ANALYSIS OF IN-SITU SPECTRAL REFLECTANCE OF SAGO AND OTHER PALMS: IMPLICATIONS FOR THEIR DETECTION IN OPTICAL SATELLITE IMAGES

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ABSTRACT:

We present a characterization, comparison and analysis of in-situ spectral reflectance of Sago and other palms (coconut, oil palm and nipa) to ascertain on which part of the electromagnetic spectrum these palms are distinguishable from each other. The analysis also aims to reveal information that will assist in selecting which band to use when mapping Sago palms using the images acquired by these sensors. The datasets used in the analysis consisted of averaged spectral reflectance curves of each palm species measured within the 345 - 1045 nm wavelength range using an Ocean Optics USB4000-VIS-NIR Miniature Fiber Optic Spectrometer. This in-situ reflectance data was also resampled to match the spectral response of the 4 bands of ALOS AVNIR-2, 3 bands of ASTER VNIR, 4 bands of Landsat 7 ETM+, 5 bands of Landsat 8, and 8 bands of Worldview-2 (WV2). Examination of the spectral reflectance curves showed that the near infra-red region, specifically at 770, 800 and 875 nm, provides the best wavelengths where Sago palms can be distinguished from other palms. The resampling of the in-situ reflectance spectra to match the spectral response of optical sensors made possible the analysis of the differences in reflectance values of Sago and other palms in different bands of the sensors. Overall, the knowledge learned from the analysis can be useful in the actual analysis of optical satellite images, specifically in determining which band to include or to exclude, or whether to use all bands of a sensor in discriminating and mapping Sago palms.

1. INTRODUCTION

The Sago palm (*Metroxylon sagu Rottb*.; Figure 1) is considered to be the highest starch producer among many other starch-producing crops (Bujang, 2008). With a yield reaching 25 tons per hectare per year, the palm is now grown commercially in Malaysia, Indonesia and Papua New Guinea for production of Sago starch and/or conversion to animal food or fuel ethanol (McClatchey et al. 2006). In the Philippines, interests are gaining to develop and sustain a large-scale Sago starch industry. Information on the present location and distribution of Sago palms is needed in order to ascertain whether there is enough supply of Sago logs to drive and sustain a large scale Sago starch industry. Therefore, mapping the location of existing Sago palms is a necessity to determine current supply, as well as for characterization of its habitat such that other areas suitable for mass propagation can also be mapped out.

Clusters of Sago palms can be found in marshlands and other wetlands of Mindanao and in some islands in the Visayas. A thorough mapping of the locations of these clusters is expensive especially when done using conventional field mapping techniques, aside from being difficult due to in-accessibility. The use of remote sensing data and techniques could lessen logistical and practical difficulties that are often encountered especially in inaccessible areas, and is considered to be the best alternative compared to mapping the Sago palms through traditional approaches.

In a study by Santillan et al. (2012), it was found that Sago palms can be detected through Maximum Likelihood classification of a combination Landsat 7 ETM+ multispectral bands, Normalized Difference Vegetation Index, and Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM). However, the Users and Producers accuracy of the detection were found to be less than 85%. These relatively low classification accuracies of the Sago palm classification were attributed to three factors: (i) the differences in the date of image acquisition and the date of field surveys when the sago ground truth data were collected; (ii.) the 30-m spatial resolution of the Landsat ETM+ image may not be optimal for classifying specific vegetation species such as the sago palms, especially in areas where sago palms are interspersed with other land-cover types; and (iii.) the similarities in the spectral characteristics of sago palm with other palm vegetation, especially coconut and oil palm (Santillan et al., 2012).

All these cited factors are few of the many challenges that are often encountered when using remote sensing-based approaches in vegetation mapping (Xie et al., 2008). Spectral similarity, in particular, is an important factor to be considered when doing image classification. Since different vegetation types may possess similar spectra, it makes it very hard to obtain accurate classification results either using the traditional unsupervised classification or supervised classification (Xie et al., 2008). The difficulty is further complicated by the fact that spectral reflectance is affected by such dynamics as seasonal vegetation development or plant stress (Feilhauer and Schmidtlein, 2011). These challenges can be addressed through the use of improved

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Figure 1. Pictures of sago palms, coconut, oil palm and nipa.

classification methods which usually focus and expand on specific techniques or spectral features, which can then lead to better classification results (Xie et al., 2008), or through the use of satellite datasets with higher spatial and spectral resolution which allows plant-level assessments such as tree species identification (Schafer et al., 2016). Another approach employed to improve mapping efficiency, as well as to provide satisfactory image classification result, is by characterizing the spectral response of every plant species being mapped through in-situ spectral measurements and analysis, or also referred to as field spectroscopy (Jimenez and Diaz-Delgado, 2015).

