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Determination of aquaculture distribution by using remote sensing technology in Thanh Phu district, Ben Tre province, Vietnam

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Abstract:

Aquaculture is an important economic activity in the coastal zone of Vietnam. Thanh Phu is one the coastal districts in Ben Tre province that rears brackish aquaculture. In recent years, farmers could not grow shrimp because of salinity intrusion and market price fluctuation. This study aims to determine aquaculture and fallow aquaculture pond distribution by using the three indices of NDVI (Normalized Difference Vegetation Index), MNDWI (Modified Normalized Difference Water Index) and NDBaI (Modified Difference Bareness Index) on Landsat 8 imagery. The results reveal that remote sensing can support the detection of aquaculture and fallow ponds with a high accuracy of 77%. The total aquaculture area is approximately 13,093.65 ha, of which the total fallow area is 581.49 ha (roughly 4.44% of the total aquaculture area). Moreover, the fallow ponds are randomly distributed in all four ecological zones and mostly in the fourth ecological region (about 73.92%). In the fourth region, saline concentration in water is from 20 to 30‰, which directly influences cultured shrimp farms. The results also indicate the spatial distribution of aquaculture ponds and ineffective aquaculture locations using Landsat 8 imagery via index image analysis. The findings support the local management's decision making on further aquaculture planning.

Keywords: **aquaculture, Ben Tre province, ecological zone, fallow pond, satellite image indices.**

Classification number: **2.3**

Introduction

Ben Tre province is one of the coastal provinces located in the Lower Mekong River, Vietnam. Its major industry is agriculture, including orchard and rice crop cultivation and aquaculture. The famous products of Ben Tre province are made from coconuts. Two types of farming system are commonly adopted in the coastal areas, namely rice-shrimp rotation and shrimp farming [1]. These farming systems can generate higher income than mono-cropping or double rice cropping.

Changes in climate have adversely affected the coastal areas in recent years, causing sea level rise, increase in temperature and rainfall, drought, salinity intrusion, and spread of epidemic diseases in both rice and shrimp farms; consequently, aquaculture farming encountered a reduction in both production and income [2].

Remote sensing and geographical information system (GIS) are useful tools for detecting the spatial distribution of natural resources and aquaculture areas. This research applied remote sensing and GIS technologies to determine shrimp farming and ineffective shrimp pond. That refers to a pond where farming culture has ceased due loss of profit caused by the damage of shrimp diseases, thereby resulting in "a fallow pond". This study aims to identify aquaculture distribution and locate ineffective shrimp ponds. Its findings endeavour to support local decision making on the management of coastal aquaculture resources.

Materials and methodology

Study area

Thanh Phu is one of coastal districts located in the

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southeast of Ben Tre province. Its distance from the seashore is approximately 45 km, and its total area is roughly 411 km^2 (Fig. 1) [3]. Thanh Phu was established by an accretion of Ham Luong and Co Chien rivers several centuries ago. Its coastal land consists of paddy fields, sand dunes and mangrove forests. Thanh Phu district is considered as a developing core of the third economic region (i.e. salty region) [4]. The entire district land is affected by salinity intrusion that is suitable for brackish farming systems, including rice-shrimp rotation, extensive-intensive shrimp and clam exploitation on the coastal tidal mudflats [4, 5]. The brackish aquaculture is a principal agricultural product and plays an important role in the district economy [6].

Materials

Satellite imagery: Landsat 8 (OLI) images from 2015 to 2016 were collected from the U.S. Geological Survey website (http://earthexplorer.usgs.gov/). The Landsat 8 images have a medium resolution with 30 metres. Eight images were used, including four images each for the sunny and rainy seasons. The acquired period was focused on the two seasons to detect shrimp culture, rice-shrimp rotation system and fallow shrimp pond culture. Farmers in Thanh Phu district discontinued the cultivation of shrimp farms in the dry season of 2016 due to shrimp diseases, which reduced production.

GIS data: administrative and land use maps, natural river and canal maps and information about ecological zones in Thanh Phu district, Ben Tre province were obtained from the Ben Tre Department of Natural Resources and Environment (Ben Tre DNRE) and the Ben Tre Department of Agriculture and Rural Development (Ben Tre ARD).

Methods

Remote sensing methods:

A subset study area was identified to limit the scope of the research area. Besides, rivers and canals were also removed to reduce the confusion between rivers and aquaculture areas throughout the year.

Removing cloud from the imagery: Landsat 8 level 1 data products include a 16-bit quality assessment (QA) band containing integer values that represent bit-packed combinations of surface, atmosphere and sensor conditions in which bits 12-13 can be cirrus cloud and bits 14-15 are cloudy pixels. The reference values from 36,864 to 39,936 may be cloud, and the values from 53,248 to 61,440 are cloudy values [7]. We also used band 1 (coastal aerosol), band 9 (cirrus) and band 10 (thermal infrared, or TIR) to remove cloud. Thick cloud was detected by selecting a threshold on bands 9 and 10 (i.e. high values on band 9 and low values on band 10). Thin cloud was masked using bands 1, 9 and 10 using only the low values in both bands

