
</tr>
<tr>
<td><strong>L. racemosa</strong></td>
<td>Tree</td>
<td>3.0</td>
<td>Leaves obviate, fleshy and without translucent dots. Salt glands absent. The sapling shows continuous or diffuse branching. Root knees present.</td>
</tr>
<tr>
<td><strong>R. apiculata</strong></td>
<td>Tree</td>
<td>6.0</td>
<td>Thick leaves, flowers small, aerial roots forming arching loops from trunk and branches. Leaf pattern minimizes self-shading. Closed canopy. There was no seasonal pattern of leaf production and shedding ‘evergrowing’.</td>
</tr>
<tr>
<td><strong>R. mucronata</strong></td>
<td>Tree</td>
<td>6.0</td>
<td>-do-</td>
</tr>
<tr>
<td><strong>R. x lamarckii</strong></td>
<td>Tree</td>
<td>6.0</td>
<td>-do-</td>
</tr>
<tr>
<td><strong>S. maritima and S. monoica</strong></td>
<td>Herb</td>
<td>1.5</td>
<td>Thin and needle shape leaves. Unclosed canopy. Mostly in landward side.</td>
</tr>
<tr>
<td><strong>S. brachiata and S. persica</strong></td>
<td>Herb</td>
<td>0.15</td>
<td>Thick leaves. Unclosed canopy and mostly in landward side.</td>
</tr>
<tr>
<td><strong>S. portulacastrum</strong></td>
<td>Creeper</td>
<td>0.10</td>
<td>-do-</td>
</tr>
</tbody>
</table>

✓ **A. marina** in Adyar location has more than 20 m. in height.
The mangrove species observed during ground truth, showed considerable variations in leaf pattern. All the species of Rhizophoraceae family are having thick leaves especially *R. apiculata*, *C. decandra* and *B. cylindrica* are having thick and broader leaves (Figure 4.24 a & b). The leaf pattern in all the species in Rhizophoraceae minimizes self-shading and forms closed canopy. *Ceriops decandra* is usually associated with *Rhizophora* and it has smaller leaves (Figure 4.24 c). The species of Avicenniaceae are having smaller leaves with decussate phyllotaxy and forms an unclosed canopy (Figure 4.24d). *Aegiceras corniculatum* and *Luminitzera racemosa* are having thick, ovate, coriaceous, spirally arranged and succulent leaves (Figures 4.25a & b). *Excoecaria agallocha* is having moderately thick and spirally arranged leaves, milky latex leaking from cut surfaces (Figure 4.25c). The species of Chenopodiaceae (*Suaeda maritima* and *S. monoica* are having thin and needle shape leaves (Figure 4.25d).

4.6.4 Leaf adaxial morphology

The variations in stomatal and epidermal patterns of mangrove leaves were usually studied by botanist to understand the genetic differences among species as well as variations in environmental factors such as temperature, humidity and light intensity. The structural changes and associated microbial activity accompanying decomposition of mangrove leaves are more in abaxial (back) surface rather than adaxial (front) surface (Steinke et al., 1990). Studies on the structure of epidermis and stomatal apparatus of 24 mangrove species from the east and west coast of India were carried out by Sidhu (1975) using Scanning Electron Microscope. He identified three kinds of stomata viz. Ranunculaceous, Rubiaceous and...
Caryophyllaceous in the mangrove species. The guard cells around stomata alter the size of the stomatal aperture in response to environmental shift and influence water loss from the leaf (Juniper & Jeffree, 1983). The structure of the leaf wax was examined for *Cot orbiculata* leaves using a Hitachi (Model S2250-N) SEM under magnification of 100 X (Robinson et al., 1993). Leaf adaxial (front) surface morphology is expected to have close relationship with spectral properties of mangrove canopy since it contains the translucent wax coatings. The adaxial surfaces of the leaves that are sunlit are the major contributors to the reflectance. The influence of leaf adaxial surface was stressed in studies carried out by Brakke et al. (1989, 1993).

Exposed and senescent leaves were collected during May 1994 to February 1995 for the analysis of leaf adaxial morphology. Only small portions of leaves were cut and pasted on the SEM plates for scanning and they were not allowed for drying before scanning. This work was undertaken to study the adaxial surface morphology in different mangrove species and to find out if similarities in structure and pattern exist in species which are dominant in the study areas. Leaf samples were scanned in different magnifications from 100 X to 510 X. The results of this study revealed the following.

