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Research Article

Assessment of Spectral Reflectance to Discriminate and Monitor the Mangrove Tree Species in South Florida

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Abstract Mangrove vegetation are critical for the environmental and ecological health of South Florida coastal ecosystems. However, they are widely threatened and becoming vulnerable to urbanization, environmental pollution, and climate changes. This study examines the differences in spectral reflectance of the red, black, and white mangrove tree species, so that they can be mapped and monitored continuously. Field studies were conducted to sample the leaves and pods of the three mangrove trees species of South Florida. The spectral reflectance (350-2500 nm spectral range) of the leaves and pods were collected using a handheld spectroradiometer and the relative water content of the leaves were analyzed. Our spectral analysis revealed that the chlorophyll peak centered at 550 nm was highest for the dorsal surface of black mangrove leaves followed by white and red mangrove species. Also, the absorption maxima of white mangrove species centered at around 900, 1200, 1400 and 1900 nm was significantly stronger than the red and black mangrove species. The relative water content of the white mangrove leaves is significantly higher than the red and black mangrove species. This study suggests the use of remote sensing to monitor the species level distribution and physiology of the mangrove species and thus assess the effect of anthropogenic and natural factors on the landscape level changes of mangrove vegetation.
Keywords *Mangrove; Spectral reflectance; Estuary; Plant physiology; Land cover*

1. Introduction

The mangrove forests are a vital component of the estuarine and marine ecosystems throughout the world. The mangrove vegetation along the coasts provides protected nursery areas for various marine organisms, stabilize shorelines, reduces turbidity, and enhances water clarity (FDEP, 2022). The mangroves, which are the most productive and ecologically important tropical ecosystems of the world, are declining at a rapid rate both globally and in US specifically within South Florida (Alongi, 2002; Cissell et al., 2018). The rapid urban development, environmental pollution, deforestation, and sea-level rise are posing constant threats to mangrove growth (Richards and Friess, 2016; Pham and Yoshino, 2016; Zhu et al., 2021). About 40% of the mangroves worldwide are adversely impacted by anthropogenic activities such as aquaculture and agriculture developments (Thomas et al., 2017)

There are three main mangrove tree species that are particularly common along the South Florida coast, they are red mangrove (*Rhizophora mangle),* black mangrove (*Avicennia germinans*), and white mangrove (*Laguncularia racemose).* Among Florida mangroves the red mangroves are most susceptible to damage from frost, while white mangroves are less susceptible, and the black mangroves are the cold tolerant (Osland et al., 2018).

Red mangroves possess a characteristics network of aerial prop roots extending from the trunk and lower branches to the soil (FDEP, 2022). Red mangroves usually attain an average height of 8 to 10 m and are located close to the shorelines. The bark of red mangroves is grey while the interior is red. The leaves are shiny, deep green on the dorsal surface and pale on the ventral surface. Flowers are small, white colored and the seeds are long about 25 to 30 cm in length, elongated and shaped like a pencil (FDEP, 2022).

White mangrove trees grow up to an average height of about 15 m and tends to be erect (FDEP, 2022). The bark is white and relatively smooth, and the leaves are thick, leathery, and oval shaped with rounded ends. Both the dorsal and ventral side of the leaves have relatively the same pale green color (FDEP, 2022).

Black mangroves have characteristics horizontal roots that radiate from the tree with short, vertical, aerating branches, called pneumatophores, extending about 2 to 20 cm above the soil (FDEP, 2022). The trees grow straight and attains an average height of 20 m. The bark is dark and scaly, the leaves are narrow, elliptic leaves with dark green dorsal surface and a pale green ventral surface. The dorsal surface of leaves is encrusted with salt excreted by the tree. The flowers are white and symmetric (FDEP, 2022).

It is important to continuously monitor and predict the future responses of the different mangrove tree species to increasing temperature, intense rain events, accelerated sea-level rise, hurricane occurrences, eutrophication, invasive plant species, land use and land cover change in South Florida (Osland et al., 2018). The structure, function, and stability of each of the mangrove tree species systems are greatly influenced by hydrologic flow, salinity levels, and sediment delivery in the estuaries (Romañacha et al., 2018). Such changes are compounded by the effects of sea-level rise which include saltwater intrusion and increased inundation (Osland et al., 2018; Romañacha et al., 2018).

