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RESEARCH ARTICLE

Remote Sensing

Estimating plant dominance using field-measured structural parameters and remotely sensed data; A case study from Rekawa mangrove forest, southern coast of Sri Lanka

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Abstract: The conventional method of determining plant dominance using the basal area is challenging for inaccessible ecosystems. Thus, the present study aimed to develop a new method to determine plant dominance in such inaccessible ecosystems using a remote sensing (RS) method. The target ecosystem of the study was the Rekawa mangrove forest. In this study, plant dominance was determined using both conventional and RS-based methods for two selected vegetation types in the Rekawa mangrove forest, *i.e.*, monospecific and mixed vegetation stands. Google Earth (GE) satellite images and drone images were used to digitize the crown area using on-screen digitization technique in ArcMap v.10.3. Finally, plant dominance values, determined through the three methods (conventional method, using GE satellite images, and using drone images) were compared in terms of their percentage deviation calculated with reference to the conventional method. This study reveals that there is a weak positive correlation ($P < 0.05$, $r = 0.132$) between basal area and individual tree crown area in a mangrove forest. Moreover, for both mangrove vegetation types, the drone imagery method has shown the least average percentage deviation in determination of plant dominance, compared to that of the GE satellite imagery method. For instance, the drone imagery method could be used with 100% and 86.02% average accuracies respectively for monospecific and mixed mangrove vegetation, whereas the GE satellite imagery method could be used with 97.85% and 42.15% average accuracies, respectively for monospecific and mixed mangrove vegetation**.** Therefore, this RS-based method could be used as an alternative method to the conventional basal area-based method of determining plant dominance in dense mangrove forests.

Keywords: Crown area, drone imagery, Google Earth satellite imagery, plant dominance, Rekawa mangrove forest, remote sensing.

INTRODUCTION

Plant dominance refers to the relative importance of a plant species in terms of the degree of influence it exerts on other plants and animals of the community (Pau & Dee, 2016). It delineates stronger links to ecological research, as it reflects the context of an ecological community. According to Pau & Dee (2016), tracking dominance facilitates early warning signs of ecosystem changes due to climate change impacts or any other impact on the ecosystem. Conventionally, plant dominance is determined by a field-based method using plant basal area. Here, the circumference at the tree base is measured by conducting a field survey. Field work becomes challenging in an inaccessible ecosystem such as a dense forest, mangrove forest, or swamp, due to certain limitations such as inundation, boggy substrate, thick cover, intensive labour and time-consuming procedures. Particularly, the harsh environment in mangrove ecosystems makes the field measurements more challenging (Wanga *et al*., 2019), especially in the middle and water edges of mangrove forests. Hence it is necessary to develop a new method that can readily be used in determination of plant dominance in such inaccessible

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areas. Remote sensing (RS) methods are being widely used nowadays by the ecologists and field researchers for finding new ways to approach their research (Kerr & Ostrovsky, 2003). Therefore, the aim of this study is to develop a new method to determine plant dominance in such inaccessible ecosystems using a more feasible RS method. In this case, an RS-based approach could be a good solution to overcome the above-mentioned limitations faced in accessing and taking measurements in the mangrove ecosystems.

Even though, plenty of studies have addressed different types of biodiversity measures (Purvis & Hector, 2000; Hillebrand *et al*., 2008) using RS, RS-based studies focused on plant dominance still remains as a gap (Pau & Dee, 2016). Therefore, this study attempts to fill the knowledge gap on the determination of plant dominance, using RS-based methods with the use of a mangrove forest as a model ecosystem, where accessibility is challenging.

According to previous studies, much of the literature related to biodiversity has focused on species richness but literature on plant dominance is lacking (Purvis & Hector, 2000; Hillebrand *et al*., 2008). According to the literature, many RS studies have been conducted to detect species richness (Warren *et al*., 2014; Pau & Dee, 2016) and species distributions (Pau *et al*., 2013; He *et al*., 2015). Moreover, different RS approaches have been practiced by researchers, including satellite and aerial RS (Nagendra, 2001; Turner *et al*., 2003; Gillespie *et al*., 2008) in order to track the biodiversity and ecosystem functions. Although there is limited scientific attention on RS studies focused on plant dominance, Pau & Dee (2016) have shown that there are some studies that address shifts in dominant vegetation (Schroeder *et al*., 2010) and species invasions (Schroeder *et al*., 2010).

