

Mapping of *Rhizophora stylosa* in the Karimunjawa Mangrove Forest, Indonesia Using Spectral Reflectance Based on WorldView-2 Imagery

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Abstract

Information regarding the species types and distribution of mangroves is essential for prioritizing biodiversity conservation and effective forest management. Remotely sensed data has been demonstrated to be a valuable tool in differentiating between mangrove and non-mangrove features. Nevertheless, the application of this data for the identification and mapping of specific mangrove species poses challenges, particularly when relying on field-based spectral reflectance measurements. This study seeks to achieve three primary objectives: (i) to collect spectral reflectance data for *Rhizophora stylosa* (Griff.) from field measurements, (ii) to develop a spectral library specifically for *Rhizophora stylosa*, and (iii) to map the distribution of this target species using WorldView-2 (WV-2) imagery. The spectral library for the targeted species was compiled utilizing a JAZ EL-350 portable field spectrometer, which operates across a wavelength range of 350 nm to 1024 nm. To ensure compatibility between the spectral data collected in the field and the WV-2 imagery, a spectral resampling technique was employed to standardize the number of spectral bands. Subsequently, the spectral angle mapper (SAM) algorithm was applied to the WV-2 imagery, using the resampled spectral data for *Rhizophora stylosa* to facilitate the spatial mapping of this species. The results indicate that *Rhizophora stylosa* can be effectively identified and mapped at an overall accuracy of 80% using both the spectral reflectance data obtained from field measurements and the WV-2 imagery. This study provides significant evidence supporting the feasibility of utilizing remote sensing data for the species-level mapping of mangroves based on the spectral reflectance characteristics of the targeted objects. By enhancing our understanding of mangrove species distribution, this research contributes to more informed conservation and management strategies for these vital ecosystems.

Keywords: Mangroves, *Rhizophora stylosa*, Spectral reflectance, WorldView-2.

1. Introduction

Mapping and inventorying mangrove biodiversity is a critical step in supporting effective management and conservation actions in coastal environments. This process involves systematically documenting the variety and distribution of mangrove species, which is essential for understanding the ecological roles these ecosystems play [1]. Comprehensive biodiversity assessments enable the identification of key habitats that require protection and inform strategies for restoration and sustainable use [2]. Furthermore, accurate mapping can reveal the impacts of anthropogenic activities and climate change on mangrove health, thus guiding targeted interventions to mitigate these threats [3].

By providing a detailed baseline of mangrove biodiversity, such efforts not only enhance conservation outcomes but also contribute to the maintenance of ecosystem services that are vital for coastal communities [4]. Ultimately, integrating biodiversity mapping into coastal management frameworks is essential for promoting the resilience and sustainability of these critical ecosystems [5]. For over twenty years, researchers and stakeholders have employed remotely sensed data to map and monitor mangrove ecosystems, recognizing the unique advantages that satellite and aerial imagery offer in capturing the spatial dynamics of these critical environments.

Remote sensing technologies facilitate the collection of extensive and high-resolution data across large geographic areas, which is particularly valuable for assessing the distribution, extent, and health of mangrove forests [6]. These technologies allow for the detection of changes over time, enabling the identification of trends related to environmental degradation, climate change, and human impacts, which are crucial for effective management and conservation strategies [7]. Moreover, the integration of remote sensing with geographic information systems (GIS) enhances the analytical capabilities for understanding complex ecological patterns and relationships within mangrove habitats [8]. This methodological approach has not only improved our understanding of mangrove dynamics but also informed policy and decision-making processes aimed at preserving these vital coastal ecosystems [9].

Remote sensing data offer numerous advantages for mangrove research, significantly enhancing our ability to assess and monitor these vital ecosystems. First, remote sensing provides access to mangrove forests that are often difficult or impossible to reach due to their remote or inhospitable locations [10] and [11]. This accessibility allows researchers to gather information from areas that would otherwise be overlooked. Second, remote sensing facilitates a synoptic overview of the research area, enabling researchers to capture large-scale spatial patterns and dynamics across extensive geographic regions, along with the ability to obtain repeat coverage over time [12]. This temporal aspect is particularly valuable for tracking changes in mangrove extent and health in response to environmental pressures or anthropogenic activities. Third, the capacity to extrapolate from sample points to the entire image scene enhances the representativeness of findings, allowing for comprehensive assessments of mangrove distributions and conditions based on limited ground data [7] and [13].

This feature is essential for creating accurate models of mangrove ecosystems. Fourth, remote sensing supports multi-scale observation, which is crucial for understanding ecological processes that occur at different spatial and temporal scales [14]. By integrating data from various sources, researchers can analyze both broad patterns and fine-scale variations within mangrove habitats. Finally, remote sensing enables the correlation of spectral responses from ground objects with corresponding pixel values in imagery. This relationship is vital for interpreting and analyzing the condition and composition of mangrove ecosystems based on their reflectance characteristics [7]. Collectively, these advantages

position remote sensing as an indispensable tool in mangrove research, providing insights that inform conservation and management strategies.