- Wax coatings were present in leaves of most of the species, however, *S. maritima*, *R. mucronata*, *R. apiculata*, *R. x lamarckii* and *A. r* leaves collected during May 1994 showed thicker wax cuticle (1.426a - e) and numerous striations (Figure 4.26e). Salt glands were present in *A. marina* leaves (Figure 4.26d). The asynchronous
Figure 4.26 Thick wax layer on the adaxial surface of leaves studied in summer (May 1994) (a) *R. lamarckii*; (b) *R. mucronota*; (c) *R. apiculata*; (d) *A. marina* with salt glands indicated by arrow; (e) thick wax layer with numerous striations in *S. maritima*. 
glands found in *A. marina* was also described along with modes of salt secretion by Ish-Shalom-Gordan and Dubinsky.

- Stomata was present on the adaxial surface of the species *A. marina, L. racemosa, A. ilicifolius* and *A. corniculatum* (Figures 4.27a-d).

- *Salvadora persica, Suaeda monoica, Suaeda maritima, Salicornia* and *Sesuvium portulacastrum* were having thick wax. Rubiaceous type stomata and high interspace were observed on the adaxial and abaxial surfaces (Figures 4.28a-e).

- Stomata was not present on the adaxial surface of the species *R. apiculata, R. mucronata, E. agallocha, C. decandra* and *B. c.* (Figures 4.29a-e).

- Leaf samples of the same species like *A. marina* from different sites did not show any significant changes in stomatal character. There was no marked difference in climatic conditions.

### 4.7 DISCUSSION

The grey level (digital number) variations of mangrove are Landsat TM and IRS LISS-II digital data of Pichavaram provide qualitative information on the variations in spectral response of mangrove areas especially in the near infrared band (band 4) of Landsat TM and in the middle infrared bands (bands 5 & 7) of TM. Whether the area is familiar or not, a clear-cut demarcation of mangrove area
Figure 4.28 Rubiaceous type stomata and thick cuticles (a) more interspersed between leaf layers (marked by arrow) in S. Persica; (b) S. monoica; (c) S. maritima; (d) S. brachiata; (e) S. portulacastrum
Figure 4.29 Absence of stomata and smoother leaf surface in Rhizophor: and Euphorbiaceae (a) *R. apiculata*; (b) *R. mucronata*; (c) *E. agalloch*. *C. decandra*; (e) *B. cylindrica* (leaves studied during February 1995)
agricultural lands is possible using the spectral response curves (based on grey level variations) derived from Landsat TM and IRS LISS-II digital data. However, the demarcation of mangroves from agricultural areas is found to be difficult on FCCs of IRS and TM since both of them appear in red tone. Therefore, the spectral response curves from satellite digital data would be useful to derive a qualitative information about the spectral properties of mangroves.

The spectral radiance study indicates the variation in amplitude of radiance from different mangrove species and also the same species in different locations during the same period of observation. Observations on changes in spectral radiance of A. marina during different seasons in Ennore (polluted) and Pichavaram (unpolluted) show marked changes in radiance in band 4 of MSS, TM and IRS. The amplitude of variations in spectral radiance in band 4 also differ in these two sites.

The spectral reflectance of a vegetation canopy varies with wavelength. The knowledge on the properties of individual leaf is inevitable to understand why a canopy reflects more of certain wavelengths than of others. Three important features of leaves i.e. pigmentation, canopy structure and leaf morphology have an effect on the reflectance, absorbance and transmittance (Curran, 1985). Also it is well established that the absorption of leaf pigments, with the green chlorophyll as main component, determines the shape of the reflection spectra rather than other leaf pigments like carotenoids, xanthophylls etc. (Buschmann and Nagel, 1993). Therefore, the influence of leaf chlorophyll has been given importance in the present study to correlate with radiance /reflectance. The important plant
parameters like leaf chlorophyll and water content, leaf morphology, leaf pattern and canopy structure will be discussed in turn. The influence of soil background is not going to be considered for this discussion since it was proved that there were no relationship existing between background soil reflectance and mangroves reflectance. Also it was observed during the ground truth that the mangrove canopy completely obscure the underlying soil surface in all our study sites. Based on earlier literatures, the due importance has been given in this study to correlate the spectral reflectance with leaf chlorophyll and water content, leaf pattern and canopy structure and leaf adaxial surface morphology.