Traditional field survey methods are time consuming, costly, and least efficient as it is difficult to obtain accurate mangrove data over large spatial scale. Remote sensing technology has broad coverage, short revisit period, making it cost-effective for continuous mangrove monitoring. Our overarching aim is to explore the differences in spectral reflectance of the red, black, and white mangrove tree species, so that they can be mapped and monitored continuously.

The objectives of this study were as follows: 1) to analyze the spectral reflectance of the red, black, and white mangrove vegetation in the visible and Near Infrared (NIR) region; 2) to compare the foliar spectral reflectance and the physiology of the main three mangrove species of South Florida. Hence, in situ spectral signatures of the three major mangrove species were measured to investigate whether these tree species could be discriminated through spectral reflectance data obtained in the visible and NIR region.

2. Material and Methods

2.1. Field study

The field study was conducted in the Anne Kolb Nature Center, a 1,501-acre coastal mangrove wetland, which is one of largest park system located in the Broward County of South Florida (Figure 1). The study site consists of several board walks, trails and a tall observation center overlooking the largest urban mangrove forest remaining in Florida. Several leaf, and pod samples were collected from 9 locations across the nature preserve in the fall of 2021. All the sampling locations were marked using a handheld global positioning system (GPS) receiver (Trimble Inc., Sunnyvale, CA, USA). The natural color image of the study area, overlaid with the sampling locations, is shown in Figure 1.

About 4-5 leaves, and pods were collected from the Red, Black, and White mangrove plants, at three selected sample locations for each mangrove plant type in the nature preserve (Figure 1). The leaf and pod samples were transported to the lab immediately and the spectral reflectance were obtained. Subsequently, the leaf samples were air dried, and the Relative Water Content (RWC) of the leaf samples were calculated. The RWC of the leaves were obtained using the formula (Fresh weight – Dry weight)/ Fresh weight (Sridhar et al., 2007, 2022).