In theory, mangrove species spectral reflectance characteristics provide the key to recognizing the feature from satellite images through its reflectance values. Every mangrove species has a unique spectral reflectance signature that distinguishes one species from the others and potentially can be discriminated from remotely sensed images [15] and [16]. In particular, the most significant difference can be found in the near-infrared (NIR; 700 - 1200 nm) and shortwave infrared (SWIR; from 1200 - 2500 nm) wavelength regions [7]. Spectral reflectance of the mangrove species can be directly compared to the image pixels spectral reflectance pattern. When a similar spectral reflectance pattern is found from both, it means that the image pixel refers to the sampled object. A previous study shows that this approach works for spectral reflectance collected in the laboratory [16], but remains a challenge when it is collected in the field. It is mainly due to the background reflectance effects from mangrove soil substrate, which is frequently inundated by tidal water and due to the forest floor organic detritus [17].

Mangrove ecosystems are located in intertidal areas between 30° north and 30° south and found in 124 countries [18]. In total, there are 73 mangrove species throughout the world and inhabiting a total estimated area of 137,760 km² [8]. The world mangrove distribution indicates a tropical dominance with major latitudinal limits relating to major ocean currents and the 20°C seawater isotherm in winter. The extent of mangrove forests throughout the world was calculated using Landsat archives [8]. They found out that the most considerable area of mangroves is in Asia (42%), followed by Africa, North and Central America, Oceania, and South America for 20%, 15%, 12%, and 11%, respectively. From that figure, Indonesia has 31,129.89 km² of mangrove forests, meaning it contributes to 22.6 % of the entire extent of the world mangrove forest. Indonesia also has the richest mangrove species in the world. Of the 73 species of the world mangroves, 61 are found in the Indo-West Pacific (IWP) area [5], and within the IWP, at least 38 true mangrove species are found in Indonesia alone [19].

The problem mentioned above corroborates the need to systematically conduct research focusing on how to appropriately collect spectral reflectance of an object of interest in the field and map the selected object spatial extent from a remotely sensed image. Reference studies in discriminating mangrove species using field spectral reflectance are scarce, especially in Indonesia.

Therefore, this paper is designed as a preliminary study to fill this gap, which was aimed to (i) collect spectral reflectance of *Rhizophora stylosa* (Griff.) from the field, (ii) develop *Rhizophora stylosa* spectral library, and (iii) map the distribution of the feature based on WorldView-2 image. To ensure that this study focuses on exploring the potential and capabilities of image-based spectral approaches for species identification, the research is limited to the mangrove species *Rhizophora stylosa*. This species was selected for several reasons: it is abundant in the study area [20], it predominantly located in the water-fringe zone of the mangrove, which is easily accessible, it has clear physical characteristics that make it easily identifiable, and this species has a high survival rate and is easy to grow [21] which makes it frequently used for mangrove planting in rehabilitation programs in Indonesia.

2. Materials and Methods

2.1 Study Site

The study site is situated within the mangrove forest of Karimunjawa Island National Park, located in Jepara, Central Java, Indonesia. Geographically, the park is positioned between latitudes 4°47'48" to 5°50'12" south and longitudes 110°24'10" to 110°30'10" east, as illustrated in Figure 1. The region experiences a maritime wet-tropical climate characterized by an average temperature ranging from 26 °C to 30 °C and relative humidity levels between 70% and 85%. The average annual rainfall in this area is approximately 2632 mm. Notably, the rainfall patterns vary significantly between the dry

and wet seasons; from April to September, the average monthly rainfall is around 60 mm, while from October to March, during the wet season, the average increases substantially to approximately 400 mm. Karimunjawa Islands host a diverse array of habitats, including rainforest, coastal forests, mangroves, seagrass beds, algal formations, and coral reefs. Specifically, the mangrove formations along the coastline of Karimunjawa Islands serve a crucial ecological role by providing protection to coastal areas against the impacts of sea waves and wind. This unique coastal ecosystem not only supports biodiversity but also plays a significant part in the conservation of coastal landscapes. Understanding the ecological dynamics within this region is vital for the effective management and preservation of its diverse habitats.

The most extensive mangrove coverage within Karimunjawa Island is found on the western portions of Karimun and Kemujan Islands. A total of 45 mangrove species have been identified in this region [20]. Among these, 27 species are classified as true mangroves, while 18 are recognized as mangrove associates, with *Rhizophora stylosa* being the most dominant species in terms of abundance and ecological significance. Field observations have revealed three distinct structural formations of mangroves, each corresponding to different ecological zones from land to sea. The landward formation is characterized by low, multi-stemmed stands primarily consisting of *Lumnitzera racemosa* and *Ceriops tagal*.