Field spectroscopy, the measurement of high-resolution spectral radiance or irradiance in the field, is applied to retrieve the reflectance or emissivity spectral signatures of terrestrial surface targets. Through this method, the uniqueness of the spectral response of individual plant species can be estimated by comparing plant spectral signatures between and within species and detecting differences and distances in their spectral shape and reflectance (Jimenez and Diaz-Delgado, 2015). The method has been used to discriminate between Mediterranean native plants and exotic-invasive shrubs (Lehmann et al., 2015). It was also used in examining the spectral separability of the invasive *Prosopis glandulosa* from co-existent species (Mureriwa et al., 2016). The use of in-situ spectral data also allows the determination of significant spectral information that might be detected by satellite sensors (Rock et al., 1998). By integrating field-measured spectral signatures with a satellite sensor's Relative Spectral Response (RSR) function, band reflectance values can be simulated as if they were measured by the satellite sensor (Fleming, 2006). This so-called spectral resampling can help on identifying which sensor or bands can best provide an imagery where the different plant species can be distinguished from each other.

2. OBJECTIVES

In the present study, we applied field spectroscopy to analyze similarities or differences in spectral signatures of Sago and other palms such as coconut, oil palm and nipa. Specifically, the study aims to: (i) ascertain on which part of the visibile to near infrared VIS-NIR) region of the electromagnetic spectrum these palms are distinguishable from each other based on the analysis of their in-situ spectral reflectance; and (ii.) conduct spectral resampling of the spectral signatures to reveal information that will assist in the interpretation and analysis of medium (ALOS AVNIR-2, ASTER VNIR, Landsat 7 ETM+, Landsat 8 OLI) and high resolution (Worldview-2) optical satellite images.

3. MATERIALS AND METHODS

3.1 In-situ Spectral Measurements

Spectral data used in this work consisted of reflectance spectra of unique stands of Sago palm, coconut, oil palm and nipa (Table 1). The data was gathered from February to May 2012 in 52 sampling sites located in the provinces of Agusan del Norte, Agusan del Sur, and Surigao del Sur in Mindanao, Philippines. The stands of palm vegetation in the sampling site ranges from 2x2 m^2 to 10x10 m^2 in size.

At each sampling site, the amount of electromagnetic radiation (i.e. radiation from the sun) reflected by a stand of palm vegetation was measured using the Ocean Optics USB4000-VIS-NIR Miniature Fiber Optic Spectrometer. The "stand of palm vegetation" being referred here is a cluster of palms and not as individual trees. However, for coconut, the measurements were done in individual trees.

Palm Species	No. of Sites (Samples)	No. of Measurement Setup/Trials Per Site	No. of Measurements Per Set-up
Coconut	9	5	25
Nipa	7	5	25
Oil Palm	5	5	25
Sago Palm	31	5	25

Table 1. Number of sampling sites for reflectance measurements.

The sensor detects and records radiance or irradiance at 1 nm resolution within the spectral range from 345 nm to 1047 nm. The set-up (Figure 2) is composed of the sensor mounted in an improvised pole, and is positioned at different portions of the palm stand. The sensor is connected to the spectrometer through a fiber optic cable. The spectrometer is connected to a laptop computer that performs the scanning procedure, displays the plot of the observed reflectance and stores the reflectance data. At each site, there were five measurement setups (or trials) wherein each setup corresponds to the measurement of reflected canopy radiation at a particular portion of the palm stand. The five set-ups corresponds to the top and the sides of the palm stand. At each set-up 25 consecutive measurements of reflected canopy radiation (R_{canopy}) were conducted.