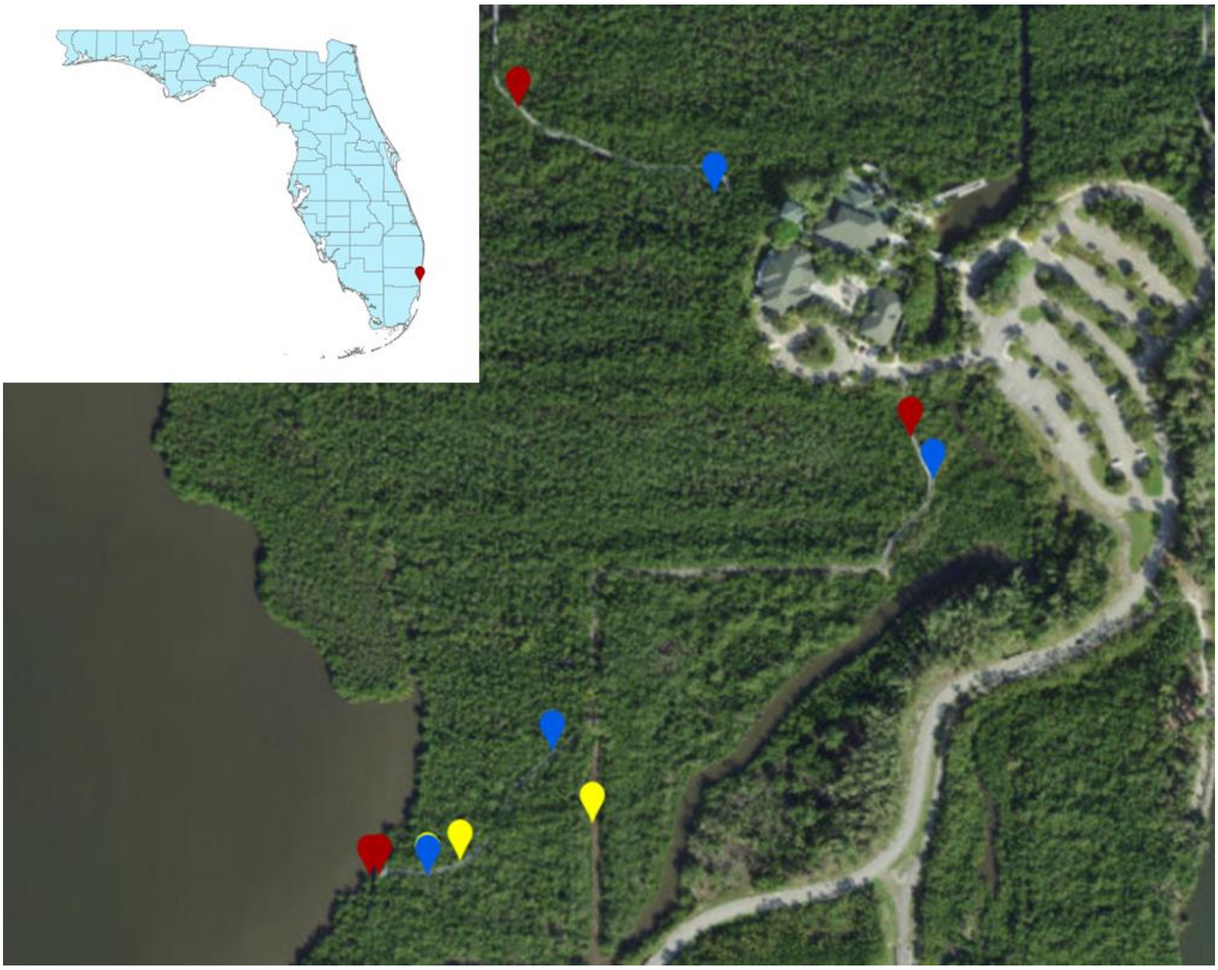

Figure 1: *The sampling locations of the red, black, and white mangroves were shown in red, yellow, and blue colors, respectively. All the three varieties of mangroves were spread across the Anne Kolb Nature Center, located in Broward County. The inset image shows the position of sampling locations in the South Florida.*