When mangrove ecosystems are taken into consideration, RS techniques have been applied in different studies in order to study various aspects including measuring their spatial extent (Long & Skewes, 1996; Conchedda *et al*., 2008; Nandy & Kushwaha, 2011; Purnamasayangsukasih *et al*., 2016) and vegetation dynamics (Madarasinghe *et al.,* 2020a; 2020b). However, no literature is available on using RS methods to estimate the plant dominance in mangrove ecosystems and therefore this study will offer a novel approach for scientists and researchers in the field of Ecology when conducting research in such inaccessible mangrove ecosystems.

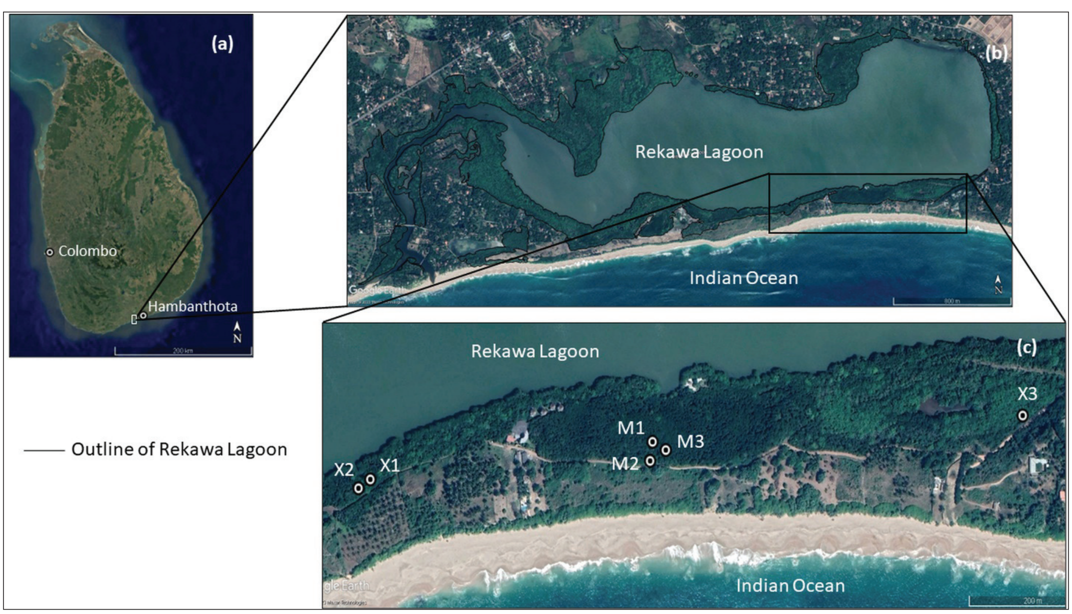

Figure 1: (a) Map of Sri Lanka showing the location of the study area indicated by a white square; (b) Map of Rekawa lagoon showing the study area indicated by a black square; (c) Google Earth (GE) satellite image (Maxar Technologies on 22.01.2022) of the study area showing mono-specific vegetation plots (M1: Mono-specific vegetation plot No.1, M2: Mono-specific vegetation plot No.2, M3: Mono-specific vegetation plot No.3) and mixed mangrove vegetation plots (X1: Mixed vegetation plot No.1, X2: Mixed vegetation plot No.2, X3: Mixed vegetation plot No.3)

MATERIALS AND METHODS

Study site

Since mangrove forests are among the most productive ecosystems with high biodiversity and significant degree of inaccessibility, a mangrove forest was selected as the target ecosystem in this study. The Rekawa mangrove forest, which is considered as one of the most untouched mangrove forests in southern Sri Lanka, consists of high mangrove biodiversity including 11 true mangrove species and 14 mangrove associates (Jayatissa *et al*, 2002). This mangrove diversity has led to the establishment of both mixed vegetation stands and monospecific vegetation stands in the same mangrove forest. Therefore, the Rekawa mangrove forest associated with the Rekawa lagoon (coordinates 6° 2′ 59.784″ N and 80°50′ 30.2244″ E; De Silva & Amarasinghe, 2021), in the Tangalle District Secretariat Division in the Hambantota District in the southern coast of Sri Lanka, was taken as a model site in the present study.