To determine the percentage of radiation coming from the sun that has been reflected by a stand of palm vegetation, it is necessary to measure also how much radiation is reflected by a reference standard ($R_{reference}$). This was done by doing another set of 25 measurements of radiation reflected by a white reference panel before and immediately after measuring reflected radiation by palm vegetation. The white reference panel used is the Ocean OpticsTM WS-1-SL White Reflectance Standard with Spectralon which approximately reflects 99% of incoming radiation with wavelengths ranging from 400-1500 nm. The averages of the measurements were then taken at each trial. With this setup, the percentage reflectance of a palm vegetation is obtained by dividing the R_{canopy} with $R_{reference}$ and multiplying the result by 100. It was assumed that the incoming radiation from the sun was the same during measurement of R_{canopy} and $R_{reference}$. At each site, the average of the five trials was then used in the analysis.

3.2 Spectral Resampling

The in-situ reflectance curves of Sago and other palms were resampled to simulate reflectance values as if they were measured by the optical satellite imaging sensors namely Landsat 7 ETM+, Landsat 8 OLI, ALOS AVNIR-2, ASTER VNIR, andWorldview-2 (Table 2). Some refer to this procedure as resampling to match the spectral response of the four sensors (e.g., Kooistra et al., 2004). Spectral resampling was done using ENVI 5 software with the aid of relative spectral response functions (RSRFs) corresponding to the VIS-NIR bands of the five sensors. The spectral response function defines the spectral sensitivities of a sensors band to reflected light. By characterizing the sensor's sensitivities, it allows the calculation of band values from any given spectral content of light reflected by an object back to the sensor (in this case the palm vegetation). The band values are calculated by integrating the RSRF over the in-situ reflectance spectra.

Figure 2. In-situ spectral reflectance measurement setup.

3.3 Spectral Characterization and Analysis

The average in-situ spectral reflectance curves of Sago, coconut, oil palm and nipa including the 95% confidence intervals (CIs) of the mean were plotted and visually examined to determine which part of the visible-NIR region of the electromagnetic spectrum these palms are distinguishable from each other. The same approach was applied to analyse the resampled spectral reflectance. Differences in band reflectance values of Sago from other palms were also computed and considered in the analysis.

4. RESULTS AND DISCUSSION

4.1 In-Situ Spectral Reflectance of Sago and Other Palms

Figure 3 shows the average in-situ spectral reflectance of Sago and other palms, including the 95% CIs of the mean. The graph shows several portions of the electromagnetic spectrum where Sago palm is distinguishable from other palms. The most obvious is at 550, at 770, at 800, and at 875 nm. At these portions, Sago palm has the lowest reflectance while nipa has the highest. In between are coconut and oil palm. It is noticeable that the Sago palm's average reflectance curve cannot be considered unique. Looking at the 95% CIs, the Sago palm's reflectance is slightly contaminated by those of Oil palm but not by coconut and nipa. Based on this data, there is high discrimination of Sago palm from nipa and coconut but relatively low discrimination from oil palm specifically at 400-700 nm. In the NIR region, specifically at 750-800 nm, the Sago palm's average reflectance is almost the same as the lower 95% CI of oil palm, while the Oil palm's average reflectance is almost the same as the upper 95% CIs of Sago palm. Considering only the average reflectance, the NIR region, specifically at 770, 800 and 875 nm, provides the best wavelengths where Sago palm can be distinguished from other palms.

Satellite and Sensor	Band No.	Band Name	Wavelength range, nm	Central Wavelength, nm
Landsat 7 ETM+	1	Blue	450-520	482.5
	2	Green	520-600	565
	3	Red	630-690	660
	4	Near Infrared (NIR)	770-900	825
Landsat 8 OLI	1	Coastal	433-453	443
	2	aerosol		
	3	Blue	450-515	482.6
	4	Green	525-600	561.3
	5	Red	630-680	654.6
		NIR	854-885	864.6
ASTER VNIR	1	Green	520-600	556
	2	Red	630-690	661
	3	NIR	760-860	825
ALOS AVNIR-2	1	Blue	420-500	460
	2	Green	520-600	560
	3	Red	610-690	650
	4	NIR	760-890	825
Worldview-2	1	Coastal blue	400-450	425
	2	Blue	450-510	480
	3	Green	510-580	545
	4	Yellow	585-625	605
	5	Red	630-690	660
	6	Red edge	705-745	725
	7	NIR 1	770-895	832.5
	8	NIR 2	860-1040	950

Table 2. Description of band numbers, names, wavelength ranges, and central wavelengths of optical satellite sensors.

