การประยุกต์ใช้เทคนิคการรับรู้จากระยะไกลเพื่อการจัดทำแผนที่ป่าชายเลน บริเวณปากแม่น้ำเวฬุ ประเทศไทย

Application of Remote Sensing Technique for Mangrove Mapping at the Welu Estuary, Thailand

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งานวิจัยนี้มีจุดมุ่งหมายเพื่อประยุกต์ใช้เทคนิคการรับรู้จากระยะไกลร่วมกับข้อมูลสิ่งแวดล้อมเพื่อทำแผนที่กลุ่มพันธุ์ไม้ในป่าชายเลน พื้นที่ศึกษาอยู่ในพื้นที่ป่าชายเลนบริเวณปากแม่น้ำเวฬุ อำเภอขลุง จังหวัดจันทบุรี ประเทศไทย ผลจากการศึกษาพบว่า ค่าความเป็นกรด-ด่าง และค่าออกซิเจนละลายในน้ำเป็นปัจจัยสิ่งแวดล้อมที่สำคัญที่เกี่ยวข้องกับพื้นที่ป่าชายเลน ส่วนผลจากการจำแนกข้อมูลภาพถ่ายจากดาวเทียมแบบกำกับดูแล และการวิเคราะห์หลังการจำแนกประเภทข้อมูลภาพถ่ายจากดาวเทียมร่วมกับค่าความเป็นกรด-ด่าง และค่าออกซิเจนละลายในน้ำเพื่อจำแนกต้นฝาดดอกขาว ต้นโกงกางใบเล็ก และต้นตะบูนขาว พบว่าความถูกต้องรวมของการจำแนกข้อมูลลดลงจากร้อยละ 91.09 เป็นร้อยละ 62.35 อย่างไรก็ตาม ผลที่ได้ภายหลังจากการจำแนกแบบกำกับดูแล พบว่าการทำภาพสีผสมเท็จโดยผสมดัชนีความแตกต่างของพืชพรรณในช่วงคลื่นสีแดง (ที่ได้จากการขยายแบบเส้นตรงของสีแดงและอินฟราเรดใกล้) ผสมช่วงคลื่นสีเขียวในช่วงคลื่นสีเขียว และผสมช่วงคลื่น สีน้ำเงินในช่วงคลื่นสีน้ำเงิน สามารถประยุกต์ใช้อย่างมีประสิทธิภาพในการจัดทำแผนที่ป่าชายเลนในพื้นที่อื่น ๆ เพื่อใช้ในการอนุรักษ์ป่าชายเลนโดยพื้นที่ป่าชายเลนควรจำแนกเป็น 3 เขต ได้แก่ พื้นที่สงวนป่าชายเลน พื้นที่อนุรักษ์ ป่าชายเลน และพื้นที่พัฒนาป่าชายเลน

คำสำคัญ : การอนุรักษ์ป่าชายเลน ปัจจัยสิ่งแวดล้อม การรับรู้จากระยะไกล ประเทศไทย

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Abstract

Integrating approach based on satellite remote sensing technique and environmental data are applied for mangrove mapping and conservation. Mangrove area in the Welu estuary, Khlung district, Chanthaburi province, Thailand, is selected as study site. Soil pH and DO are major environmental factors related with the mangrove area. The results of supervised classification and post-classification integrated with soil pH and DO to classify *L. racemosa*, *R. apiculata* and *X. granatum* showed that overall accuracy was decreased from 91.09% to 62.35%. RGB (NDVI-Green-Blue) multispectral images, derived from linear contrast stretch of red and near infrared, after supervised classification were efficiently applied for mangroves mapping in other mangrove areas. Three mangrove zones (preservation, conservation and development zones) were classified and suggested for mangrove conservation.

Keywords : mangrove conservation, environmental factors, remote sensing, Thailand

Introduction

Mangrove functions and structures have a variety of benefits. The functions of mangrove are very important to the food webs of estuarine ecosystems, while the structures are benefits for nursery habitat for young aquatic animals and sediment trapping. Understanding mangrove adaption in an estuary is important for mangrove conservation (Tomlinson, 1986).

