Assessment of Spatial Resolution in Estimating Leaf Area Index from Satellite Images: A Case Study with *Avicennia Marina* Plantations in Thailand

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Abstract
This study aims to test whether a well-established method of high resolution remote sensing can be used for estimating the mangrove leaf area index (LAI) of the Avicennia marina plantation in Thailand. The hemispherical photographs of sixty-two A. marina plantation plots in Bangpu, Samut Prakan, Thailand were used for in situ leaf area index (LAI) calculation using CAN-EYE software. The location of each plot was recorded by dual frequency GPS receiver. The geo-referenced QuickBird image was resampled to 2.5, 5, 10, 15, 20, 25, and 30 meter pixel sizes, then were calculated for five Vegetation Indexes to predict LAI. Regression analysis showed a good agreement of the field LAI and models. The relationship between field LAI versus model derived from GVI, NDVI and EVI which resample to 10 meter pixel size yielding R^2 *=0.797, 0.796 and 0.794 respectively. The GVI model produced the lowest error when compared against the independent field data (RMSE=0.188). The results confirmed that a well-established method of high resolution remote sensing can be used for estimating the mangrove LAI of the A. marina plantation in Thailand. Additionally, the results also suggested possibility to use moderate spatial resolution satellite imagery with about 10-meter ground resolution for estimating the mangrove LAI with lower cost than the sub-meter high resolution data.*

1. Introduction

The Thai government reported that mangrove forests throughout the country were severely damaged (Thampanva et al., 2006 and Giesen et al., 2007). The expansion of the human settlement, the boom of the shrimp farming business, and the growth of the tourism industry were found to be the major causes of the mangrove loss. Restoration of these damaged mangrove forests has therefore become a priority for the government and non-government organizations as it was evident that such restoration could sustainably conserve the inter-tidal ecosystem of the affected areas (Dierberg and Kiattisimkul, 1996, Primavera, 1997, Giesen et al., 2007 and Al-Nafsi et al., 2009). Three notable examples are the Rhizophora plantation at the Kung Krabaen bay (Tookwinas, 1998), the Laem Phak Bia mangrove restoration area (Boonsong et al., 2002), and the *Avicennia marina* restoration site at the Bangpu district (WWF Greater Mekong Programme, 2012). Traditional field based measurements (e.g., measuring the tree diameter at breast height (DBH), the tree crown diameter, leaf area index (LAI) and the height of the tree) have been the most popular means for the Thai practitioner to estimate the physical conditions of the replanted mangroves despite the considerable time and effort required (Lewis, 2001, Erftemeijer, 2002 and Aksornkoae, 2003). This was evident in the study by the department of marine and coastal resources of Thailand that the cost of a field-based approach for assessing the mangrove forest biophysical conditions covering the total area of 258 km^2 was approximately Baht 2,000,000 (around USD 70,000) and the whole process took 12 months to complete (Patanaponpaiboon et al., 2008). It has been confirmed by many scientists (Green et al., 1997, Kovacs et al., 2004, 2005, 2009, 2010, 2011, Wang et al., 2004, Vaiphasa et al., 2005, 2007, Jean-