5a shows the resampled in-situ reflectance values of Sago and other palms in Bands 1-5 of Landsat 8 OLI. The reflectance values of Sago palm appear to be similar to those of nipa in Band 1, and to oil palm in Bands 3 and 5. There is slight difference in reflectance values of Sago palm to those of other palms in Bands 2 and 4. Looking at the differences in reflectance values of Sago with those of other palms (Figure 5b), it appears that Landsat 8 OLI bands, just like Landsat 7 ETM+, may not be suitable to discriminate Sago with other palms if they are to be used individually.

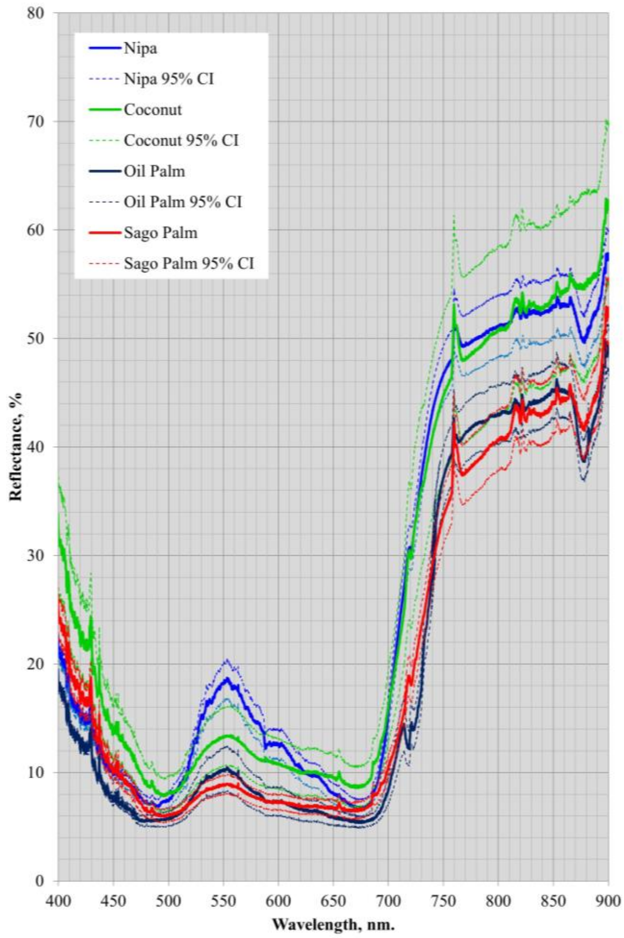

Figure 3. Average in-situ spectral reflectance of Sago and other palms, including the 95% confidence interval of the mean.

4.2 Simulated Sensor-specific Reflectance of Sago and Other Palms based on Spectral Resampling

4.2.1 Landsat 7 ETM+ Resampled Reflectance Values: Figure 4a shows the resampled in-situ reflectance values of Sago and other palms in Bands 1-4 of Landsat 7 ETM+. The reflectance values of Sago palm appear to be similar to that of oil palm in Bands 2, 3 and 4. There is slight difference in reflectance values of Sago palm to those of other palms in Bands 2 and 4. Looking at the differences in reflectance values of Sago with those of other palms (Figure 4b), it appears that none of the four bands of Landsat 7 ETM+ is suitable to discriminate Sago with other palms if they are to be used individually.

4.2.2 Landsat 8 OLI Resampled Reflectance Values: Figure

4.2.3 ASTER VNIR Resampled Reflectance Values: Figure 6a shows the resampled in-situ reflectance values of Sago and other palms in Bands 1-3 of ASTER VNIR. The reflectance values of Sago palm appear to be similar to those of oil palm in Band 1. In Bands 2 and 3, the reflectance values of Sago palm appear to be dissimilar with the other palms. Looking at the differences in reflectance values of Sago with those of other palms (Figure 6b), it appears that Bands 2 and 3 are useful to discriminate Sago with other palms with the differences greater than 1%. In Band 3, there is relatively large separability between reflectance values compared to the other bands implying that Sago palm may be best discriminated in this band.

4.2.4 ALOS AVNIR-2 Resampled Reflectance Values: Figure 7a shows the resampled in-situ reflectance values of Sago and other palms in Bands 1-4 of ALOS AVNIR-2. The reflectance values of Sago palm appear to be similar to those of oil palm in Bands 2 and 3. In Bands 1, the reflectance of Sago palm has value nearer to that of Nipa. Looking at the differences in reflectance values of Sago with those of other palms (Figure 7b), it appears that ALOS AVNIR-2 bands 1-3 may not be suitable to discriminate Sago with other palms if they are to be used individually. In Band 4, there is better separability between reflectance values implying that Sago palm can be best discriminated in this band.