The comparison of work on spectral reflectance of mangrove species in Okinawa Island, Japan (Sato et al., 1992) with the present study shows that the amplitude of spectral reflectance and the reflectance pattern are having much similarity. The study by Sato et al. (1992) also indicates that the spectral reflectance varies in the same species that occurs in different sites. However this study doesn't provide with vegetation parameters to compare them with reflectance.

Leaf pigments like chlorophyll \(a\) and \(b\), which are the most important pigments, absorb portions of the blue and red light; chlorophyll \(a\) absorbs at wavelengths of 0.43 \(\mu m\) and 0.66 \(\mu m\) and chlorophyll \(b\) at wavelengths of 0.45 \(\mu m\) and 0.65 \(\mu m\) (Curran, 1985). With increasing chlorophyll concentration the reflection signal decreases in the far-red absorption maximum chlorophyll, i.e., at 680 nm (Buschmann and Nagel, 1993). Leaf chlorophyll doesn't absorb much beyond 0.7 \(\mu m\) (Jacquemoud and Baret, 1990). This is also evidenced while comparing the spectral reflectance of
mangrove species like Ceriops decandra, Excoecaria agallocha and Luminitzera racemosa with their chlorophyll content (afternoon time) at the time of spectral reflectance study. All the above three species are having high chlorophyll content and also showing lower spectral reflectance in the green to red region from 0.52 - 0.69 µm. (Figures 4.14 & 4.15). Also the study on in-vivo reflection spectrum of a water-infiltrated leaf showed that there was a decrease in reflection signal (Buschmann and Nagel, 1993). This phenomenon could also be observed in the present study that the mangrove leaves with high chlorophyll are having less leaf water content (Figures 4.23a & c), for example, C. decandra, E. agallocha and L. racemosa are having high chlorophyll and less leaf water content. Both increase in chlorophyll content and decrease in leaf water content lead to decrease in reflection signal in the red (Figures 4.14 & 4.15). Leaf chlorophyll content fluctuates in different seasons. High chlorophyll content was observed in the mangrove leaves during summer season, for example in A. marina, R. apiculata and R. mucronata. The seasonal changes in spectral radiance and spectral reflectance in the visible bands of MSS, TM and IRS are mainly due to the variations in leaf chlorophyll content. In order to visualize the seasonal changes in radiance, the error bar plots were constructed, with the x-axis representing wavelength, and y-axis radiance (Figures 4.11). Figure 4.11 shows that much variations in near infrared band (band 4 of IRS & TM), are due to the leaf chlorophyll content in different seasons. This kind of approach was already attempted for deciduous tree canopies using field spectroradiometer and proved the influence of leaf chlorophyll content on seasonal changes in reflectance (Blackburn and Milton, 1995).
The red edge is the point of maximum slope in vegetation reflectance spectra. It occurs between wavelengths of 0.68 and 0.75 μm, where the reflectance changes from very low in the chlorophyll red absorption region to very high in the near-infrared. Some red edge parameters in the first derivative reflectance curve (wavelength, amplitude and area of the red edge peak) were studied to evaluate plant chlorophyll content, biomass and Relative Water Content (Filella and Penuelas, 1994). The above study carried out for Capsicum annuum and Phaseolus vulgaris shows that the red edge peak was very sharp and its changes in the amplitude throughout the growth cycle. The inflection point of the red edge is well correlated with the chlorophyll content of the leaf (Gates et al., 1965). Also the relationship between reflectance red edge and chlorophyll concentration in slash pine leaves were explored by Curran et al. (1995). The above study indicates the linear relationship between red edge and chlorophyll concentration. The red edge (0.69 - 0.75 μm) in mangrove species doesn't have a peak like agricultural crops. However the amplitude of reflectance variations in this region could be used as a valuable indicator for leaf chlorophyll content and biomass. The variations in amplitude of reflectance from Muthupet mangroves in bands 2 and 3 of IRS (Figure 4.18b) would have been due to high leaf chlorophyll content than the same species in other places. It will be more noteworthy to mention here the contrast in geomorphological setup in Muthupet and in Pichavaram. The Muthupet mangroves forms a fringe along the seashore and narrow lagoons and located on paleoshorelines of progradation deltaic coast, whereas the mangroves in Pichavaram are located in the Vellar-Coleroon estuarine complex. The complete absence of Rhizophoraceae family in Muthupet is still unclear. The next expected cause
for the variations in spectral reflectance is the difference in age of mangroves in different study areas. The mangroves of Muthupet are now separated from the sea by a coastal sandy spit which makes the entry of sea water into the channels more difficult day by day. In these regions the tides are only of about 1m twice a day. These morphogenetic phenomena lead to a rapid aging of the mangroves in Muthupet (Blasco, 1977). Although reflectance changes in relation to variations in stand age and structure are subtle and influenced by topography, recent studies demonstrated that certain spectral characteristics of stands in the Western Hemlock predictably change in relation to age and structure (Cohen and Spies, 1992) and also in Western Oregon (Cohen et al., 1995). Therefore in this study the changes in visible and near-infrared reflectance in Muthupet might have been due to rapid aging of mangroves. Since our Spectroradiometers don't have sharp bandwidths between the red edge region, it is very difficult to come to definite conclusions on the red edge applications in mangroves. Further study of this phenomenon with more spectral bands in the red edge region is warranted to apply for mangroves.