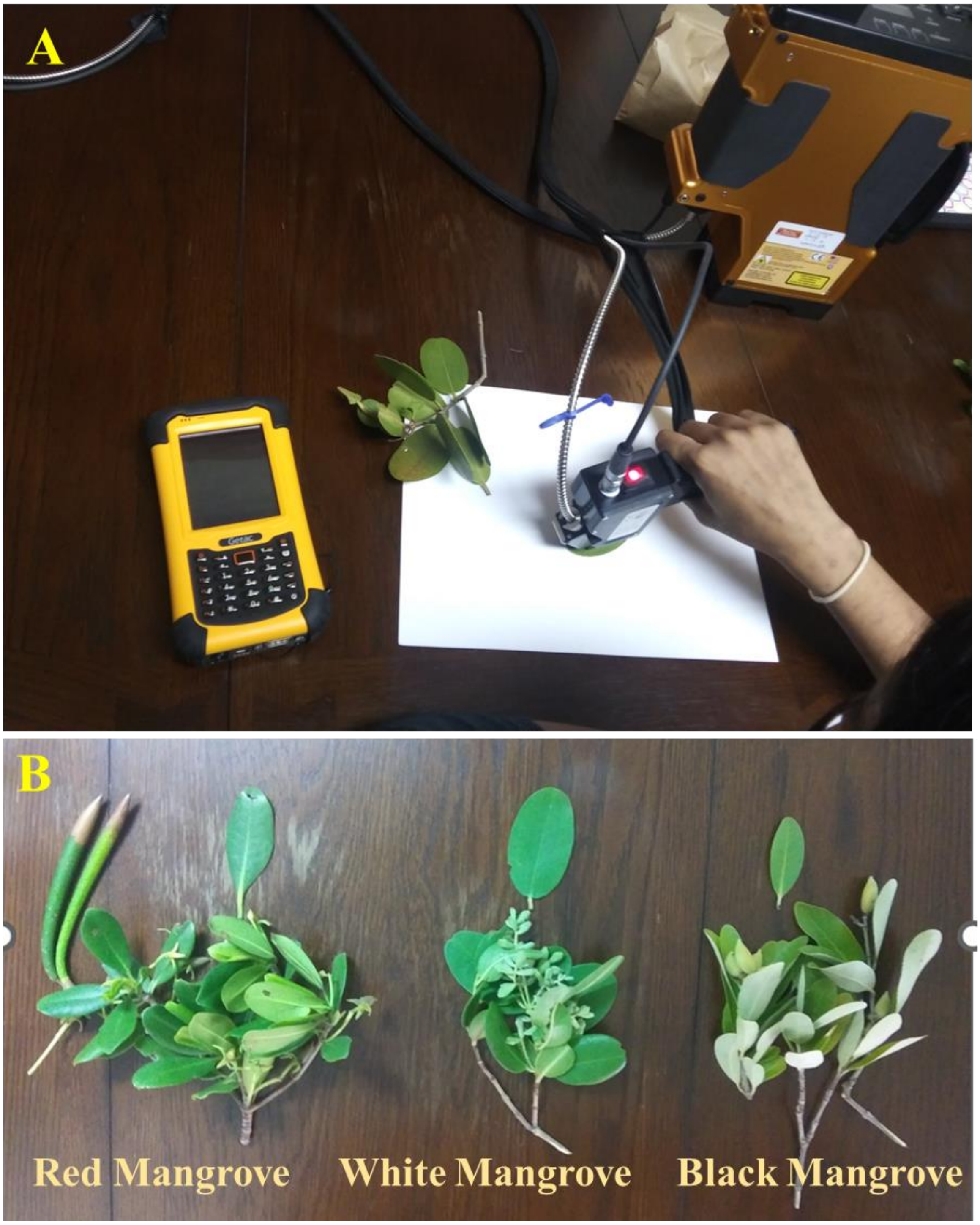

Figure 2: *Experimental setup (A) to obtain the foliar spectral reflectance of the red, black, and white mangroves. The leaf, flower and pods of the mangroves were also shown in the image (B).*

2.2. Spectral reflectance

A Spectral Evolution spectroradiometer (Spectral Evolution Inc., Haverhill, MA, USA) with a spectral range of 350–2500 nm was used to obtain the reflectance spectra of each individual mangrove leaf, and pods in the lab, with a quartz-tungsten-halogen (QTH) lamp as a light source using a contact probe. Diffused light from the contact probe was used to illuminate the leaf surface when spectra were collected in the laboratory. The foreoptics were aligned vertically and the height of the foreoptics from the leaf was adjusted so that only the reflectance of the targeted material filled the field of view (FOV) of the instrument. The height of the foreoptics was kept constant throughout the experiment from the surface of targeted plant material such as leaf or pods in this experiment. The same experimental setup was used to obtain the spectra of all the samples. Calibration spectra of a white Spectralon panel (Labsphere Inc., North Sutton, NH) were acquired before recording the leaf spectra. The spectral recording software in the spectroradiometer was set in such a way that each reflectance spectrum recorded was obtained by collecting and averaging 10 individual reflectance spectra. Each spectrum was normalized by dividing it with the measured spectrum of the standard (Spectralon panel). The spectral reflectance procedure was reported in detail elsewhere by Sridhar et al. (2007, 2022).

2.3. Statistical Analysis

The spectral measurements of leaves, and pods of each mangrove type (n = 3) from the field survey were averaged to overcome individual variations. Changes in spectral reflectance along with RWC were used to characterize the plant morphological and physiological characteristics. The significant differences between the RWC of plant leaves were evaluated through analysis of variance (ANOVA).