4.2.5 Worldview-2 Resampled Reflectance Values: Figure 8a shows the resampled in-situ reflectance values of Sago and other palms in Bands 1-8 ofWorldview-2. Compared to the other 3 sensors, there are several bands of Worldview-2 that are useful in discriminating Sago from other palms. These bands are 1, 6, 7 and 8. The greatest difference in reflectance values can be found in Band 8 followed by Band 6 (Figure 8b).

5. SUMMARY, CONCLUSIONS AND FUTURE WORK

In this paper, important information with regards to differences in spectral reflectance of Sago and other palms in the visible to near infra-red region of the electromagnetic spectrum was revealed using field spectroscopy. In general, Sago, coconut, nipa and oil palms have lower reflectance in the blue and red regions but higher reflectance in the green region. The NIR region, specifically at 770, 800 and 875 nm, provides the best wavelengths where Sago palm can be distinguished from other palms. However, the validity of this result when applied in analysing optical satellite images must be evaluated since the bands of the sensors does not actually equate to a specific wavelength but to a range of wavelengths. Also, the conditions during the in-situ reflectance measurements are different from the condition when the satellite images were acquired. Moreover, reflectance values measured by satellite sensors are also affected by atmospheric effects which will make the in-situ spectral reflectance different from the image-based reflectance. There is also the issue of spectral variance in satellite image data. Satellite images have several meters wide pixel sizes so they are not only capturing the leaf surface but also other parts of the canopy, stem, ground, and shadows that will all add up to the variance in the spectral reflectance. This makes it almost impossible for the in-situ spectral reflectance to be the same to the image-based reflectance especially that the in-situ spectral reflectance data were collected on just five locations in a stand of palm vegetation, and more or less, represents only spectral reflectance of leaf surfaces.

The resampling of the in-situ reflectance spectra to match the spectral response of optical sensors made possible the analysis of the differences in reflectance values of Sago and other palms in different bands of the sensors. Results showed that both Landsat 7 ETM+ and Landsat 8 OLI bands may not be suitable to discriminate Sago with other palms if they are to be used individually. On the other hand, Sago palm can be best discriminated in Band 3 of ASTER VNIR because of large differences in reflectance values. For ALOS AVNIR-2, all of its four bands appear to be not suitable to discriminate Sago with other palms if used individually. This observation is the same with that of Landsat 7 ETM+ and Landsat 8 OLI. It suggest that if images acquired by either Landsat 7 ETM+, Landsat 8 OLI, ALOS AVNIR-2 and even ASTER VNIR are to be used to detect Sago palms, the use of single band may not provide good

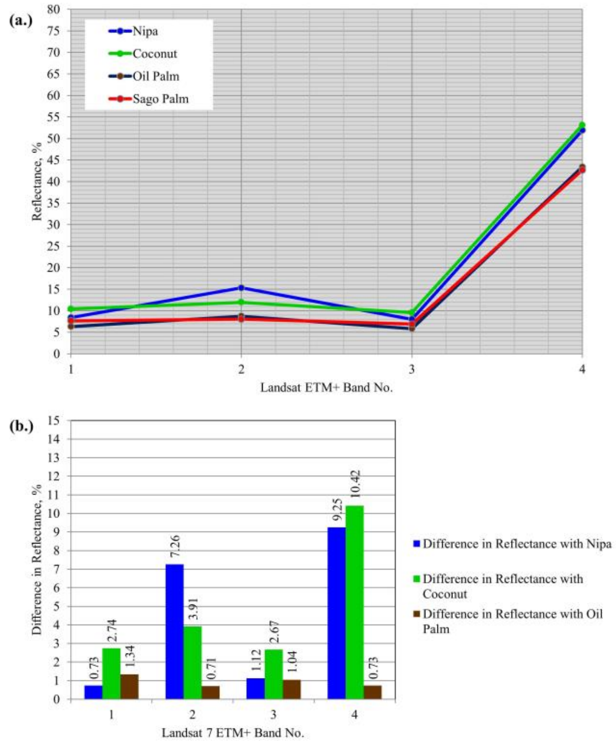

Figure 4. (a.) Resampled in-situ reflectance values of Sago and other palms in Bands 1-4 of Landsat 7 ETM+; (b.) Difference in resampled in-situ reflectance of Sago with those of other palms.