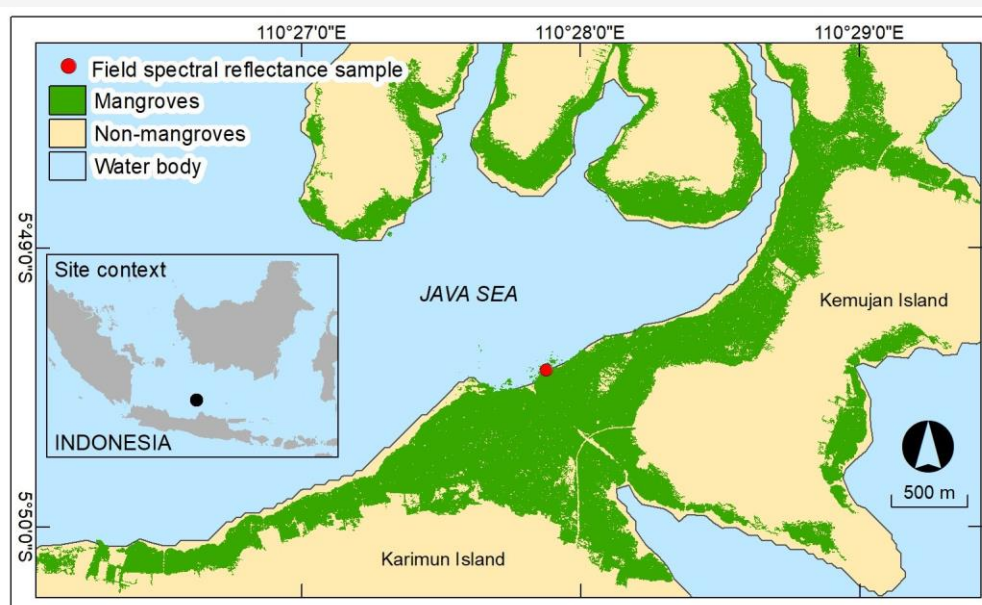


Figure 1: Mangrove forest at Karimunjawa Island, Central Java, Indonesia

This zone serves as a transitional area between terrestrial and aquatic environments, providing critical habitat for various fauna. The middle formation exhibits a more complex structure, dominated by both single and multi-trunk trees, which include a diverse mix of species such as *Lumnitzera sp.*, *Ceriops tagal*, *Bruguiera gymnorrhiza*, and various *Rhizophora* species. This layer plays a vital role in nutrient cycling and offers additional habitat complexity, fostering a rich biodiversity. Finally, the seaward formation is characterized by a multi-trunked forest primarily composed of *Rhizophora mucronata*, *Rhizophora stylosa*, and several individuals of *Xylocarpus granatum*, alongside *Bruguiera gymnorrhiza*. This outermost zone is critical for coastal protection, mitigating wave energy and preventing shoreline erosion. Collectively, these structural formations illustrate the ecological diversity and functional importance of mangroves in Karimunjawa Island, underscoring the need for ongoing conservation efforts in this unique habitat.

2.2 Remotely-Sensed Image Data

The remotely sensed image data employed in this study was obtained from the WorldView-2 (WV-2) satellite, with the imagery collected on May 24, 2012. This satellite imagery encompasses eight multispectral bands, each with a pixel resolution of 2 meters, specifically including the coastal blue, blue, green, yellow, red, red edge, near-infrared 1 (NIR1), and near-infrared 2 (NIR2) bands (Table 1). Additionally, the dataset features a panchromatic band that provides a higher spatial resolution of 0.5 meters [21]. For the purposes of this research, all eight multispectral bands were utilized to construct endmembers corresponding to the targeted species, *Rhizophora stylosa*. By integrating these diverse spectral bands, the study aims to capture a comprehensive representation of the spectral characteristics associated with the mangrove species in question. This approach enhances the accuracy of species identification and mapping, facilitating a

more detailed analysis of mangrove distribution and health within the study area. The high-resolution capabilities of the WV-2 imagery, combined with its multispectral data, provide a robust framework for assessing mangrove ecosystems and their complexities, thus contributing valuable insights for conservation and management efforts.

We conducted a comprehensive geometric correction using local reference points, followed by radiometric and atmospheric corrections to achieve surface reflectance levels prior to further data processing. For the radiometric correction, we converted the pixel values, expressed as digital numbers (DN), to top-of-atmosphere (ToA) spectral radiance measured in watts per square centimeter per steradian per nanometer ($W/cm^2sr.nm$) utilizing ENVI 5.2 software. This conversion process adhered to the image correction coefficients and procedures outlined for the WorldView-2 (WV-2) and WorldView-3 (WV-3) satellites [22]. Subsequent to the radiometric correction, we performed atmospheric correction to convert the ToA pixel values into surface spectral reflectance values. For this purpose, we employed the Fast Line-of-sight Atmospheric Analysis of Hypercubes (FLAASH) correction model, which is recognized for its efficacy in atmospheric correction of hyperspectral imagery. This model accounts for various atmospheric conditions, such as aerosol presence and water vapor, thereby improving the accuracy of reflectance measurements. The application of these correction techniques is critical for enhancing the quality and reliability of the remotely sensed data, enabling more accurate analyses of the target mangrove species and their distributions.

2.3 *Rhizophora Stylosa* (Griff.) Characteristics

Rhizophora stylosa is a true mangrove species that dominates the mangrove forests of the Karimunjawa Islands. In terms of its formation, this species is generally located at the forefront of the mangrove forest, facing the sea.