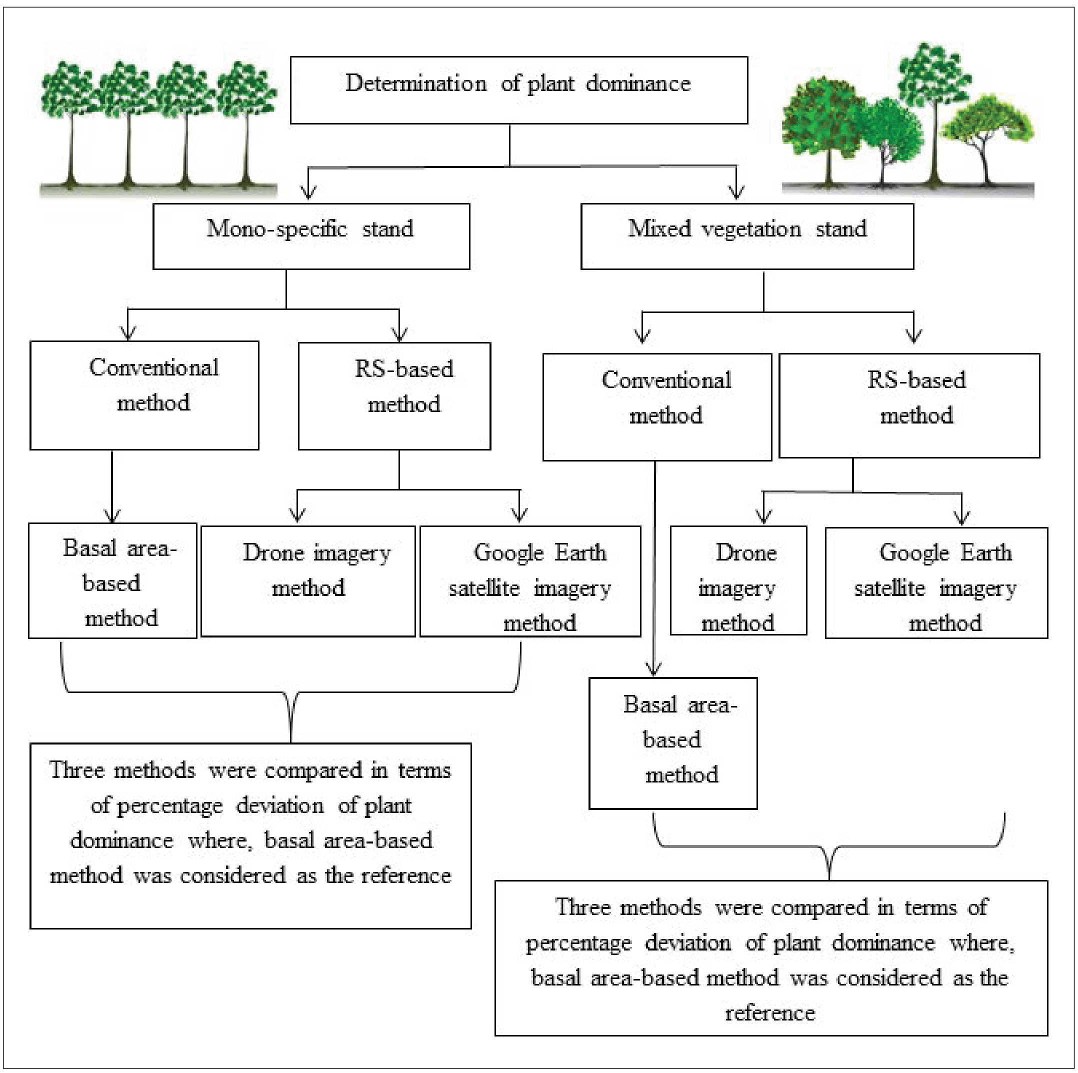

Figure 2: Flow chart showing the summary of methods followed in the study.