Regional environmental conditions control growth and distribution of mangroves. Soil physiochemical factors in relation with hydrology are used to describe natural adaption of mangrove species (Lugo & Snedaker, 1974; Krauss *et al*., 2008). For example, *Rhizophora mangle* grows in sand (Ferreira *et al*., 2007) while *Sonneratia caseolaris* can grow in silt and silty-sand (Satyanarayana *et al*., 2009). These environmental influences provide knowledge for appropriate mangrove plantation.

Global mangrove areas have reduced during the past 25 years (1980-2005) from 18.8 to 3.6 million hectares (ha). Mangrove areas in Asia dramatically lost to 1,911 million hectares during the 1980-2005 period (Food and Agriculture Organization of The United Nations (FAO), 2007). Especially, mangrove areas in Thailand decreased from 265,000 ha in 2005 to 240,000 ha in 2015 (FAO, 2015). Such a worst situation requires proficient reforestation for mangrove conservation.

Satellite remote sensing is a useful tool for the multi-temporal analysis of mangrove areas, effective for monitoring the changing condition of mangroves. However, the traditional technique needs improvement for more accurate classification. The knowledge of relationship between mangrove species and their environmental conditions has been applied to improve the accuracy of satellite image classification (Kovacs *et al*., 2005; Vaiphasa *et al*., 2006).

The Welu estuarine mangrove is considered as the largest mangrove area in the eastern part of Thailand (Office of Environmental Policy and Planning (OEPP), 2002). Unfortunately, the area was changed from 19,000 ha in 1975 (Aksornkoae, 1975) to 7,206 ha in 2009 (Mansilp, 2011). Satellite image processing and mangrove-environment relationship are integrated for mangrove mapping for the effective mangrove conservation.

Methods

1. Study site

The mangrove area (134 ha) in the Welu estuary, under responsibility of Mangrove Resource Development Station 2, Khlung district, Chanthaburi province, is selected for the study site. The area is located from latitude $12^{\circ}21'42''$N to $12^{\circ}23'20''$N and longitude $102^{\circ}19'59''$E to $102^{\circ}21'38''$E. The length of transects varied according to size and shape of the study site. Ten line transects (298 plots) were established, and a stratified random sampling technique with mangrove zonation derived from field survey results was used. Seventy-six study plots were permanently fixed (15 × 15 m quadrat) along the transect lines (English *et al*., 1994). As a result, 38 plots for training samples (green quadrats) and 38 plots for testing samples (blue quadrats) were used for mangrove mapping processes.

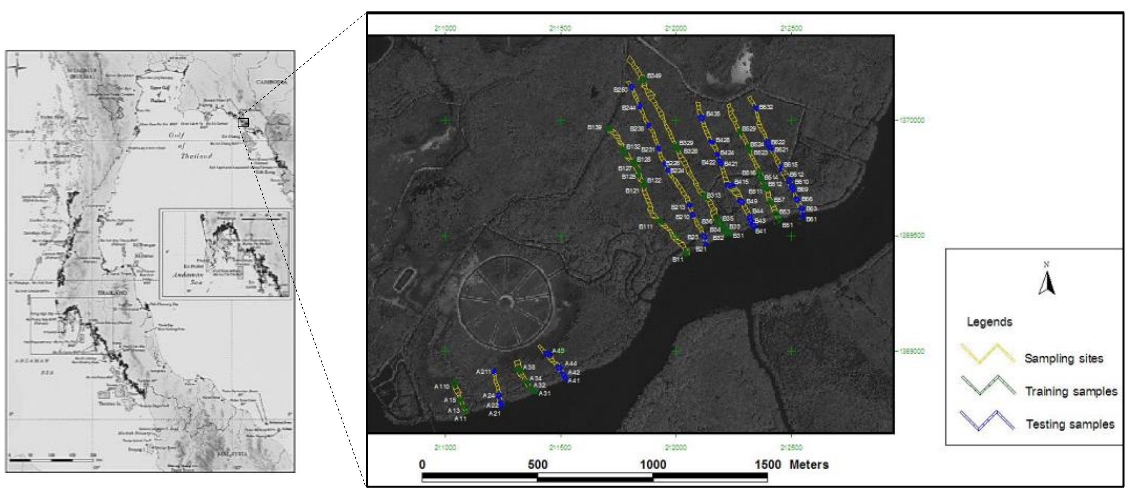

Figure 1 The study site at the Welu estuary. (Modified from Tuck *et al*., 2012; THEOS panchromatic image on 24 December 2009)