Table 1: WorldView-2 image spectral characteristics [21]

Imagery mode	Spectral range (nm)	Spectral band name
Multispectral (MS)	400-450	coastal blue
	450-510	blue
	510-580	green
	585-625	yellow
	630-690	red
	705-745	red edge
	770-895	NIR1
	860-1040	NIR2
Panchromatic (P)	450-800	

Its trunk can have one or multiple stems, reaching heights of up to 10 meters. The bark is smooth, fissured, and ranges in color from gray to black [20]. This species possesses prop or stilt roots that can extend up to 3 meters in length, along with aerial roots that emerge from the lower branches. These prop roots allow the species to survive in waterlogged areas. *Rhizophora stylosa* is characterized by elliptical leaves with pointed tips and black spots on the underside (Figure 2). It has flowers with white petals and greenish-yellow sepals. The fruit is cylindrical in shape, with slightly rough green spots, and the cotyledon neck turns yellowish-green as it matures [21]. *Rhizophora stylosa* species grows in a variety of habitats in tidal zones, including mud, sand, and rocks. It prefers tidal riverbanks but also serves as a pioneer species in coastal environments or on the landward side of mangrove forests. One distinct niche it occupies is the mangrove edge on islands or coral substrates. Its distribution in Indonesia is recorded in Java, Bali, Lombok, Sumatera, Sulawesi, Sumba, Sumbawa, Maluku, and Papua.

2.4 Field Spectral Reflectance Collection

Field samples were collected purposefully, guided by the known locations of *Rhizophora stylosa* and the accessibility of the targeted sites. To gather spectral reflectance data from this mangrove species, we employed a portable JAZ EL-350 field spectrometer manufactured by Ocean Optics (www.oceanoptics.com). This spectrometer is capable of measuring wavelengths ranging from 350 nm to 1024 nm, with a spectral resolution of 1 nm, and features a sensor field of view of 14.25°. Spectral reflectance samples were collected from individual leaves at a distance of 2 cm to minimize interference from surrounding

features and enhance the accuracy of the measurements [23]. To optimize the quality of the data collected, the spectrometer sensor was positioned facing away from the incoming sunlight, ensuring that the readings were influenced predominantly by the leaf's reflectance rather than ambient light conditions. To establish a robust spectral library, we conducted ten repeated measurements of the spectral reflectance from each *Rhizophora stylosa* leaf sample. This approach not only enhances the reliability of the spectral data but also aids in the creation of a comprehensive endmember spectrum, which is essential for subsequent analyses of the species distribution and ecological characteristics within the mangrove ecosystem. By systematically collecting and processing this data, we aim to contribute to a more nuanced understanding of the spectral properties associated with *Rhizophora stylosa* and its role in the coastal environment. The overall research flowchart is presented in Figure 3, and a detailed explanation of the procedures is provided in the following sections.

2.5 Spectral Angle Mapper for Mapping the Targeted Mangrove Species

The spectral library developed in the previous step served as a crucial reference for mapping the spatial distribution of *Rhizophora stylosa* using the WorldView-2 (WV-2) imagery. To accomplish this, we employed the spectral angle mapper (SAM) technique, a method that effectively quantifies the similarity between spectral reflectances by calculating the "spectral angle" between them. This technique treats spectral reflectances as vectors in a multi-dimensional space, where the dimensionality corresponds to the number of spectral bands utilized [24].



Figure 2: The physical characteristics of *Rhizophora stylosa* collected from the field, include: (a) prop or stilt roots and tree stands, (b) elliptical leaves with pointed tips, and (c) flower buds

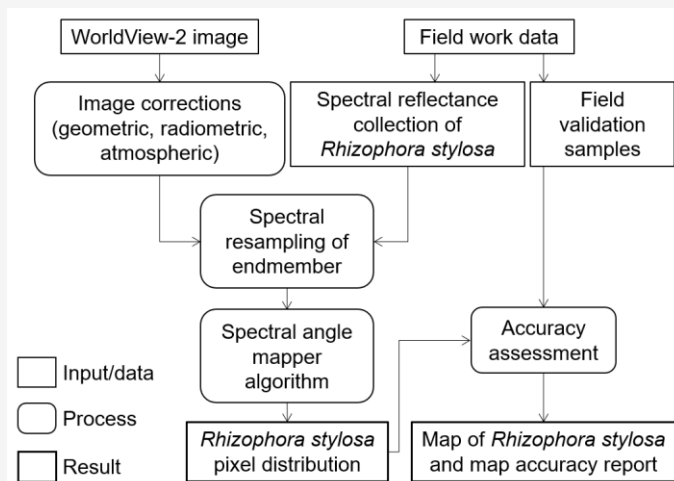


Figure 3: *Rhizophora stylosa* mapping workflow

The spectral angle is a critical metric; its magnitude indicates the degree of similarity between the unknown spectrum of the target object and the reference spectrum from the spectral library. Specifically, a smaller spectral angle signifies a closer match to the reference material [25], thereby enhancing the accuracy of mangrove species identification. Prior to applying the spectral library or endmember to the input image, we need to perform the spectral resampling process. Spectral resampling aims to resample spectral data files collected by the field spectrometer to match the wavelengths of a specific image input file [26]; in this case the WorldView-2 image. The result of this process is a field spectral library with equal spacing between the image bands. The SAM decision process is illustrated in Figure 4.