Data collection

Field data collection

According to previous research studies and ground observations two sampling sites were selected representing the two mangrove vegetation types available in Rekawa lagoon, *i.e.*, monospecific mangrove vegetation and mixed mangrove vegetation. Here, Mangrove patches having more than three different species were considered as mixed-species sites and sites which have only one species or mainly one species with few trees of another mangrove species were considered as monospecific/ monodominant site.

Then, three quadrats, where each quadrat was 20 m × 20 m in size, were plotted for each type of mangrove vegetation, following the stratified random sampling method using a grid map of Rekawa lagoon and a random number table. Ground truthing was carried out during the field survey. In order to increase the accuracy of GPS coordinates, each corner of all six plots was manually related to a tree or landmark(s) which are clearly identifiable in both drone images and GE satellite images. Circumference at the tree base, diameter at breast height (DBH), tree height, and individual tree crown area in each plot were then measured. Tree height was estimated by ocular method while DBH was measured using a diameter tape. According to Fadrique *et al*. (2021), only the mangrove plants with DBH ≥ 10 cm were taken in to account in this case. Circumference at the tree base was measured to calculate the basal area which is used when calculating plant dominance. Photograph(s) covering the whole individual tree crown area of each plant was captured by using a smartphone (Redmi Note 11) with the aid of a reference scale and the reference scale was held at 1.3 m height from ground level with the help of a tripod. Then, individual tree crown areas were measured using ImageJ v.2006 software. Here, polygons were sketched according to the crown shape and area measurements tool was used to calculate the individual crown area. The exact individual crown area of each species in each plot was extrapolated by using the above crown area measurements (calculated via ImageJ v.2006) and tree height.

Remote sensing - based data collection

Four drone images (obtained from DJI Mavic Air 2 on 08.09.2022) and three GE satellite images (Maxar Technologies on 22.01.2022), which delineate the studied plots were used in this study (see Figure 1). Drone images of each plot were captured at an altitude of 50 m. The GE satellite image for mono specific plots, *i.e.*, M1, M2 and M3 (see Figure 1) were downloaded at an eye altitude of 146 m, whereas mixed vegetation plots, *i.e.*, X1 and X2 at 203 m and X3 (see Figure 1) at a 161 m eye altitude. The aforementioned images were downloaded at the best eye altitude that shows crown attributes for identification of different species of the particular plot. All these drone images and GE satellite images were geo-referenced on ArcMap v.10.3 using ground control points obtained from GPS (eTrex Garmin 10). Thereafter, the crown area of each species was digitized and the generated map of each plot was validated with ground truthing. Then the crown area values of each species in each plot were measured. Similarly, species-wise crown area measurements were estimated for both drone images and GE satellite images of each plot. As the location of each plant in the plot was validated with ground truthing, the error/accuracy values are given due to the errors in mapping the crowns.

Determination of plant dominance

Conventional method

The basal area for each tree (DBH ≥ 10 cm) was calculated using circumference at tree base data obtained from field surveys. Then the correlation between the basal area and the individual tree crown area (obtained by analyzing the photograph(s) on ImageJ v.2006 software) of mangrove species was checked and a regression equation was formulated. The original equation of plant dominance is given in Equation 1, while the formulated regression equation is given in Equation 2.

$$\text{Plant dominance} = \frac{\text{Basal area of the species}}{\text{Total basal area of all species}} \qquad ...(1)$$

$$\text{Individual tree crown area} = 5.67(\text{Basal area}) + 1303.5 \qquad ...(2)$$

Plant dominance was calculated for all the mangrove species of each plot by following the three methods; conventional method (using basal area- Equation 1), drone imagery method and GE satellite imagery method.

Remote sensing-based methods

"Basal area" in the original equation of plant dominance (Equation 1) was replaced by substituting the formulated regression equation and plant dominance was calculated. Here, crown area statistics for each mangrove species obtained by on-screen digitization of drone images and GE satellite images on ArcMap v.10.3 were used as individual tree crown area. Plant dominance values obtained from all three methods (conventional method, drone imagery method and GE satellite imagery method) were compared and percentage deviations and average percentage deviations of RS-based methods (drone imagery method and GE satellite imagery method) were calculated taking the conventional method as the reference. Here, percentage deviations and average percentage deviations of plant dominance were calculated according to the mangrove species studied and the type of mangrove vegetation, respectively.