3. Results and Discussion

The leaf and pod samples of the various mangrove tree species that were collected in the field were all healthy, green and are free from any visual symptoms of disease and stress. The averaged (n = 3) reflectance spectra of the dorsal and ventral side of the mangrove leaves are given in Figure 3. The foliar spectral reflectance of the dorsal surface of the three mangrove species showed strong absorption maxima of leaf pigments in the blue and red regions of the visible spectrum at 470 nm and 680 nm, respectively, while the green reflectance peak is centered at 550 nm. The chlorophyll peak was highest for the dorsal surface of black mangrove leaves followed by white and red mangrove species. The spectral reflectance in the 700-1100 nm of NIR region remained higher for black and white mangroves compared to the red mangrove species. However, the reflectance of the red and black mangrove leaves remained higher in the 1100-2500 nm region compared to the white mangrove leaves (Figure 3A).

Among the ventral surface of the leaves (Figure 3B), the green reflectance peak at 550 nm is higher for red and black mangrove species compared to the white mangrove species. The reflectance in the visible region (400-700 nm) is higher for all the ventral surface of leaves compared to their corresponding dorsal surfaces. The spectral reflectance in the 700-1100 nm remained higher for black and white mangroves compared to the red mangrove species. However, the reflectance of the white mangrove leaves decreased and remained lower in the 1100-2500 nm region compared to the red and black mangrove leaves (Figure 3A). The spectral absorption of white mangrove species centered at around 900, 1200, 1400 and 1900 nm was significantly stronger than the red and black mangrove species for both the dorsal (Figure 3A) and ventral (Figure 3B) surfaces of leaves.

The leaf-level spectra of both the dorsal and ventral surfaces indicate that the white mangrove species has strong absorption bands in the 470 nm and 680 nm of the visible region of the spectrum compared to the white and black mangroves (Figure 3A, B). This can be attributed to the near uniform distribution of chlorophyll on both sides of the leaf in white mangrove species. The dorsal surface of all the mangrove species leaves has strong chlorophyll peak centered around 550 nm (Figure 3A). This is because of the higher concentration of chlorophyll on the dorsal side of their bilateral leaves. The ventral surface of the black and red mangrove leaves shows a broader chlorophyll peak, which can be attributed to lower chlorophyll distribution on their ventral surfaces (Figure 3B). This agrees with the findings of Zulfa et al. (2020) indicating that the reflectance in the 550 nm region is strongly correlated to the chlorophyll content of the leaves.