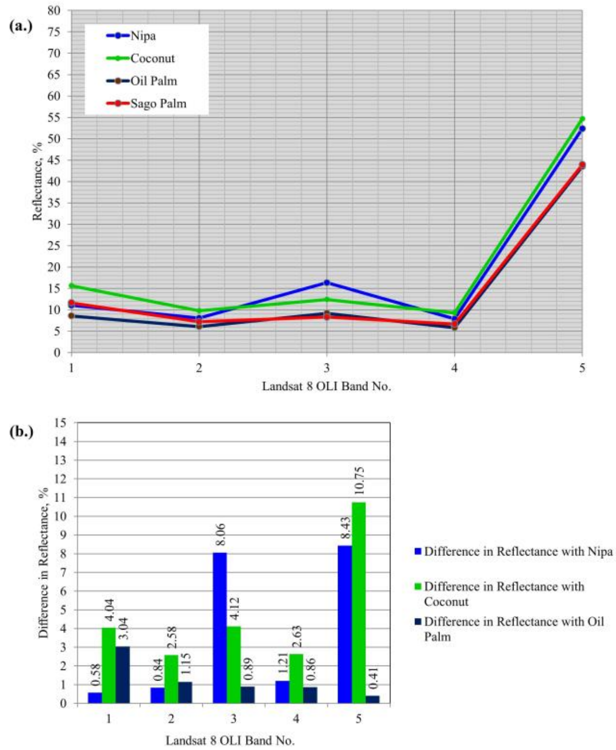

Figure 5. (a.) Resampled in-situ reflectance values of Sago and other palms in Bands 1-5 of Landsat 8 OLI; (b.) Difference in resampled in-situ reflectance of Sago with those of other palms.

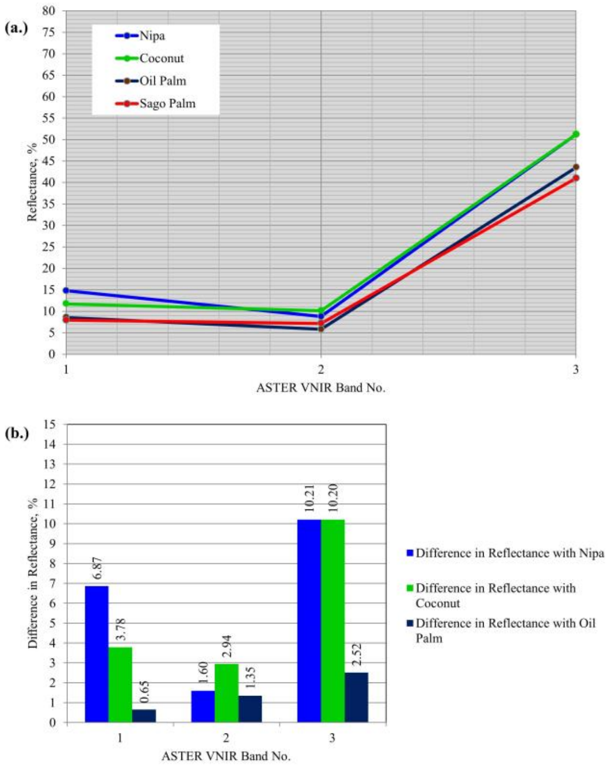

Figure 6. (a.) Resampled in-situ reflectance values of Sago and other palms in Bands 1-3 of ASTER VNIR; (b.) Difference in resampled in-situ reflectance of Sago with those of other palms.