2. Field survey and environmental data collection

Healthy mangrove area was selected from the topographic map, the survey results and the satellite image of the study site. Mangrove structure and zonation manners and their analysis are previously reported following Suk-ueng *et al*. (2013). The environmental data contained soil pH/redox potential, soil water salinity, dissolved oxygen, electrical conductivity of water, soil textures and total organic carbon were collected at selected plots. Inundation frequency and waterlogging periods were used to estimate tidal action in the area. Both mangrove and environmental data collected in the training sites were used in the canonical correspondence analysis (CCA) in R statistical program (R Development Core Team, 2010).

3. Classification accuracy assessment

THEOS images, acquired on 24 December 2009, were used for mangrove type mapping. From the result of the limitation of the program, spatial resolution of the images after image registration was improved to 5.5×5.5 m, fittingly matched with sampling plot 15×15 m in the ratio of 1:3. It was allowed sample sizes to increase from 38 pixels to 281 pixels. RGB were transformed to IHS (Intensity-Hue-Saturation) images and merged with panchromatic. Three channels (R-G-B) of low spatial resolution was substituted by intensity (brightness) values of panchromatic band into IHS color space. False color composite derived from NDVI, principle component and R-G-B images were merged and transformed into IHS components. Then, the modified IHS was transformed back into RGB (Jensen, 1996). This method was useful to enhance group of mangroves. The result of transforming band 1, band 2 and NDVI (derived from linear contrast stretch of band 3 and band 4) in R-G-B (NDVI-2-1) was provided better result of mangrove discrimination by visual interpretation (Figure 2). This image was continuously considered to do supervised classification and post-classification processes.

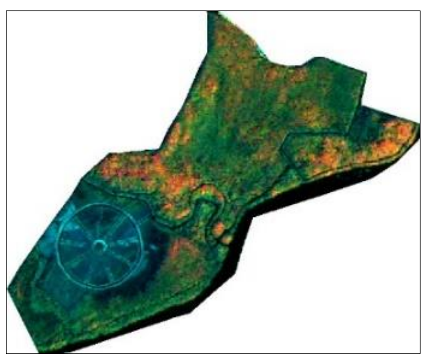

Figure 2 Transformed image of band 1, band 2 and NDVI (linear contrast stretch), substituted by brightness values of panchromatic band, in R-G-B (NDVI-2-1)

Three mangrove species including *Lumnitzera racemosa*, *R. apiculata* and *Xylocarpus granatum* (Figure 3) were selected for mangrove classification themes in agreement with species lists that were found in both training and testing samples. Classification results are verified with testing samples from the field surveys for accuracy assessment.

Lumnitzera racemosa *Rhizophora apiculata* *Xylocarpus granatum*

Figure 3 Selected three mangrove species for mangrove classification

Kappa coefficient of agreement (Equation 1) (Banko, 1998) and Z-test were applied for this purpose (Vaiphasa *et al*., 2006). The values of kappa coefficient of agreement ranged from -1 to 1. Ranges of kappa coefficient of agreement were categorized into strong (>0.8), moderate (0.4-0.8) and poor (<0.4) agreements following Landis & Koch (1977).

$$\text{Kappa coefficient of agreement} = \frac{N\sum_{h=1}^{q} N_{hh} - \sum_{h=1}^{q} N_h M_h}{N^2 - \sum_{h=1}^{q} N_h M_h} \quad (1)$$

where q is number of rows and columns in error matrix; N is total number of observations; N_{hh} is observation in row h and column h; N_h is marginal total of row h; and M_h is marginal total of column h.