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Baptiste and Jensen, 2006, Guimaraes et al., 2010 and Fei et al., 2011) that satellite remote sensing helped reduce the need for the extensive field-based procedures. Some of the scientists reported the benefits of satellite remote sensing technology for mangrove classification and change-detection (Wang et al., 2004, Altamirano et al., 2010, Guimaraes et al., 2010, Kirui et al., 2011 and Kovacs et al., 2011). The recent focus was on the use of modern remote sensing sensors and new calculation techniques to help improve the class separate ability between different mangrove species (Vaiphasa et al., 2005, 2007, Wang et al., 2009, Guimaraes et al., 2010,; Fei et al., 2011 and Kovacs et al., 2011). This and other relevant aspects were exhaustively discussed in recently-published review papers (Heumann, 2011 and Kuenzer et al., 2011). Despite some technical concerns (Diaz and Blackburn, 2003, Eriksson et al., 2006 and Ryu et al., 2010), the other group of scientists exploited mathematical modeling and related statistical methods to estimate mangrove biophysical variables (e.g., leaf area, canopy closure, species composition, canopy height, and standing biomass) (Green et al., 1997, Kovacs et al., 2004, 2005, 2009, 2010 and Jean-Baptiste and Jensen, 2006). This included the recent findings that confirmed the statistical relationships between the vegetation indices derived from high resolution satellite sensors and the mangrove leaf area index (LAI) (Kovacs et al., 2004, 2005, 2009). Unfortunately, the existing studies (Kovacs et al., 2004, 2005, 2009) were carried out under a specific environment of South American mangroves. Thus, it is still in doubt if the methodology of the previous works (Kovacs et al., 2004, 2005, 2009) can be directly extrapolated to the case of *A. marina* that is one of the most popular mangrove species found in Thailand's re-plantation sites (WWF Greater Mekong Programme, 2012). Consequently, the purpose of this research is to investigate if the well-established methodology of high resolution remote sensing (Kovacs et al., 2004, 2005, 2009) can be adjusted and used for estimating the LAI of the *A. marina* mangrove. The mangrove site is located in the Bangpu nature education center, Samut Prakan, Thailand. The high resolution satellite data (QuickBird) is chosen for the LAI modeling in this study. Then, the results of the LAI models are to be compared against the independent testing data so as to report the root mean square errors of the models. The result of this mangrove plantation area study may suggest the routine assessment of the other areas in Thailand.

2. Materials and Methods

2.1 Study Area

The study area (Figure 1) is located within the Bangpu restoration project, Samut Prakan, Thailand (Longitude 100.656 E, Latitude 13.519 N). The total area of the project is about 1km^2.

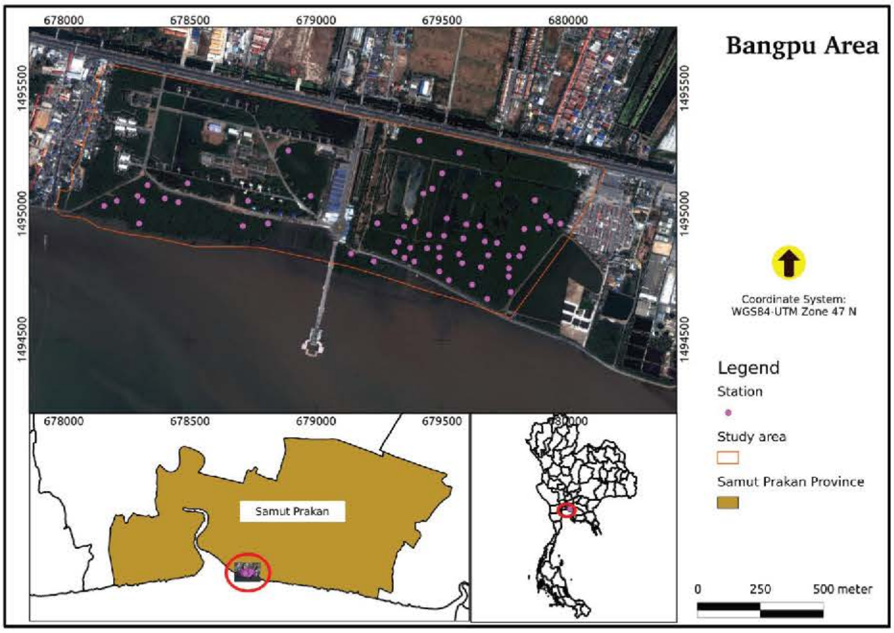

Figure 1: The location of the Bangpu mangrove restoration project (the area within the red boundary), Samut Prakan, Thailand and the thumbnail of the QuickBird satellite image