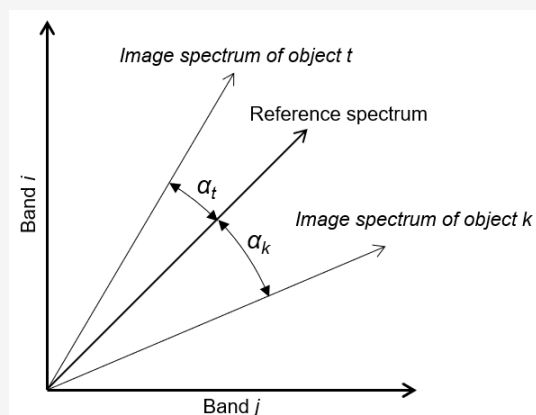


Figure 4: Object t has smaller angle (α in radians) to the reference spectrum than object k , meaning the object t is more similar to the reference spectrum (modified from [27])

The spectral angle is the angle between any two vectors originating from a common origin (the 0-band axis value). The magnitude of the angle specifies the degree of similarity between the material and the reference; a smaller angle corresponds to a more similar spectral signature, or one that is closer to the reference material [25] and [26]. The image spectrum is then assigned a correlation factor between 0 (low correlation) and 1 (high correlation) relative to the spectral library or endmembers. This attribute makes SAM particularly valuable in remote sensing applications, as it allows for the differentiation of spectral signatures even in complex ecological landscapes. However, because SAM uses only the 'direction' of the spectra and not their 'length', this method is insensitive to the unknown gain factor, and all possible illuminations of the same target are treated equally. The SAM algorithm computes the similarity of an unknown spectrum t to a reference spectrum r using the following equation, where n equals the number of bands in the image [26]. A small spectral angle or coincidence between an unknown pixel and a specific feature class indicates the likelihood that the unknown pixel will be assigned to that feature class [27] and [28]. Therefore, smaller angle values indicate higher similarity between the pixel and the endmember. The smaller the angle, the darker the features appear in the SAM rule images. The number of derived SAM images is equal to the number of endmember spectra used in the mapping. The SAM equation is presented in Equation 1:

$$\alpha = \cos^{-1} \left(\frac{\sum_{i=1}^n t_i r_i}{\sqrt{\sum_{i=1}^n t_i^2} \cdot \sqrt{\sum_{i=1}^n r_i^2}} \right)$$

Equation 1

Where:

α = the angle between the reference spectrum and the image pixel measurement vector

r = the reference spectrum

t = the image pixel measurement vector in n -dimensions

n = the number of bands in the image

This mathematical framework enables a systematic comparison of spectral data, thereby facilitating the effective mapping of *Rhizophora stylosa* across the study area. Any coincidence or small spectral angle between the unknown pixel and the reference spectrum indicates that the unknown pixel likelihood would be assigned as the reference class. Therefore, smaller angle values suggest a higher similarity between pixels and the reference spectrum. In this case, the SAM algorithm was used to discriminate a single *Rhizophora stylosa* species class within the study site. By utilizing this rigorous approach, we aim to contribute to the understanding of mangrove ecosystems and enhance management strategies aimed at conserving these vital coastal resources. The results of mapping the *Rhizophora stylosa* objects using the SAM algorithm were then evaluated for accuracy using a binary accuracy assessment technique based on the confusion matrix. This accuracy assessment involved only two classes: *Rhizophora stylosa* (as true positive) and non-*Rhizophora stylosa* (as true negative). Through this accuracy assessment, the effectiveness of applying the SAM algorithm to WorldView-2 imagery for mapping *Rhizophora stylosa* objects in the study area can be assessed. Several accuracy assessment statistics were also calculated, including: producer's accuracy (PA) or sensitivity, user's accuracy (UA) or precision, and overall accuracy (OA).

3. Results and Discussion

3.1 Spectral Library Development

The spectral reflectance measurements were conducted at a distance of 2 cm from the targeted leaf sample of *Rhizophora stylosa* (Figure 5(a)). To establish a robust field spectral library, ten repeated spectral reflectance readings were averaged, resulting in a comprehensive dataset that serves as a reference for identifying similar spectral reflectance patterns in each pixel of the imagery (Figure 5(b)). The results of these measurements exhibit a typical response characteristic of healthy green vegetation. Specifically, the spectral reflectance profile demonstrates pronounced absorption features in the blue region (400 - 500 nm) and the red region (600 - 670 nm) of the electromagnetic spectrum, alongside reflectance in the green region (500 - 600 nm). Notably, there is a significant increase in reflectance at the red-edge (680 - 730 nm) and an exceptionally high reflectance in the near-infrared range (730 - 900 nm). The absorption features in the blue and red regions are primarily attributed to the photosynthetic activity of healthy vegetation, which absorbs light to drive photosynthesis [26] and [27]. Conversely, the high reflectance observed in the near-infrared region is indicative of light reflection from the leaf mesophyll tissue, a characteristic commonly associated with vigorous, healthy plant foliage. The spectral reflectance shown in Figure 5(b) is unique to *Rhizophora stylosa* (or Rhizophoraceae) mangroves. Previous studies have reported that each mangrove species has its own spectral reflectance characteristics that distinguish it from others, including *Rhizophora stylosa* [28] and [29]. However, it is important to note that the spectral reflectance curve reveals noise at wavelengths exceeding 900 nm.