Data Analysis

As this is a preliminary study, we just wanted to show what the level of accuracy is, of using remote sensing methods to determine plant dominance. Therefore, all raw data collected for each parameter were checked for parametric assumptions. The Shapiro-Wilk normality test was performed to check the normality of the data. The data were then transformed to log values, square root values and arc-sin values and normality was checked. As the data were not normally distributed even under such transformation, nonparametric analysis was selected. Therefore, the Spearman rank correlation test was performed to check whether there is a significant correlation between the basal area and the individual tree crown area as Spearman correlation is strong enough to study the correlation between the real basal area and the crown area. When mentioning the accuracy of using remote sensing methods (X %), (100-X) is the error of the method. That is mentioned for each method (ground truthing was conducted for each plot) and to increase the clarity, a new text was added to mention the error of each.

The statistical significance of analyses was considered at a 95% confidence interval and $P < 0.05$. All the statistical analyses were performed using R.4.2.3 statistical software whereas ArcMap v.10.3 area statistics were used to measure mangrove tree crown area in drone images and GE satellite images.

RESULTS AND DISCUSSION

Maps of crown area of monospecific and mixed mangrove vegetation created using ArcMap v.10.3 are shown in Figures 3 and 4. Despite the presence of *Excoecaria agallocha* in the M2 plot, *Ceriops tagal* dominated in all three monospecific vegetation plots (M1, M2, M3). The crown area of *C. tagal* is 370 m^2, 248 m^2 and 350 m^2 respectively for the M1, M2 and M3 plots. Hence, monospecific vegetation is dominated by *C. tagal*. Regarding mixed vegetation stands (X1, X2, X3), six true mangrove species *Avicennia marina, Bruguiera gymnorrhiza, C. tagal, E. agallocha, Lumnitzera racemosa,* and *Rhizophora mucronata* were found. *B. gymnorrhiza* dominated in X1 with a crown area of 81 m^2, while C. *tagal* dominated in X2 with a 140 m^2 crown area. The X3 plot was dominated by *A. marina* with a 318 m^2 crown area. The total area of the plot could not be occupied by the tree crowns due to two main reasons, *viz.,* the presence of dead crowns and trees (specially *C. tagal*) and leaning trees and crowns.

Plant dominance values calculated using the three methods (conventional method, drone imagery method, and GE satellite imagery method) are shown in Table 1. According to the results, the drone imagery method can be used without an error and with 13.98% average error, for monospecific mangrove vegetation and mixed mangrove vegetation respectively, whereas, the GE satellite imagery method can be used with 2.15% and 57.85% average error for monospecific mangrove vegetation and mixed mangrove vegetation, respectively.

Plant dominance values for both monospecific and mixed vegetation stands determined by RS-based methods (drone imagery method and GE satellite imagery method) have deviated from the conventional method because, in RS-based methods, only the surface attributes of the vegetation are detected. This may lead to underestimation of plant dominance. For both vegetation types in the mangrove forest, the drone imagery method has shown the least average percentage deviation in determination of plant dominance, compared to the GE satellite imagery method, because drone imagery possesses high resolution compared to GE satellite imagery.

Considering the determination of plant dominance in mangrove forests by the drone imagery method, monospecific vegetation has exhibited results almost similar to the conventional method, while mixed vegetation stands have exhibited a deviation from the conventional method. Results indicate that, under RS-based methods, monospecific vegetation has shown less error in the determination of plant dominance than mixed vegetation stands. It is evident that monospecific vegetation possesses a simple structure without (or with less) stratification and low biodiversity, whereas mixed vegetation possesses a complex community structure with a high level of stratification, overlapped tree crowns and high biodiversity. Hence, detection of the understory