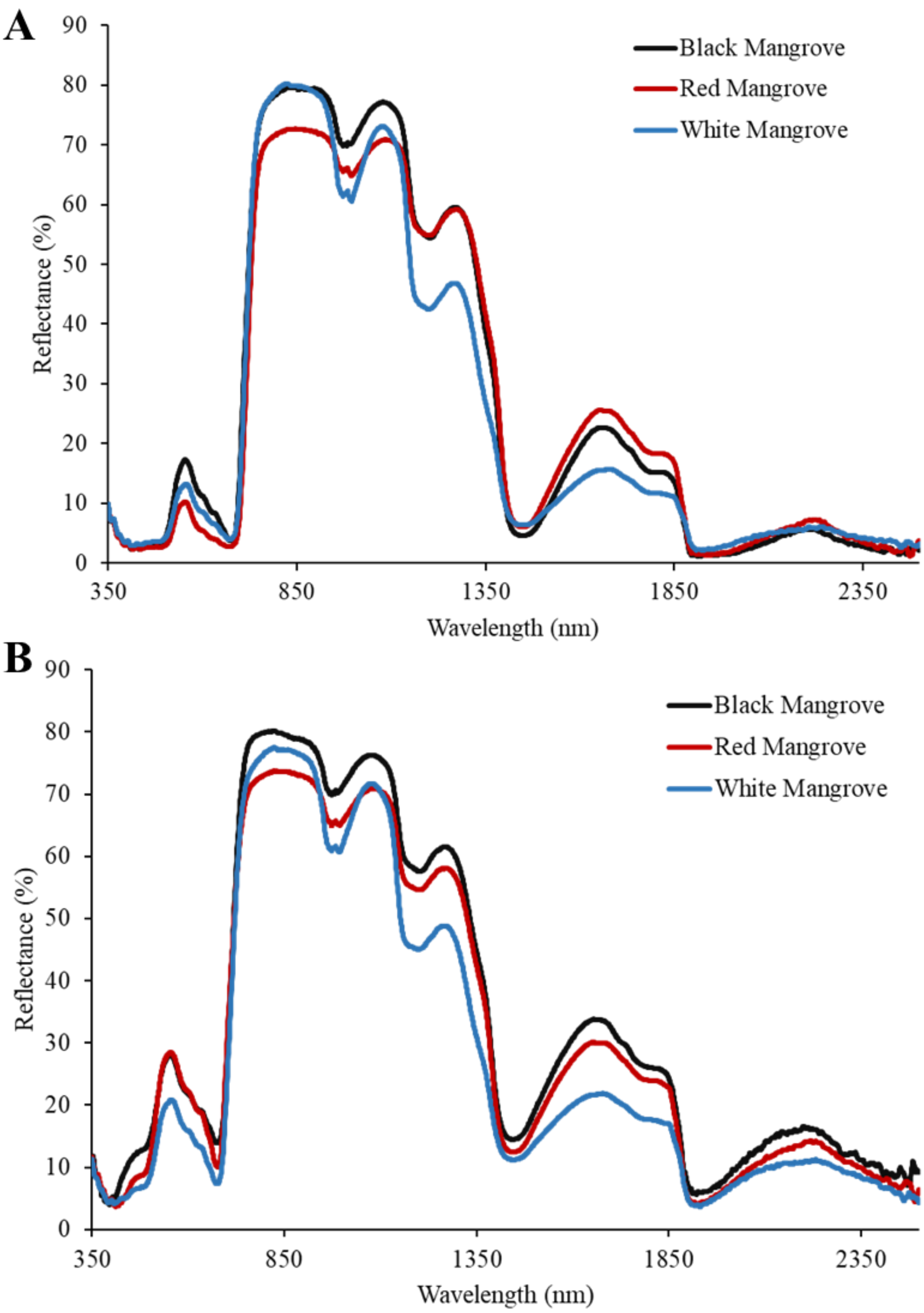

Figure 3: *Averaged (n = 3) foliar reflectance spectra of dorsal (A) and ventral (B) side of the red, black, and white mangroves.*

The spectral absorption maxima of the dorsal and ventral surface of white mangrove leaves at 900, 1200, 1400 and 1900 nm were significantly stronger than the red and black mangrove leaves (Figure 3A B). This can be attributed to the more water content in the leathery, thicker leaves of white mangroves over other species. The higher water content in the white mangrove leaves was also confirmed by its high RWC values, which were at least 14% and 44% higher than the RWC of red and black mangrove leaves (Figure 5).

Photosynthetic pigments, leaf internal structure, and water content of plants have distinct light absorption and reflectance characteristics which can affect the amount of leaf reflectance in the respective regions of the spectrum (Slaton et al., 2001; Davids and Tyler, 2003; Sridhar et al., 2007; 2022). The absorption maxima of leaf pigments occur in the blue and red at 470 nm and 680 nm, respectively, while the familiar green reflectance peak occurs at 550 nm. In the near infrared (NIR) region, these pigments are transparent and internal leaf structure and biochemical composition control reflectance. The reflectance spectra of principal biological interest occur in the NIR between 700 nm and 1300 nm, where reflectance is high, and absorption is minimal (with two minor water absorption bands at 975 nm and 1175 nm). Beyond 1300 nm, major water absorption bands (at 1450 nm and 1950 nm) become significant. Thus, analysis of remotely sensed reflected light could be used to assess both biomass and physiological status of plants (Sridhar et al., 2007; 2022).

The spectral reflectance of all the three mangrove species pods are given in Figure 4. The red mangrove pods showed a sharp chlorophyll peak centered at 550 nm while the white and black mangrove pods showed higher reflectance in the 500-700 nm range within the visible region of the spectrum (Figure 4). The red, white, and black mangrove pods appear in green, pale green and in yellow color, respectively (Figure 2B). The red mangrove pods have higher reflectance in the 700-1100 nm region compared to the other species while the NIR reflectance decreased and remained lower in the 1100-2500 nm region compared to the red and black mangrove pods. The RWC of the white mangrove leaves was significantly higher than the red and black mangrove species (Figure 5). The black mangrove leaves showed the lowest RWC among all the species (Figure 5).