A z-test (Equation 2) based on kappa coefficient of agreement was applied for comparing image classification results between supervised and post classifications (Stehman, 1996; Rossiter, 2004; Vaiphasa *et al*., 2006)

$$Z = \text{Kappa (K)/standard error of Kappa (S.E.)} \quad (2)$$

Results and Discussion

1. Field survey on mangrove structure and zonation results

Mangrove composition and structure are reported in Suk-ueng *et al*. (2013). The structural analysis can be used to categorize the distribution of mangrove species into 9 zones as shown in Table 1.

Table 1 Zones and structure of mangrove species according to landward distances from the river

Zones	Landward distances from the river (m.)	Major species	Numbers of species	Total stem basal area (m^2)	Tree density (tree/0.01 ha)
Zone 1	0-90	*R. apiculata*	12	215.48	664.9
Zone 2	90-180	*R. apiculata*	5	11.03	264.2
Zone 3	180-270	*R. apiculata*	3	7.62	142.5
Zone 4	270-360	*R. apiculata*	5	4.99	270.9
Zone 5	360-450	*R. apiculata*	5	4.04	218.7
Zone 6	450-540	*R. apiculata*	3	3.90	144.0
Zone 7	540-630	*R. apiculata*	1	1.17	44.0
Zone 8	630-720	*R. apiculata*	3	1.25	21.6
Zone 9	>720	*R. apiculata*	1	1.11	73.9

2. Relationship between mangrove species and their environmental conditions

Only structures of *R. apiculata* were selected for the analysis because it is the dominant species with highest IVI (Suk-ueng *et al*., 2013). The relationship between structures of *R. apiculata* and environmental conditions was demonstrated the structures depend on 5 environmental factors in different distances and directions. In addition, the CCA ordination results in both rainy and dry seasons were indicated structures of *R. apiculata* was weakly correlated to environmental conditions. However, the results of the ordination analysis suggested that soil pH and soil dissolved oxygen were the key environmental factors (Suk-ueng, 2014).

3. Remote sensing for mangrove mapping

Georeference information of the images, geometrically corrected and resampled by the topographic map, can be inherited from the georeferencing process of the topographical map (The International Institute for Aerospace Survey and Earth Sciences (ITC), 2001). As a result spatial resolution of the new images may be permitted an increase in sample sizes according to georeferencing of the topographic map.

Due to dominance of *R. apiculata* in the mangrove area, the resulting map (Figure 4) showed that overall accuracy of supervised classification was 91.09% with kappa coefficient of agreement of -0.0276 (poor agreement). The Z-test was -0.617 that this relationship was explained by 38.07% of Z^2. From the confusion matrix (Table 2), the producer's and user's accuracies presented only *R. apiculata* were quite high at 97.40% and 93.36%, respectively.

Table 2 Confusion matrix of testing data set and classified data based on supervised classification

	Testing data set					Producer's accuracy (%)	User's accuracy (%)
	225	LR	XG	RA	Total		
Classified data	LR	0	0	2	2	0	0
	XG	0	0	4	4	0	0
	RA	7	9	225	241	(225/231)×100 = 97.40	(225/241)×100 = 93.36
	Total	7	9	231	247		

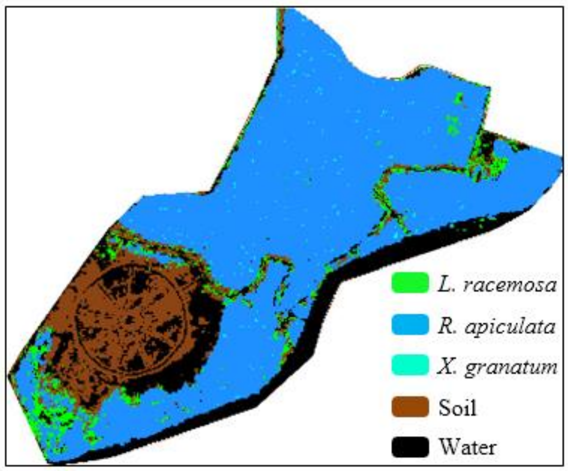

Figure 4 The classification results of mangrove species using maximum likelihood classification via supervised classification process

The resulting map (Figure 5) showed that overall accuracy of post-classification was 62.35% with kappa coefficient of agreement of 0.024 (poor agreement). The Z-test was 0.0746 that this relationship was explained by 0.56% of Z^2. From the error matrix shown in Table 3, higher producer's and user's accuracies of *L. racemosa*.