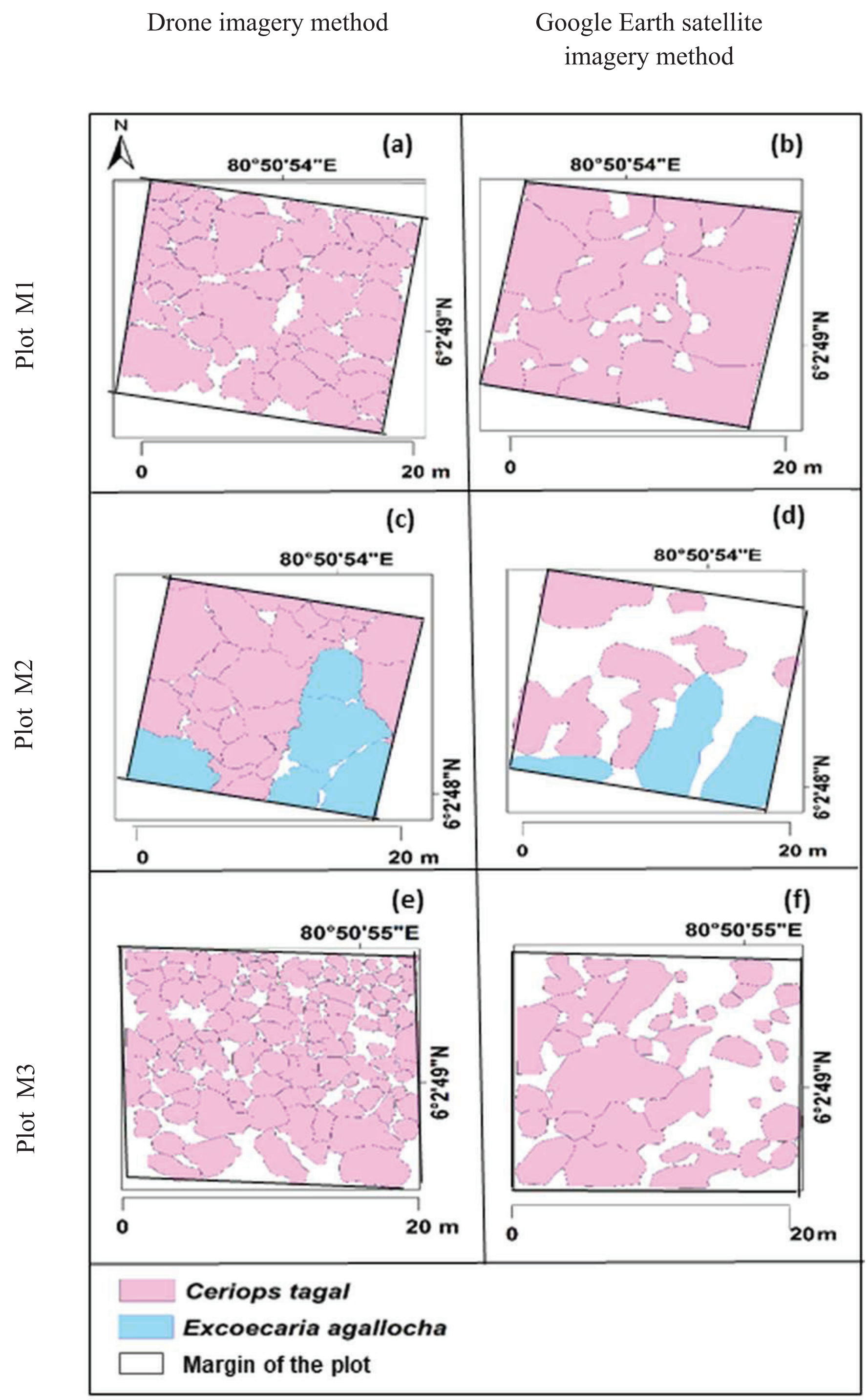

Figure 3: Maps showing the crown area of mangrove species in each monospecific plot according to the drone imagery method and Google Earth satellite imagery method.