Among the spectra of the pods, the red mangrove pods have strong absorption bands in the 470 nm and 680 nm of the visible region of the spectrum compared to the white and black mangroves (Figure 4). This can be attributed to high chlorophyll content of red mangrove pods over the black and white mangroves which were in pale green and in greenish-yellow color, respectively. Several studies have reported that the use of remote sensing using various satellite imagery to monitor the mangrove vegetation (Heenkenda et al., 2014; Zulfa et al., 2021). However, the detailed spectral reflectance differences between the three different mangrove species of South Florida in the spectral range of 350-2500 changes on the various surface of the leaves was not evaluated so far until this study. Deriving the appropriate spectral bands, spectral ratios and spectral indices based on the detailed spectral reflectance differences can aid in identifying and mapping the different mangrove species. Heenkenda et al. (2014) suggested that more advanced techniques and algorithm approaches need to be used to discriminate between the mangrove species (Zulfa et al., 2021). Thus, remote sensing can be used to monitor the impact of climate and anthropogenic stress on the health of mangrove vegetation.

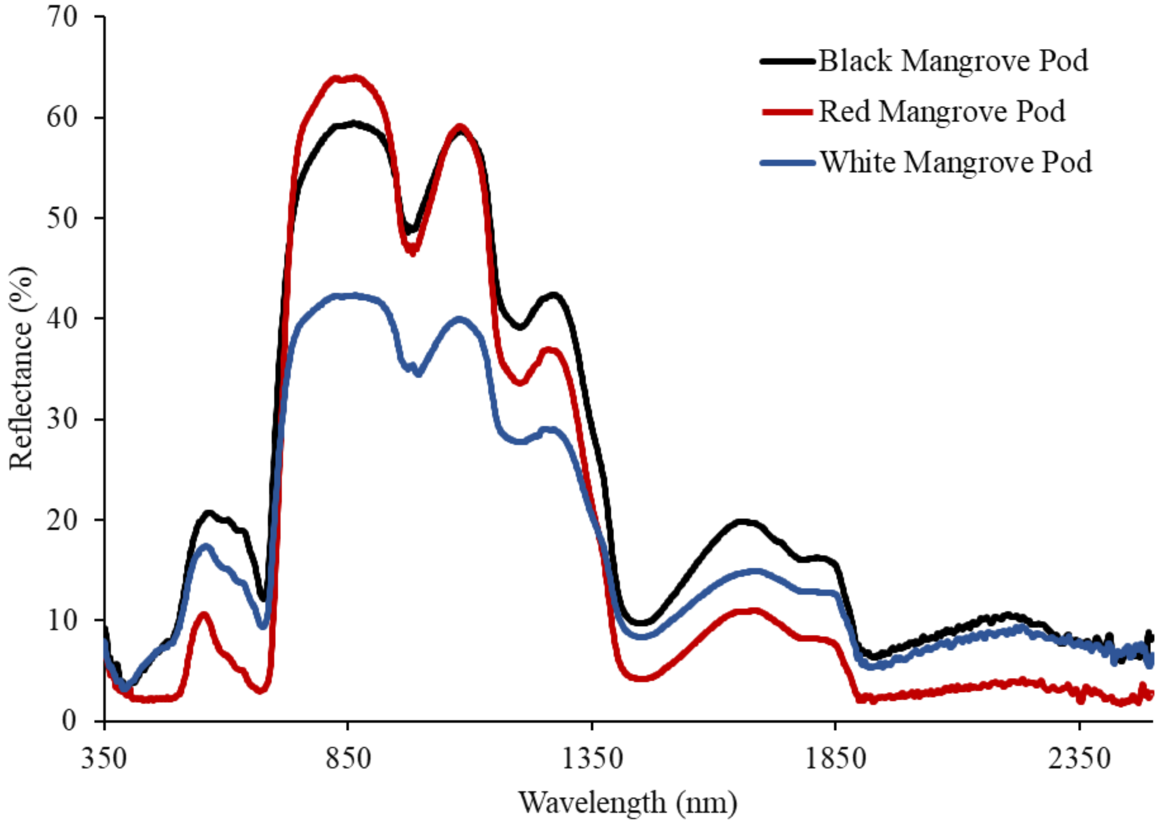