The near infrared reflectance of vegetation is greatly influenced by leaf morphology (Gausman, 1977). Studies carried out on the absorption of Global radiation by *Tussilago farfara* L. shows that both leaf position and leaf waxes have significant changes in the absorbed energy. Leaf pattern constitutes various leaf angle in mangrove species, for example, *Rhizophora* has near-vertical leaf angle, while *Bruguiera* with large, horizontally arranged leaves, was less abundant at the top of the canopy. Thus, two different strategies for adopting to high solar radiation levels may exist in these species (Lovelock and Clough, 1992). The above study also indicates
different strategies for adopting to high solar radiation levels may exist in these species (Lovelock and Clough, 1992). The above study also indicates that leaf angles vary among mangrove species, the importance of leaf angle is influencing the concentration of xanthophyll cycle components. Similar conditions were also noticed in the present study especially the contrast in leaf pattern and leaf angle among mangrove species. *E. agallocha* is having less leaf angle (leaves are looking almost vertically down) when compared to *Rhizophora*. This again affects the near-infrared reflectance of species like *E. agallocha* and *B. cylindrica*. The reflectivity of the leaf adaxial surface is lowered by removing the waxes and increases transmission more than absorption in the near infrared (Eller and Willi, 1977). Study on the bidirectional reflectance and transmittance using a goniometer on the leaves of Yellow Poplar, Red Oak and Red Maple indicates the influence of leaf waxes. Leaf waxes are reported to occur as plates, tubes, rods, filaments, coiled ribbons, or dendrites (Reed, 1979). Certain plants may, in extreme habitats, seek not to concentrate light but to reflect it, for example, *Kleinia articulata* from the Karrow desert. A combination of light scattering with the help of wax layer for short-term water storage in epidermal cells of *Halimione pertulacoides*. Other plants like *Dactylopius coccus* has a waxy epicuticle to reduce water loss and to defend itself against insects and birds. Waxes protect the leaf from desiccation, hinder the penetration of pathogens and insects, and may reflect, diffuse, or concentrate the rays of the sun (Juniper and Jeffree, 1983). Cameron (1970) found that the difference in reflection characteristics caused by the amount and orientation of waxes on the leaf cuticle resulted in variation in the capability of leaves to absorb light
in the waveband 400-700 nm. Removing the wax, lowered the reflectance and increase photosynthesis in the species of *Eucalyptus*.

Thicker wax layers were present on the adaxial surface of *S. maritima*, *R. apiculata* and *R. mucronata* during summer season (May) rather than in postmonsoon (February). The influence of adaxial surface wax layer on spectral reflectance in the near-infrared region is evidenced in this study. The increase in spectral reflectance could be observed in the near-infrared bands of *A. marina* especially in summer season. This was also proved by the study carried out by Robinson et al. (1993) on *Cotyledon orbiculata*. They have observed that leaf wax is low in plants grown under low light in controlled environments than those at high light in the field and also the leaf wax protection was confined to the upper (adaxial) layers of the leaf. Species like *E. agallocha*, *C. decandra* and *B. cylindrica* don’t have stomata on the adaxial surface. Due to the absence of leaf stomata, the guard cells were also not present and the leaf surface becomes smooth. This feature is expected to lower the spectral reflectance of the above species. Some of the species like *S. maritima* are having thick wax cuticle, but the interspace between the leaf surfaces is more and this in turn leads to more absorbance and decrease in spectral reflectance ultimately.