The project zone is adjacent to the south bank of the Chao Phraya River. The surrounded water is therefore brackish due to the fresh water inputs from the north. The topography of the area is rather flat. Most of wetlands are covered by the replanted Avicennia marina trees. This project is a collaborative activity between the royal Thai army and the World Wildlife Fund (WWF) Thailand (Bangpu Nature Education Centre, 2012). The replanted procedures used in this project area are adopted by the other mangrove restoration sites throughout the country (Mangrove for the Future project, 2011). The average DBH of the selected plots is 5.1 cm with a standard deviation of 1.3 cm, and the average number of trees per plot is 115 with a standard deviation of 10.

2.2 Satellite Image

The QuickBird image (Figure 1) of the Bangpu mangrove restoration project was acquired on March 6, 2010 via a satellite image provider (Geo-informatics and Space Technology Development Agency (GISTDA), Bangkok, Thailand). The sensor has one panchromatic (wavelength: 0.45 - 0.90 µm and IFOV=1.37 µrad) and four multispectral channels (wavelength: 0.45-0.52, 0.52-0.60, 0.63-0.69, 0.76-0.90 µm and IFOV=5.47 µrad). The BGIS 2000 instrument on board has a swath width of 16.5 km at the 450 km altitude (FOV=2.12°) (Ball Aerospace & Technologies Corp., 2012). The image was corrected for the atmospheric noise using the Fast Line of sight Atmospheric Analysis of Spectral Hypercubes model (FLAASH) using commercial software (ENVI version 4.7). The FLAASH model parameters were set to the tropical atmosphere with the urban aerosol mode. The visibility was fixed at 10 km. Then, the image was georeferenced with 10 control points using a 1st order polynomial transformation (RMSE = 0.4002 pixel). The 10 ground control points were collected by a dual frequency GPS receiver (the Leica GPS System 500) and post-processed with the Virtual Reference Station (VRS) network of Department of Land Development (Landau et al., 2002 and Satirapod and Homniam, 2006). Then, the image was resampled to seven different pixel sizes (i.e., 2.5, 5, 10, 15, 20, 25, and 30 meters) using the nearest neighbor algorithm.

2.3. Field Data Collection

The indirect optical technique was applied for leaf area index measurement in the field of this study. The hemispherical photographs were taken from sixty-two mangrove plots in the study area during the low tide using a fish-eyed digital camera attached with a magnetic compass (Cannon DC10 attached with 120 degree fish-eyed lens). For a 10-m x 10-m mangrove plot, four hemispherical photographs were taken at the height of 170 cm above the ground from each quadrant of the plot (avoid direct sunlight into camera). Therefore only mature stands were taken a photo. An example of the classified hemispherical photographs is illustrated in Figure 2. The optical center and the polynomial distortion function of the camera and lens were first calibrated. The effective LAI and true LAI were computed by adjusting a clumping index (Weiss et al., 2004) based on the Lang and Xiang (1986) averaging method from the hemispherical photographs using the gap fractional analysis method by free software; CAN-EYE version 5.0 (http://www.avignon.inra.fr/can_eye). The effective LAI (L_{eff}) is computed from the gap fraction

P_o,CAN_EYE(θ) following the Poisson law (Welles and Norman, 1991) (Equation 1): while true LAI derive from (Equation 2) (Weiss et al., 2004; Demarez et al. , 2008).

$$P_{o,CAN\_EYE}(\theta) = \frac{\exp\left(-L_{eff} \cdot G\left(\theta,\varphi,\theta_{leaf,eff}\right)\right)}{\cos\theta}$$

Equation 1

where θ and φ are respectively the zenith and azimuth angles of the direction of propagation of the incident beam, L_{eff} refers to effective LAI, $G(\theta,\varphi)$ is the mean projection of a leaf area unit in a plan perpendicular to direction (θ,φ).

$$L_{eff} = \lambda_0 L$$

Equation 2

Where λ_0 is the clumping index.