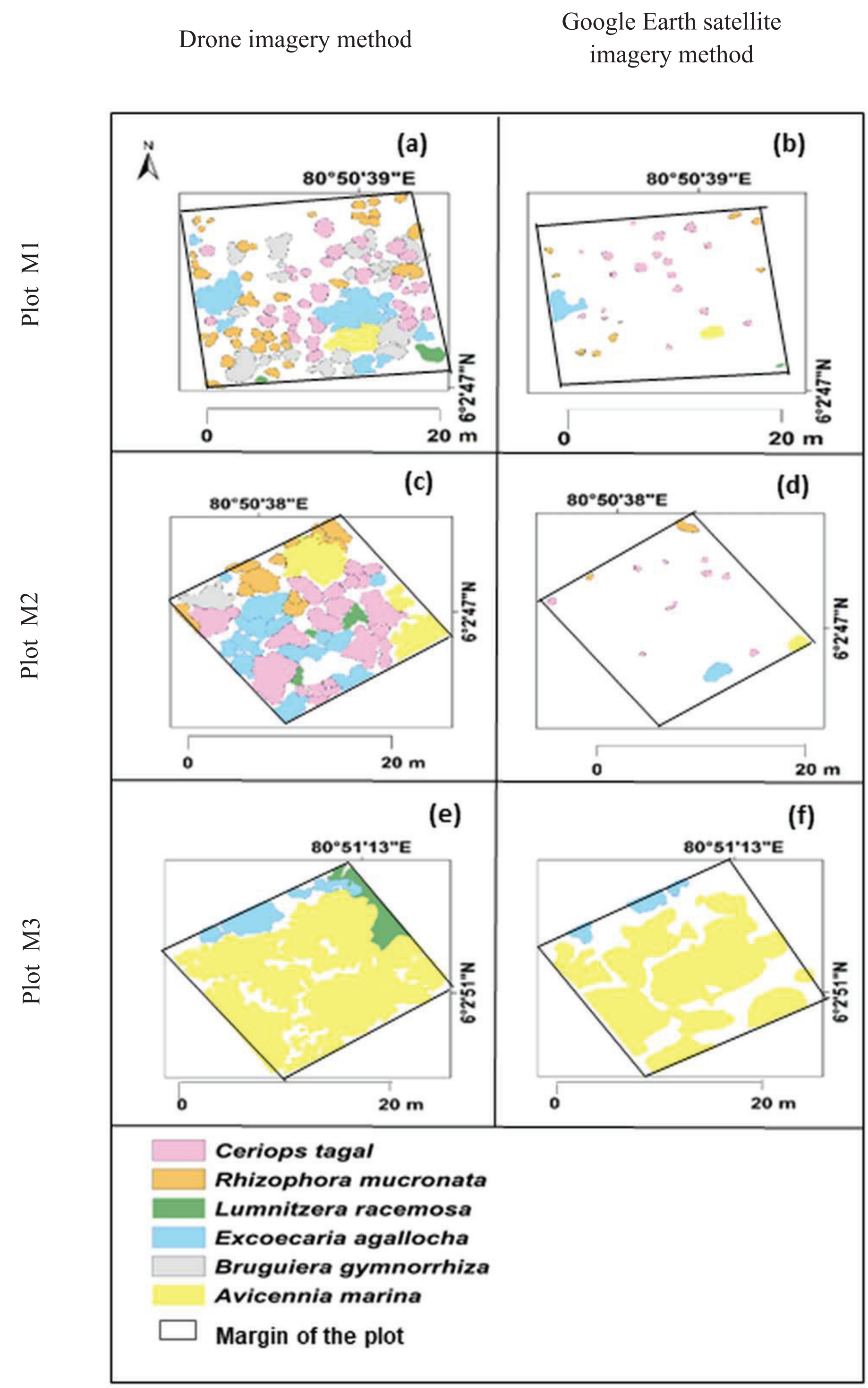

Figure 4: Maps showing the crown area of mangrove species in each mixed plot according to the drone imagery method and Google Earth satellite imagery method.

Table 1: Plant dominance values for each plot (species-wise) determined by the imagery method.