This study elucidates the following:

1. since this study was undertaken using calibrated radiometers and also the radiometric measurements were carried out in standard time to mimic the effect of sun elevation angle, the vegetation parameters
could be taken into account for validating the spectral properties of mangroves (Table 4.7),

2. the influence of soil background on the spectral properties of mangroves are not observed and doesn't require to introduce normalization indices (most commonly applied methods of reducing the influence of soil background in spectral data), (Table 4.7).

3. the changes in spectral radiance and reflectance in the visible wavelength region is highly influenced by the leaf chlorophyll content and this variation could be the main cause for seasonal changes in spectral properties of mangroves,

4. many of the mangrove species shows that increasing leaf chlorophyll with decrease in leaf water content. Both these parameters affect (decrease) the red reflectance,

5. the near-infrared radiance and reflectance are very much influenced by leaf pattern, canopy structure and leaf adaxial surface wax than the ageing of species,

6. the leaf wax layer especially on the adaxial surface is responsible for the variations in spectral radiance and reflectance in the near-infrared wavelength region next to leaf pattern and the canopy structure. The presence of wax layer increases the radiance and reflectance in this region,
Table 4.7 Validation of spectral properties of mangrove species with plant parameters and environmental conditions

<table>
<thead>
<tr>
<th>Species</th>
<th>Location</th>
<th>Environmental conditions</th>
<th>Plant parameters</th>
<th>Spectral properties</th>
<th>Validation remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avicennia marina (Forsk) Vierh</td>
<td>Ennore</td>
<td>Industrial pollution</td>
<td>Closed canopy and leaf wash-outs are more due to the deposition of pollutants</td>
<td>High spectral radiance and reflectance in summer (May)</td>
<td>Local environmental condition (industrial pollution) affects spectral properties</td>
</tr>
<tr>
<td>Avicennia marina (Forsk) Vierh</td>
<td>Adyar</td>
<td>Sewage pollution</td>
<td>Abnormal height of mangrove stand with leaf disease</td>
<td>Decrease in spectral radiance (May)</td>
<td>Leaf Area Index (LAI) is less due to leaf density, very much affected by leaf disease</td>
</tr>
<tr>
<td>Avicennia marina (Forsk) Vierh</td>
<td>Pichavaram</td>
<td>Unpolluted and high saline areas</td>
<td>Closed canopy and healthy species</td>
<td>High radiance and reflectance than the other locations</td>
<td>Presence of salt glands, stomata and wax layer on the adaxial surface increases near-infrared radiance and reflectance</td>
</tr>
<tr>
<td>Avicennia marina (Forsk) Vierh</td>
<td>Madavamedu</td>
<td>Unpolluted and less saline freshwater influenced area</td>
<td>High leaf chlorophyll content</td>
<td>Less reflectance when compared to high saline area (Pichavaram)</td>
<td>High leaf chlorophyll content decreases visible reflectance</td>
</tr>
</tbody>
</table>

Table 4.7 (Contd.)
Table 4.7 Validation of spectral properties of mangrove species with plant parameters and environmental conditions (Contd.)

<table>
<thead>
<tr>
<th>Species</th>
<th>Environment</th>
<th>High leaf chlorophyll and canopy structure</th>
<th>Increase in near-infrared reflectance and decrease in visible reflectance</th>
<th>High chlorophyll content makes a shift due to decrease in reflectance in the red edge. Due to dense canopy structure near-infrared reflectance increases</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Avicennia marina</em> (Forsk) Vierh</td>
<td>Unpolluted deltaic environment</td>
<td>High leaf chlorophyll and more dense canopy structure</td>
<td>Decrease in reflectance in both visible and near-infrared regions</td>
<td>High leaf chlorophyll affects visible reflectance. Thin spiny leaves and unclosed canopy also affect near-infrared reflectance. High leaf chlorophyll and aging of species further decrease the reflectance</td>
</tr>
<tr>
<td><em>Acanthus ilicifolius</em> L.</td>
<td>Pichavaram &amp; Muthupet</td>
<td>Unpolluted</td>
<td>High leaf chlorophyll and unclosed canopy structure</td>
<td>Decrease in reflectance in both visible and near-infrared regions</td>
</tr>
<tr>
<td><em>Aegiceras corniculatum</em> (L.) Blanco</td>
<td>Pichavaram &amp; Muthupet</td>
<td>Unpolluted</td>
<td>High leaf chlorophyll and closed canopy</td>
<td>Decrease in visible reflectance especially in the species from Muthupet</td>
</tr>
</tbody>
</table>
Table 4.7 Validation of spectral properties of mangrove species with plant parameters and environmental conditions (Contd.)