2.4 Data Modeling and Regression Analyses

Following the regression-based methodology used by (Kovacs et al., 2004), five popular vegetation indices including the simple ratio vegetation index (SR), the normalized difference vegetation index (NDVI), the soil adjusted vegetation index (SAVI), the enhanced vegetation index (EVI) and the tasseled cap transformed green vegetation index (GVI) were selected to develop the LAI estimated models (Table 1).

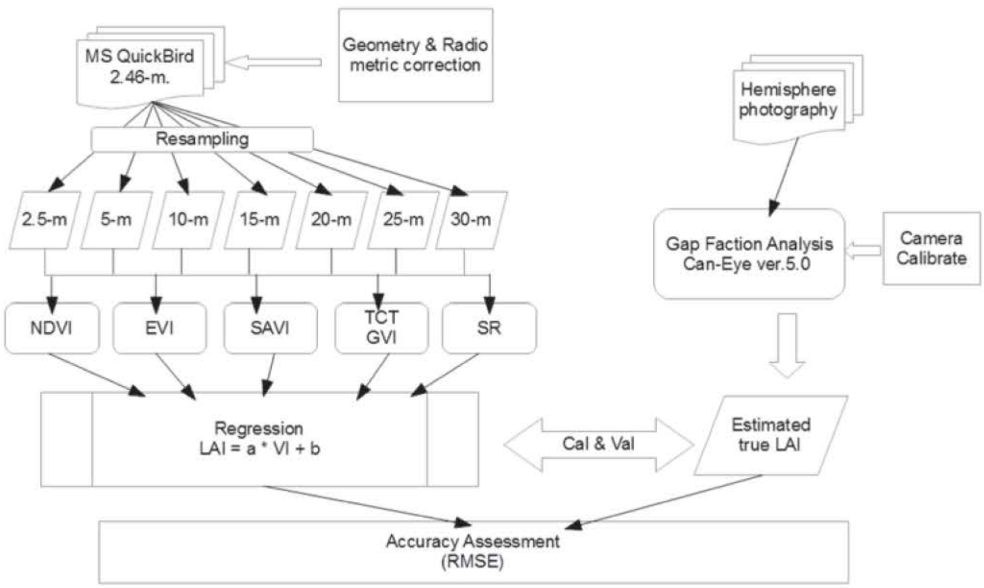

Figure 2: Flowchart showing methodology of LAI regression analysis and evaluation

Table 1: Five selected vegetation indices

Vegetation Index	Author
SR = NIR/R	Birth and McVey (1968)
NDVI = (NIR – R) / (NIR + R)	Rouse et al. (1974)
SAVI = (1.5*(NIR – R)) / (NIR + R + 0.5)	Huete (1988)
EVI = 1.0 * ((NIR – R) / (NIR + 6.0R – 7.5Blue + 1.0)) * (2.0)	Huete et al. (1999)
GVI = (-0.121)x_{blue} + (-0.331)x_{green} + (-0.517)x_{red} + 0.780x_{nir} *where X for GVI are digital numbers	Kauth and Thomas (1976) and QuickBird calibrated by Yarbrough et al. (2005)

Table 2: The adjusted R2 values of the linear regression models at seven different pixel

VIs	2.5-m	5-m	10-m	15-m	20-m	25-m	30-m
SR	0.295**	0.701***	0.718***	0.344**	0.344**	0.164*	0.159*
NDVI	0.622***	0.637***	<u>0.796***</u>	0.463**	0.396**	0.185**	0.132*
SAVI	0.414**	0.566**	0.691***	0.295*	0.171*	0.120*	0.125*
EVI	0.522**	0.568**	<u>0.794***</u>	0.472**	0.538**	0.146*	0.217*
GVI	0.420**	0.568**	<u>0.797***</u>	0.340**	0.243**	0.061	0.019

with *, **, and *** indicating P<0.05, P<0.01, and P<0.001 respectively

Half of the mangrove plots were randomly selected for developing the linear regression models between the vegetation indices and the LAI. The remaining field data were used for calculating the root mean square errors of the regression models (RMSE). The methodology of this study is show in Figure 3.