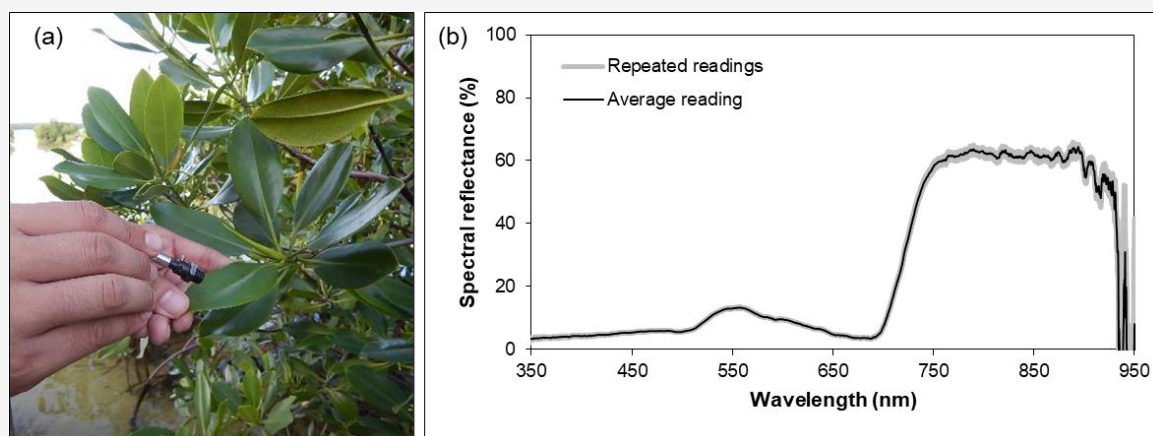


Figure 5: Spectral reflectance collection;

(a) spectral reflectance field measurement and (b) spectral reflectance of *Rhizophora stylosa*

This noise is likely due to the field spectrometer's detector, which is composed of silica and exhibits sensitivity within this wavelength range. Such noise can interfere with the accuracy of reflectance measurements and may necessitate careful calibration and post-processing to mitigate its effects. Overall, this analysis highlights the importance of precise spectral measurements in constructing a reliable spectral library for effective remote sensing applications.

3.2 Image Endmember Derivation

A well-defined set of endmembers is essential for capturing the spectral variability present across all pixels in a remote sensing image, producing unique and scientifically relevant results [25] and [28]. The endmembers are pure spectral signatures that represent the reflectance characteristics of pixels belonging to a single surface material. The endmembers are collected from pure pixels (i.e., pixels that contain only a single object) in a remote sensing image, typically from hyperspectral images [30]. An endmember represents a distinct ground material and its reflectance spectrum, referred to as the endmember spectrum. The selection of class members is a crucial initial step in the image classification process, as it establishes the thematic content derived from the imagery and directly influences the accuracy of the resulting maps. The preliminary phase in developing these class members involves the identification of 'endmembers', which are defined as unique ground materials characterized by their specific reflectance spectra, known as endmember spectra. This identification process is vital, as it encapsulates the spectral signatures associated with the properties of various features within the study area.

Endmembers can be obtained through multiple methods, including laboratory analyses, direct field measurements, or extraction from existing images of known ground objects [25] and [31]. In this study, the

endmember spectra were derived from the field spectral library established in the previous step. This library provides a reliable reference for the spectral characteristics of *Rhizophora stylosa*, ensuring that the classification process is grounded in empirical data. By utilizing a robust set of endmembers, the study enhances the precision of the classification scheme, allowing for more accurate mapping of mangrove distributions and improving our understanding of the ecological dynamics within these critical coastal ecosystems.

All multispectral bands of the WorldView-2 (WV-2) image were utilized as the foundational dataset for mapping the distribution of *Rhizophora stylosa*. In order to integrate the spectral reflectance data collected with the JAZ-350 field spectrometer, which operates at a 1 nm spectral resolution, it was necessary to resample this data to align with the eight broader bands of the WV-2. To achieve this resampling, we employed the spectral resampling function available in ENVI 5.2 software, which facilitates the adjustment of spectral data according to the center wavelengths of the WV-2 multispectral bands (Figure 6). This process is crucial for ensuring compatibility between the high-resolution field data and the lower-resolution satellite imagery, allowing for a more accurate analysis of the target species.

As depicted in Figure 6(a), the spectral reflectance pattern of the endmembers aligns closely with that shown in Figure 6(b), indicating that the fundamental spectral characteristics of *Rhizophora stylosa* are preserved despite the reduction in spectral resolution inherent to the eight bands of the WV-2. This alignment underscores the effectiveness of the resampling technique in maintaining the integrity of the spectral information, which is essential for precise classification and mapping of mangrove distributions within the study area. By harmonizing these datasets, we enhance the potential for robust analyses of mangrove ecosystems and their ecological dynamics.