<table>
<thead>
<tr>
<th>Species</th>
<th>Location</th>
<th>Condition</th>
<th>Leaf Chlorophyll</th>
<th>Refl. Change</th>
<th>Environmental Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Bruguiera cylindrica</em> (L.) Blume</td>
<td>Pichavaram</td>
<td>Unpolluted</td>
<td>Low chloro.</td>
<td>Increase</td>
<td>Thick and closely arranged leaves with self-shading affects the near-infrared reflectance.</td>
</tr>
<tr>
<td><em>Ceriops decandra</em> (Griffth) Ding Hou</td>
<td>Pichavaram, Madavamedu and seedlings</td>
<td>Unpolluted</td>
<td>High chloro.</td>
<td>Increase</td>
<td>Seedlings show increase in visible reflectance and decrease in near-infrared reflectance.</td>
</tr>
<tr>
<td><em>Excoecaria agallocha</em> L.</td>
<td>Pichavaram, Madavamedu and Muthupet</td>
<td>Unpolluted</td>
<td>Deciduous</td>
<td>Decrease</td>
<td>High chlorophyll affects the visible reflectance. The leaf pattern (leaves almost looking downward) affects the near-infrared reflectance. Also the adaxial wax layer is less dense and absence of stomata. This in addition affects near-infrared reflectance.</td>
</tr>
</tbody>
</table>

Table 4.7 (Contd.)
Species in Pichavaram has high reflectance in all the bands of IRS and TM than in Madavamedu.

Leaf adaxial wax are less dense and absence of stomata. Smooth leaf surface decreases near-infrared reflectance. Less chlorophyll doesn't affect the visible reflectance. However the less developed leaf wax and absence of stomata affects the near-infrared reflectance.

Luminitzera racemosa Willd & Madavamedu | Unpolluted | Leaf chlorophyll is high | Less reflectance in both visible and near-infrared regions | Species in Pichavaram has high reflectance in all the bands of IRS and TM than in Madavamedu

Rhizophora apiculata Blume | Pichavaram | Unpolluted | Leaf chlorophyll is moderate and closed canopy structure | No abrupt changes in reflectance | Leaf adaxial wax are less dense and absence of stomata. Smooth leaf surface decreases near-infrared reflectance

Rhizophora mucronata Poiret | Pichavaram | Unpolluted | Leaf chlorophyll is less and closed canopy structure | Increase in visible reflectance than R. apiculata | Less chlorophyll doesn't affect the visible reflectance. However the less developed leaf wax and absence of stomata affects the near-infrared reflectance

Salicornia brachiata Roxb, Sesuvium portulacastrum (L.) L and Suaeda monoica (Forsskalex) J.Gmelin | Pichavaram | Unpolluted | Less leaf chlorophyll and the species height is less than one meter | Very less visible and near infrared reflectance | All the three species are having larger cellular space when compared to all other species. Unclosed canopy of these species occurs in landward side
apart from vegetation parameters, the environmental i.e. industrial pollution can be taken into account for the decrease in spectral radiance and reflectance of mangroves,

since the spectral properties of mangroves vary temporally in relation with their plant parameters, this technique could be used to assess the plant health (chlorophyll, water stress, biomass etc.). However it is recommended to use narrow spectral channels in the red edge region to precisely identify the shift in red edge among mangrove species,

since the bidirectional scattering of light from tree leaves using a laboratory goniometer have been proved to be useful for spectral studies (Brakke, 1989), this kind of approach will be useful for mangroves, and several models have been developed to describe the reflection of optical radiation from vegetation canopies, for example, visible and near-infrared radiant flux model (Roberts et al., 1990) to study the effects of variable background reflectance, leaf size and leaf height above the background; Nilson-Kuusk canopy reflectance model (Kuusk, 1991, 1994) to study the canopy optical and structural parameters; leaf optical model by Jacquemoud and Baret (1990) and many others. The present study could be used as a valuable input for using various vegetation models to study the mangroves.