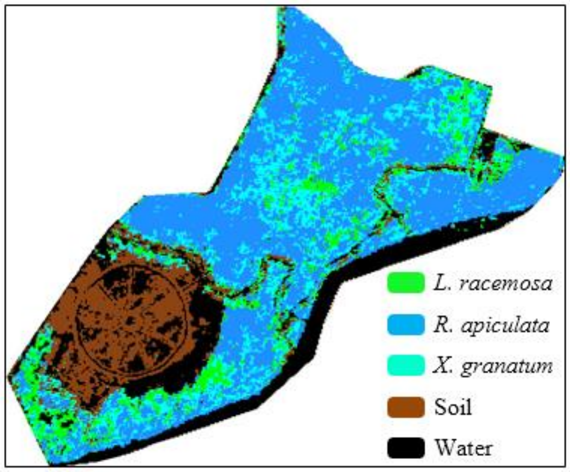

Figure 5 The classification results of mangrove species using maximum likelihood classification via post-classification process

Table 3 Confusion matrix of testing data set and classified data based on post-classification

	Testing data set					Producer's accuracy (%)	User's accuracy (%)
	154	LR	XG	RA	Total		
Classified data	LR	5	1	18	24	(5/7)×100 = 71.43	(5/24)×100 = 20.83
	XG	0	0	64	64	0	0
	RA	2	8	149	159	(149/231)×100 = 64.50	(149/159)×100 = 93.71
	Total	**7**	**9**	**231**	**247**		

The results of confusion matrix of both supervised and post-classifications were not good because THEOS sensor specification may not appropriate for mangrove species classification. The results showed that the mapping accuracy was not improved in post-classification process. As a result, using spectral base alone with traditional supervised classification was sufficient for mangrove species classification if the study site was dominated by only one mangrove species (*R. apiculata*). Furthermore, using hyperspectral satellite imagery or high spatial resolution with multispectral bands (e.g. WorldView-2) should be presented to support mangrove-environment relationship to improve mangrove mapping (Vaiphasa *et al*., 2006; Kanniah, 2011).

According to the results of integrating satellite remote sensing technique and mangrove-environment relationship, 3 main zones for mangrove conservation and reforestation were established as follows (adapted from Aksornkoae (1993)):

(1) Preservation zone: Zone 1 (0-90 m) serves to important true mangroves for natural regeneration. Twelve species of important true mangroves namely *Avicennia alba*, *Avicennia officinalis*, *Bruguiera gymnorrhiza*, *Bruguiera parviflora*, *Bruguiera sexangula*, *Ceriops tagal*, *Excoecaria agallocha*, *R. apiculata*, *R. mucronata*, *Sonneratia caseolaris*, *X. granatum* and *X. moluccensis* include in this zone.

(2) Conservation zone: Zone 2 to 5 (90-450 m) should be rehabilitated by forester ranger and local people. Suitable mangrove species in this zone are consist of *A. officinalis*, *B. cylindrica*, *B. hainesii*, *B. parviflora*, *B. sexangula*, *C. taga*l, *E. agallocha*, *R. apiculata* and *X. granatum*.

(3) Development zone: Zone 7 to 9 (>540 m), generally found *R. apiculata*. Five selected species, *B. parviflora*, *B. sexangula*, *E. agallocha*, *R. apiculata* and *S. ovata*, are considered to be tolerance species for plantation. Plantation of *R. apiculata*, for example, is beneficial to human for charcoal production.

Conclusions

Relationships between mangrove species and their environmental conditions in this study can be used as database for monitoring mangrove growth and distribution. This results are, therefore, able to consider suitable species for specific environmental conditions and reforestation. The traditional classification technique is, however, sufficient for mangrove species classification in this mangrove area.

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