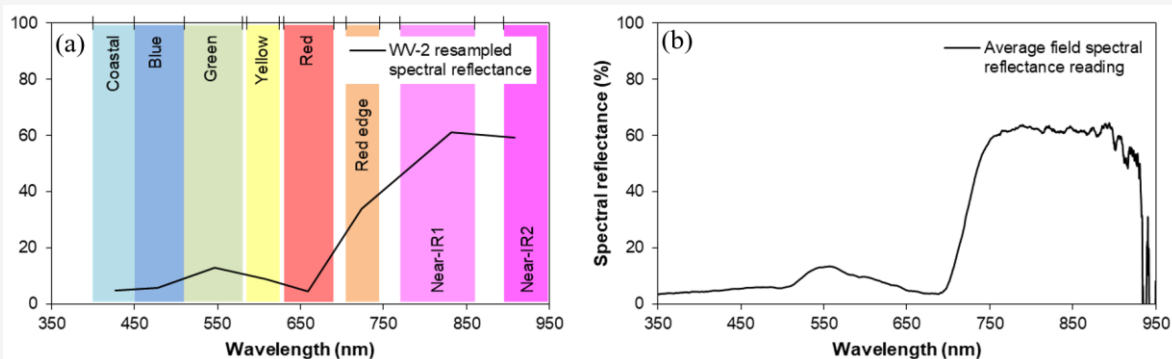


Figure 6: Endmember derivation; (a) the WV-2 resampled spectral reflectance, overlaid on WV-2 bands wavelength and (b) original spectral library of *Rhizophora stylosa*

3.3 Spatial Distribution of *Rhizophora stylosa*

The derived endmember spectra (Figure 6(b)) were subsequently utilized within the spectral angle mapper (SAM) algorithm to identify pixels corresponding to *Rhizophora stylosa* throughout the satellite image. Through several trials, we determined that a spectral angle threshold of 0.055 radians was optimal for effectively mapping the targeted species. This threshold facilitates the differentiation of *Rhizophora stylosa* from other spectral signatures present in the image. Figure 7 presents a subset of the spatial distribution of *Rhizophora stylosa* within the study area. Notably, dense populations of this species were observed along the sea-fringe on the western edge of the mangrove forest, where tree heights can reach up to 15 meters and canopy density exceeds 80%.

These findings align with the habitat characteristics outlined by [20], which indicate that *Rhizophora stylosa* predominantly inhabits areas near the coastal waterfront of mangrove forests. The dispersal mechanism of this species involves tidal action, which transports its seeds to the mangrove forest margins, facilitating germination and growth in these coastal environments. The identification of dense *Rhizophora stylosa* populations not only contributes to our understanding of mangrove ecology but also underscores the importance of these ecosystems in coastal protection and biodiversity. By accurately mapping the distribution of *Rhizophora stylosa*, this study provides essential insights for

conservation strategies and effective management of mangrove habitats. Toward the landward areas, *Rhizophora stylosa* exhibits a patchy growth pattern that is interspersed with other mangrove species, including *Rhizophora apiculata* (Blume), *Ceriops tagal* [(Pers.) C.B.Rob], *Lumnitzera racemosa* (Willd.), and *Bruguiera gymnorrhiza* [(L.) Lam]. The mangrove forest of Karimunjawa is recognized as one of Indonesia's most mature mangrove ecosystems [20] and [28], characterized by a highly mixed vegetation structure throughout the area. This complexity in the vegetation composition often obscures the clear distinction between individual species and their respective structural zonations.

Despite this inherent complexity, the application of the spectral angle mapper (SAM) algorithm effectively identified the distribution of *Rhizophora stylosa* within the study site. The classification results revealed a high degree of concordance with field verification data, confirming the accuracy of the algorithm in detecting the spatial extent of this species. The successful identification of *Rhizophora stylosa* amidst a diverse assemblage of mangrove species highlights the potential of remote sensing techniques to provide valuable insights into the dynamics of mangrove ecosystems, even when species boundaries are not distinctly defined. This capability is crucial for informing conservation efforts and sustainable management practices in these vital coastal habitats.