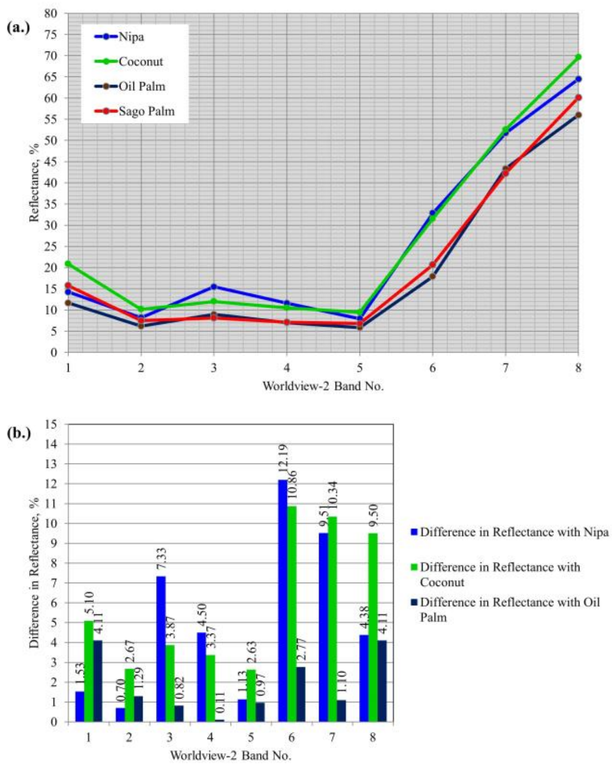

Figure 8. (a.) Resampled in-situ reflectance values of Sago and other palms in Bands 1-8 Worldview-2; (b.) Difference in resampled in-situ reflectance of Sago with those of other palms.

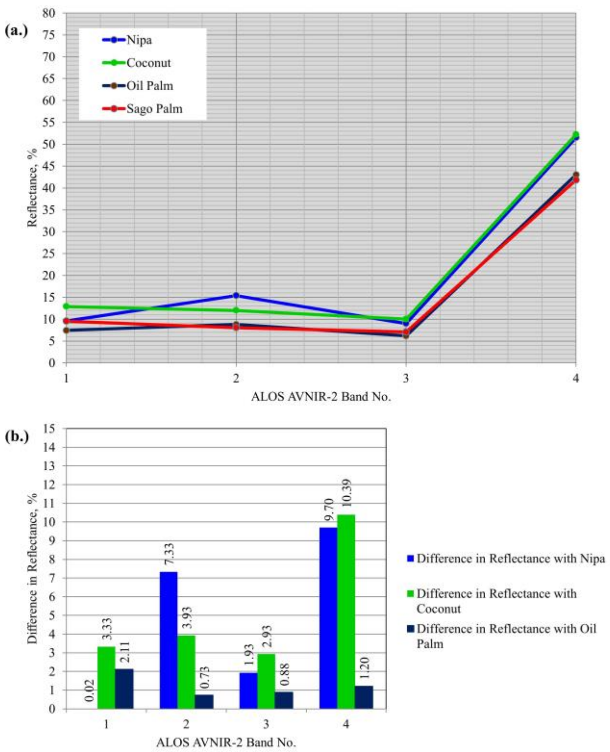

Figure 7. (a.) Resampled in-situ reflectance values of Sago and other palms in Bands 1-4 of ALOS AVNIR2; (b.) Difference in resampled in-situ reflectance of Sago with those of other palms.

results. The use of all bands (and maybe some derivatives such as NDVI) may be helpful to successfully detect Sago palms by discriminating them from other palm vegetation.

A more interesting result was obtained with the analysis of Worldview 2 reflectance values of Sago and other palms. Compared to the other 3 sensors, there were four bands that appear to be useful in discriminating Sago from other palms: Bands 1, 6, 7 and 8. It is in these bands that the large differences in reflectance values were obtained.

In all the optical sensors, it was very evident that the resampled reflectance of Sago palm is similar with those of Oil palm. This is similar to what can be observed even if the spectral reflectance curves of these two palms have not yet been resampled. As far as spectral reflectance information is used, this similarity can greatly affect the discrimination of Sago palm from oil palms in any of the images such as misclassifying oil palms as Sago palm or vice-versa. This finding can explain the low accuracy of Sago palm classification encountered in a previous study (Santillan et al., 2012).

The knowledge learned in this study is useful in the actual analysis of optical satellite images, specifically in determining which band to include or to exclude, or whether to use all bands of a sensor in discriminating and mapping Sago palms using the images. An important matter not discussed in this paper is testing the statistical significance of the differences in in-situ reflectance between the palm species. The consistency of the patterns obtained in the analysis of in-situ reflectance values with those obtained from the images (i.e., image-based reflectance values), including the seasonal changes in the reflectance values, must also be evaluated. Another matter not done is the comparison between the palm reflectance values with non-palm vegetation. Although it was shown that Sago palms are distinguishable from other palms, it was not established if they are also distinguishable from other types of vegetation.

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