3. Results and Discussions

The average field LAI value measured with the fish-eyed instrument was 2.46 m^2/m^2 (N = 62, SD = 0.40). The adjusted R^2 values of the linear regression models between field and predicted LAI were reported in Table 2. The three highest values were underlined. The highest adjusted R^2 values were obtained when the pixel size was resampled to the 10-m size. The maximum adjusted R^2 value belonged to the GVI model (Adjusted R^2=0.797). The plots of the three winning models (the GVI model, the EVI model, and the NDVI model) were illustrated in Figure 4. It was found that the GVI model produced the lowest error when compared against the independent field data (RMSE=0.188). The final LAI map of the best model (i.e., the GVI model) is shown in Figure 5.

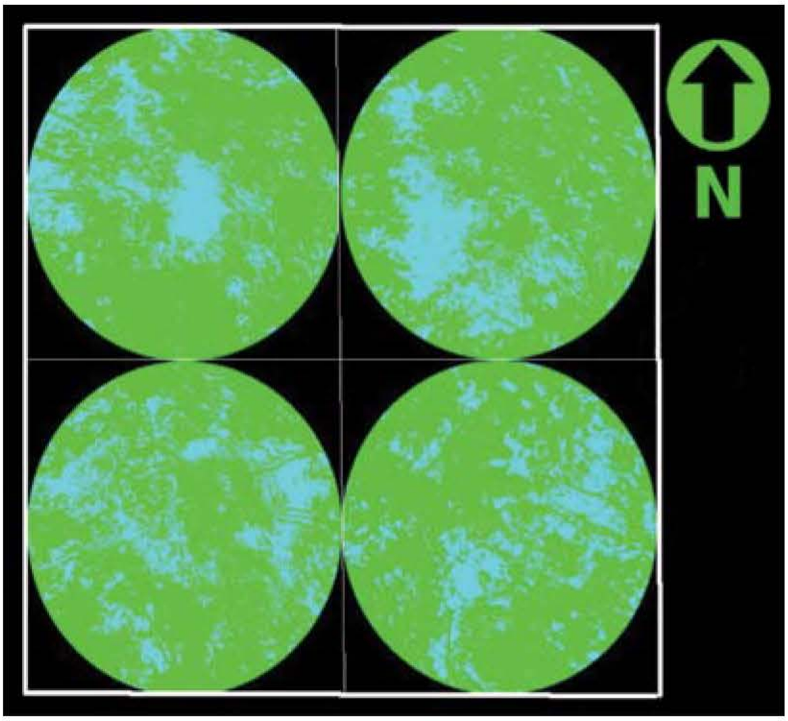

Figure 3: An example of the classified hemispherical photographs

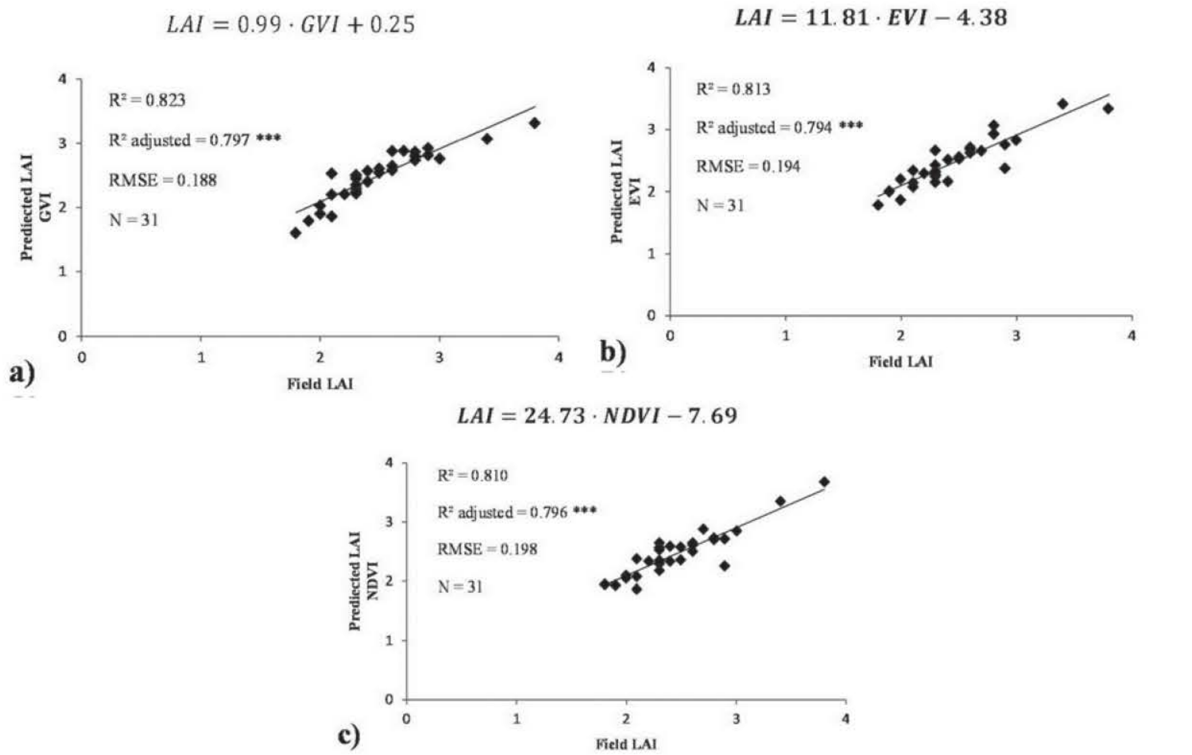

Figure 4: The scattering plots with the RMSE values of the top-three models: (a) the GVI model, (b) the EVI model, and (c) the NDVI model.

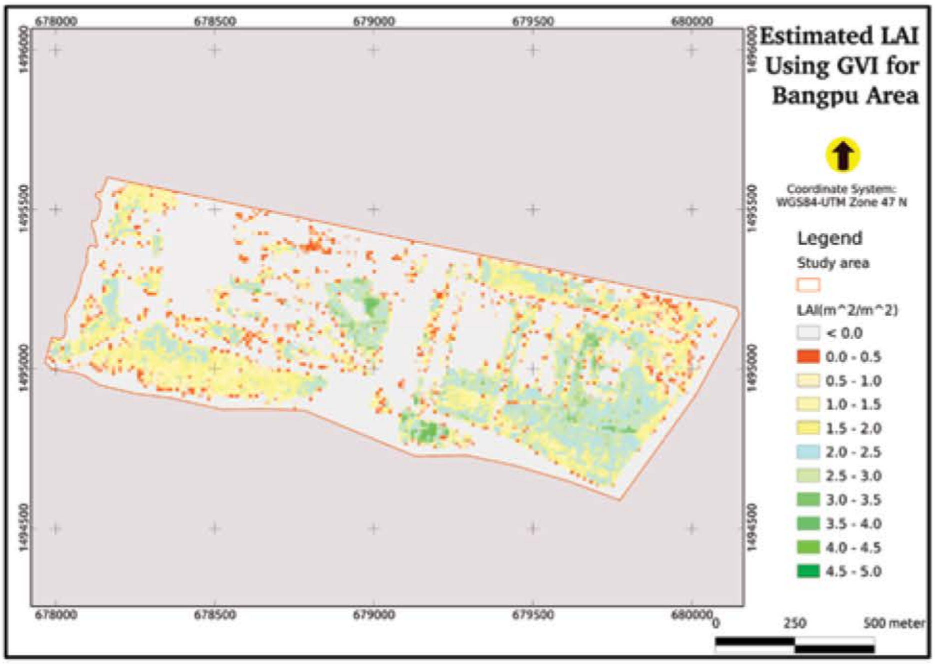

Figure 5: The final LAI map estimated by the GVI model (the non-mangrove areas are masked out in gray)