Plot	species	Plant dominance			Percentage deviation of plant dominance from conventional method (%)	
		Conventional method	Drone imagery method	Google Earth satellite imagery method	Drone imagery method	Google Earth satellite imagery method
M1	*Ceriops tagal*	1	1	1	0%	0%
M2	*Ceriops tagal*	0.62	0.62	0.61	0%	6%
	Excoecaria agallocha	0.38	0.38	0.37	0%	2.6%
M3	*Ceriops tagal*	1	1	1	0%	0%
X1	*Bruguiera gymnorrhiza*	0.27	0.27	0	0%	100%
	Excoecaria agallocha	0.27	0.23	0.07	14.8%	74%
	Ceriops tagal	0.22	0.22	0.13	0%	41%
	Rhizophora mucronata	0.16	0.16	0.12	0%	25%
	Avicennia marina	0.06	0.06	0.03	0%	50%
	Avicennia officinalis	0.01	0	0	100%	100%
	Lumnitzera racemosa	0.01	0.01	0.01	0%	0%
X2	*Ceriops tagal*	0.40	0.40	0.29	0%	28%
	Excoecaria agallocha	0.30	0.23	0.10	23.3%	67%
	Rhizophora mucronata	0.14	0.10	0.07	28.6%	50%
	Avicennia marina	0.09	0.09	0.08	0%	11.1%
	Bruguiera gymnorrhiza	0.04	0.04	0	0%	100%
	Lumnitzera racemosa	0.03	0.03	0	0%	100%
X3	*Avicennia marina*	0.89	0.86	0.85	3.4%	4.5%
	Lumnitzera racemosa	0.07	0.05	0	28.6%	100%
	Excoecaria agallocha	0.04	0.03	0.01	25%	75%

Source: based on data analysis.
(M1: Monospecific vegetation plot No.1, M2: Monospecific vegetation plot No.2, M3: Monospecific vegetation plot No.3, X1: Mixed vegetation plot No.1, X2: Mixed vegetation plot No.2, X3: Mixed vegetation plot No.3)

by the RS-based method is interrupted due to the presence of strata at different levels and overlapped crowns. Therefore, crown area in mixed vegetation stands has been underestimated. As a result, plant dominance has also been underestimated in mixed vegetation stands. Therefore, determination of plant dominance using the drone imagery method for mixed vegetation stands in mangrove forests showed an average error of 13.98%. Moreover, the effect of wind and leaning trees also provide reasons for the underestimation of plant dominance.

GE satellite images were downloaded at a time close to the period when drone images have been captured. All drone images and GE satellite images were captured during the time between January to September in 2022. Hence, possible errors that can result due to temporal changes between GE satellite images and drone images were avoided. Mangrove species were easily identified from drone images using crown attributes including crown color, crown texture and crown size. Regarding GE satellite images, identification of different mangrove species using the above mentioned crown attributes was challenging due to some obvious technical difficulties in GE satellite imagery method (Madarasinghe *et al*., 2020c), such as the high number of unidentifiable prominent crowns/margins due to comparatively less detail in GE images than in drone images. Therefore, in the GE satellite imagery method, crown area was underestimated regardless of the vegetation type. However, the results revealed that, between these two

RS-based methods, the drone imagery method is more accurate in the determination of plant dominance than the GE satellite imagery method, for inaccessible mangrove forests. Even so, the GE satellite imagery method can be applied as an alternative method to the drone imagery method when determining plant dominance in mangrove forests.

Moreover, the results of the Spearman rank correlation test revealed that there is a weak positive correlation ($P < 0.05$, $r = 0.132$) between the basal area and the individual tree crown area of mangrove species.

CONCLUSION

The results of the present study suggest the applicability and accuracy of RS-based methods (drone imagery method and GE satellite imagery method) in the determination of plant dominance in dense, inaccessible mangrove forests. According to the results, RS-based methods could be used as an alternative method to the conventional basal area-based method of determining plant dominance in mangrove forests, with different accuracy levels. The drone imagery method can be used with 100% and 86.02% average accuracies respectively for monospecific mangrove vegetation and mixed mangrove vegetation respectively, whereas the GE satellite imagery method can be used with 97.85% and 42.15% average accuracies for monospecific mangrove vegetation and mixed mangrove vegetation, respectively. Therefore, this RS-based method could be used in determining plant dominance in dense mangrove forests.

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