Figure 4: *Averaged (n = 3) reflectance spectra of the different mangrove pods.*

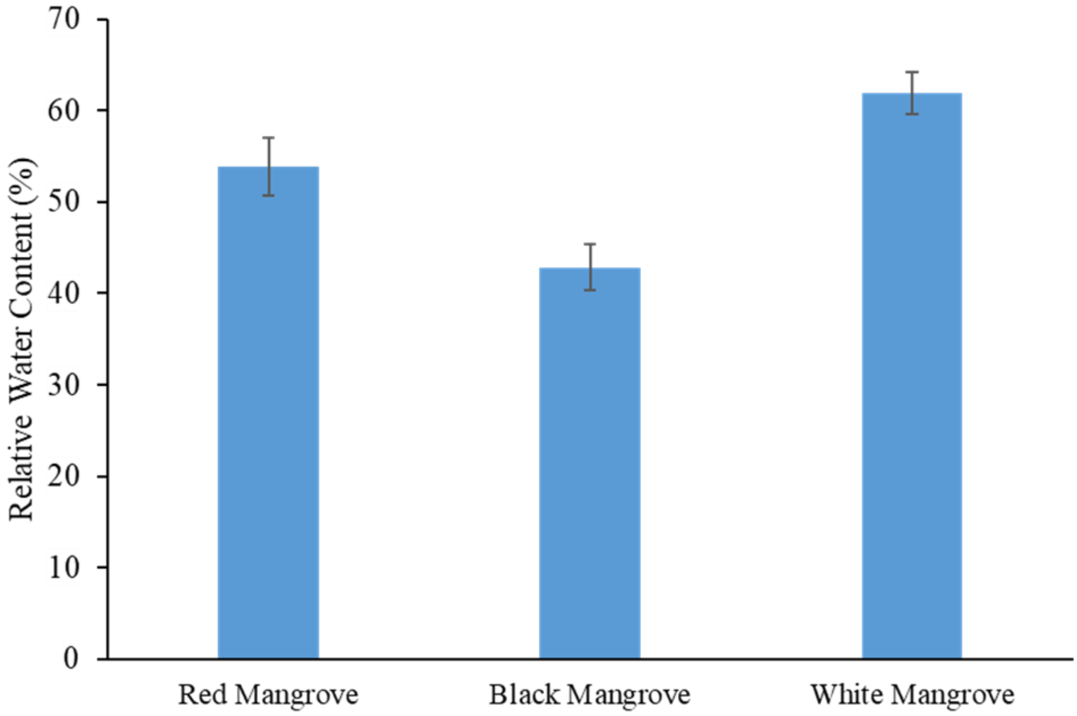

Figure 5: *Relative Water Content of the red, black, and white mangroves. Bars are ± standard error of three replicates.*

4. Conclusions

The results of our study show the potential of remote sensing to monitor and map the species level morphological and physiological differences among the white, black, and red mangrove species. Previous studies showed that the multispectral satellite sensors using single bands cannot be simply used for the specific mangrove species distribution mapping (Peng et al., 2018; Ajithkumar et al., 2008; Zulfa et al., 2020). However, the plant spectral reflectance differences in the various visible and NIR spectral regions can be explored to discriminate the selected mangrove species and can be used to classify and map them using hyperspectral imagery. Also, by finding the relationship between patterns of spectral reflectance and plant physiology, the multi-temporal satellite imagery and drone imagery with high spectral and spatial resolution can be used to determine the seasonal variation, plant adaptation and phenological changes in mangroves in response to ongoing environmental pollution and climate change.

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