The outcome of this study confirms that the methodology of Kovacs et al. (2004, 2005, and 2009) can be adjusted and used for estimating the LAI of the tropical *A. marina* mangrove. This claim is supported by the strength of the statistical relationships between the three vegetation indices derived from the QuickBird data and the mangrove LAI, plus the low RMSE values of the three models (see Table 2 and Figure 4). The highest adjusted R^2 value belongs to the GVI regression model (Adjusted R^2=0.797) and this best-fit model predicts correct LAI values when compared with the independent testing field dataset (RMSE=0.188). The existing work (Kovacs et al., 2004) selected the 8-m and 15-m resampled image data for their analysis that is more or less comparable to the 10-m pixel size selected in this study. This similarity suggests that the appropriate spatial resolution for estimating the mangrove LAI is not as small as one might expect. Moderate spatial resolution satellite sensors may be a better alternative for estimating the mangrove LAI to a more expensive sub-meter high resolution data. However, this conclusion has yet to be confirmed by future studies. The vegetation indices reported in the previous work (Kovacs et al., 2004, 2009) were the SR and NDVI transformations. The author (Kovacs et al., 2004, 2009) argued that even if the results from both methods were not statistically different, the NDVI model would be a better choice. This is because the SR transformation is generally susceptible to the atmospheric effects (Mather, 1987). It is, however, hard to determine if this argument made by the authors (Kovacs et al., 2004, 2009) is correct as the authors did not explicitly report the RMSE values of the prediction models. In contrast, the best-fit vegetation indices for estimating the LAI of *A. marina* reported in this study are the GVI, the EVI, and the NDVI (see Table 2). Although the three indices are not statistically different (one-way ANOVA test p-value<0.01, N=31), the slight superiority of the GVI model (i.e., possessing the lowest RMSE) may be explained by the nature of the tasseled cap transformation (Yarbrough et al., 2005) that exploits additional spectral information from the blue and green bands to create the transformed space. The other two transformations never use the spectral information from the blue and green areas. Please also note that the adjusted R^2 is used instead of the traditional R^2 in this study to account for the tradeoff between the strength of a model and its complexity (Moody and Woodcock, 1995). The reader should note that natural mangrove forests in the tropical area are more complex than man-made mangrove plantations. Natural mangroves usually comprise species growing in a mosaic of patches with different densities and age levels. Additionally, the influence from cloud cover, background vegetation, tree shadows, signal saturation, sensor calibration, and atmospheric noise also plays an important role in developing a mathematical model between the vegetation indices and the field LAI (Eriksson et al., 2006 and Heumann, 2011). A linear regression model may not be appropriate for such conditions (Heumann, 2011 and Kuenzer et al., 2011). It is suggested that a more complex mathematical models should be tested when working with natural mangrove forests (Heumann, 2011 and Kuenzer et al., 2011) or resort to a more expensive option such as using an airborne laser scanning system (Heumann, 2011 and Kuenzer et al., 2011).

4. Conclusion

The outcome this study has confirmed the capability of a well-established method of high resolution remote sensing for estimating the LAI of the *A. marina* mangrove. This is supported by the evidence of the strong statistical relationships (the adjusted R^2 values) between the three best-fit vegetation indices and the mangrove LAI as well as the small estimation errors (the RMSE values). Although the three indices are not statistically different, the GVI model possesses the lowest RMSE value. The findings also suggest that inexpensive satellite data of moderate spatial resolution sensors may be an alternative to those sub-meter resolution satellite sensors. It is therefore anticipated that the 10 meter resolution satellite data may be used as an operational tool for estimating the mangrove LAI of the *A. marina* plantation in Thailand from GVI model.

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