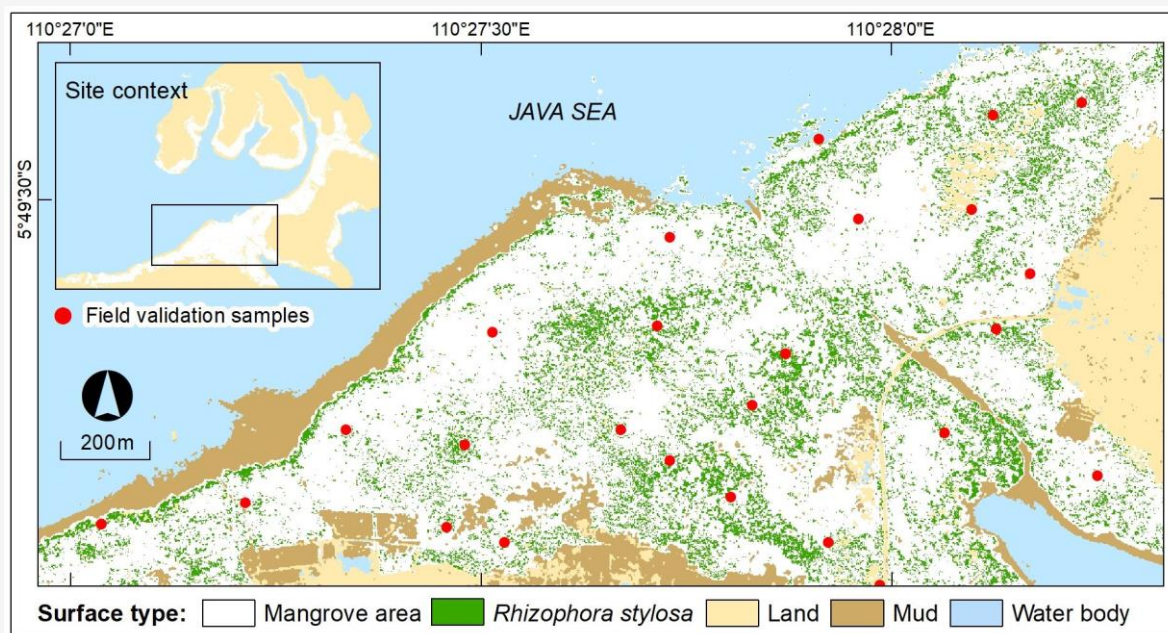


Figure 7: Spatial distribution of *Rhizophora stylosa* resulted from WorldView-2 image analysis

Table 2: The accuracy assessment matrix

Classification	Field Data		User's Accuracy (%)
	<i>Rhizophora stylosa</i>	Non- <i>Rhizophora stylosa</i>	
<i>Rhizophora stylosa</i>	21	3	87.50
Non- <i>Rhizophora stylosa</i>	5	11	68.75
Producer's accuracy (%)	80.76	78.57	OA = 80.00

3.4 Accuracy Assessment of the Map Result

To quantitatively assess the accuracy of the resulting distribution map of *Rhizophora stylosa*, we compared the mapped locations (Figure 7) with the field data previously collected in the study area in 2012, 2018, and 2021. From our observations, there has been no significant change in the mangrove vegetation structure and species distribution over the years in the study site. It is also confirmed by the Karimunjawa National Park Authority that the mangroves at the study site are well-preserved and have slow growth. A total of 40 independent field samples of *Rhizophora stylosa* were utilized for this accuracy assessment. We conducted a classification accuracy assessment technique based on confusion matrix concept [32]. In this case we applied it for binary classification where there are only two classes [33], *Rhizophora stylosa* and non-*Rhizophora stylosa* classes. It means that when a mapped category corresponded to the field data, it was classified as correctly identified. The overall mapping accuracy was calculated as the ratio of correctly classified sample points to the total number of sample points, expressed as a percentage (Table 2).

From our calculations, 21 of the validation samples were correctly classified as *Rhizophora stylosa* (i.e. true positive), and 11 correctly classified as non-*Rhizophora stylosa* (i.e. true negative), resulting in an overall mapping accuracy (OA) of 80%. The producer's accuracy (PA) reflects the omission error (or sensitivity) or the probability that a reference object is correctly classified, whereas the user's accuracy (UA) or commission error (or precision) indicates the probability that an object classified on the map actually represents that category on the ground [32]. For instance, for the detection of *Rhizophora stylosa* class using the WV-2 image, 80.76% of the *Rhizophora stylosa* objects were correctly classified as *Rhizophora stylosa* class, and 87.50% of the objects called *Rhizophora stylosa*. This step is crucial for maintaining the integrity of the spectral signatures and enhancing the reliability of the classification results. Third, the spectral library developed from field measurements successfully detected the distribution of *Rhizophora stylosa*, demonstrating the potential of this methodology for identifying specific mangrove species.

on the map were actually *Rhizophora stylosa* on the ground. The 20% of mapping inaccuracy can be attributed to two primary factors. First, the high species diversity and mixture within the mangrove ecosystem complicate the differentiation of *Rhizophora stylosa* from other mangrove species. The overlapping spectral signatures of coexisting species can lead to misclassifications, a challenge noted in previous studies on mixed-species mangrove environments. Second, the discrepancy in observational scales between the field spectrometer measurements and the spatial resolution of the WV-2 image, which is 2 meters, may further contribute to classification inaccuracies. The spectrometer captures data at a close-range level, focusing on the leaf structure of *Rhizophora stylosa*, while the WV-2 imagery provides a broader canopy-level perspective. This difference in scale can obscure finer details necessary for accurate species identification. Collectively, these factors underscore the challenges inherent in remote sensing applications within heterogeneous ecosystems and highlight the need for improved methodologies to enhance classification accuracy in mangrove mapping efforts.

4. Conclusions

This study utilized a spectral library of *Rhizophora stylosa*, collected from the field, to effectively map the distribution of this species using the WorldView-2 (WV-2) imagery and the spectral angle mapper (SAM) algorithm. Several important lessons emerged from this research. First, it is critical to ensure that field spectral reflectance measurements of the targeted object are conducted with precision, particularly concerning the measurement distance and angle, as these factors can significantly influence the accuracy of the spectral data collected. Second, it is essential to resample the spectral library to align with the spectral resolution of the WV-2 imagery before applying the mapping algorithm.

The accuracy assessment show that this study result in 80% overall accuracy of the mapping results, which demonstrate the potential of the approach in mapping mangrove species. The 20% error highlights the challenges associated with species differentiation in mixed mangrove ecosystems.

Future research will focus on expanding this approach to map multiple targeted species simultaneously. Additionally, investigations will be conducted to examine the influence of varying spectral reflectance measurement distances on the overall accuracy of the produced maps. This will provide valuable insights into optimizing remote sensing techniques for more effective mangrove ecosystem management and conservation efforts.

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