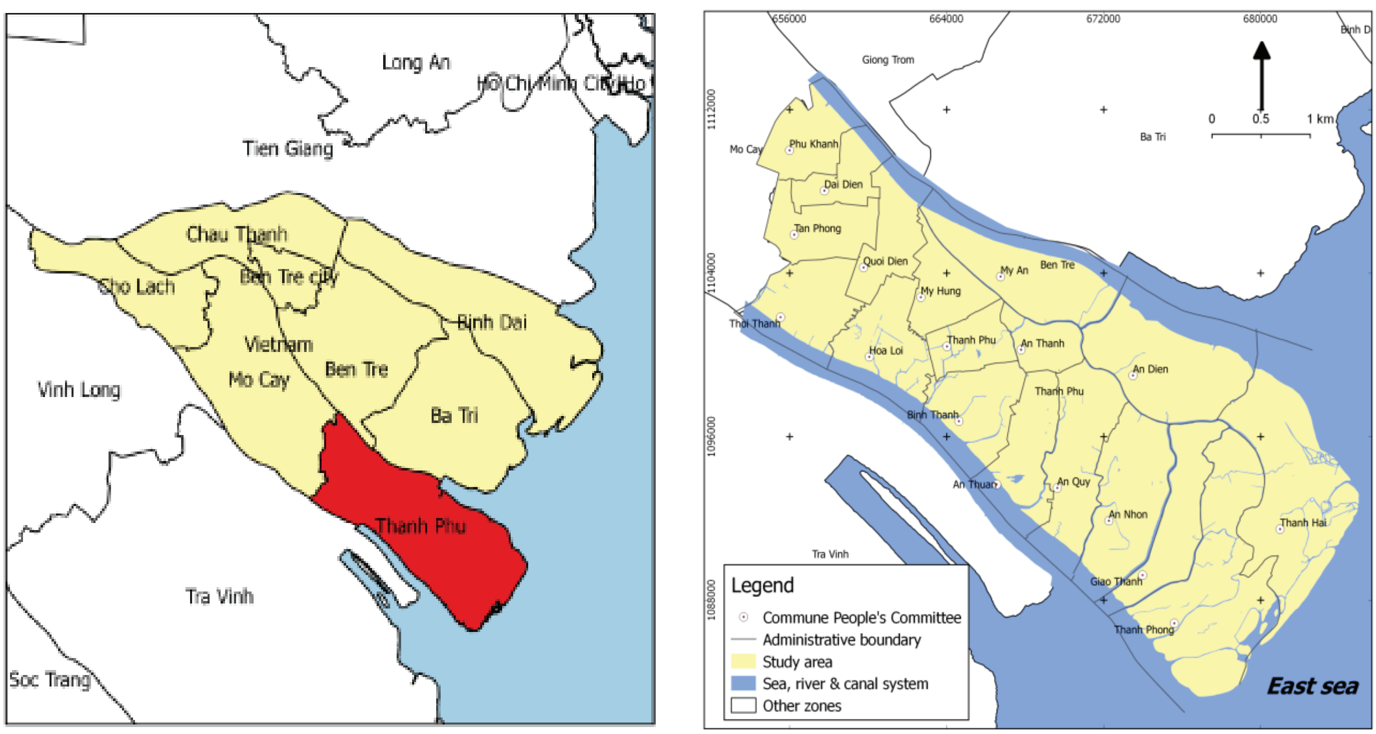


Fig. 1. Study site of Thanh Phu district.

9 and 10. Cloud is also normally brighter than the other objects, especially in the blue band, which is given a result in high pixel values on band 1 [8]. The cloudy values were used to create cloud mask in each image; cloud pixels were subsequently deleted by the cloud mask and filled values by multi-time images.

Creating spectral indices: the research applied three indices to extract information about vegetation, water and bare land from Landsat 8 imagery. The corresponding indices are normalized difference vegetation index (NDVI), modified normalized difference water index (MNDWI) and modified difference bareness index (NDBaI). These indices were calculated using Equations (1) to (3) (Table 1).

Table 1. Spectral index equations.

Index name	Equation	Reference	Equation number
NDVI	$\frac{NIR - Red}{NIR + Red}$	[9]	(1)
MNDWI	$\frac{Green - SWIR}{Green + SWIR}$	[10, 11]	(2)
NDBaI	$\frac{SWIR - TIRS}{SWIR + TIRS}$	[12, 13]	(3)

*Note: on the Landsat 8 (OLI) imagery, Red: visible spectrum band of red wavelength (band 4); Green: visible spectrum band of green wavelength (band 3); NIR: near-infrared radiation (band 5); SWIR: shortwave infrared (band 6); and TIR: thermal infrared (band 10).

Classification: the range of the index value is from -1 to 1. The threshold method of classification was applied to categorize the index images into three land cover types, namely aquaculture, vegetation and bare land. Positive values ranging from 0 to 1 were applied to classify water body and vegetation using NDVI and MNDWI indices; meanwhile, the beginning values of the NDBaI range were categorized for bare land.

Accuracy assessment:

The accuracy of class identification requires assessment. This research applied a confusion matrix (or error matrix) as the quantitative method of characterizing image classification accuracy. The overall accuracy (OA) of the classification is the sum of the pixels of diagonal elements by the total number of pixels (see Eq. (4)), where PCP are pixels correctly classified, and TP is the total pixels on the image classification [14].

$$OA = \frac{PCP}{TP} \quad (4)$$

Kappa coefficient is another accuracy indicator. It is a measure of how the classification results compare to the values assigned by chance. It can take values from 0 to 1. The random point tool was used to create 100 randomly ground truth points on the classified results that were collated with the aquaculture layer on the land use map.

GIS methods:

The land cover classifications from the eight index images were converted to vector file data. The same index data were overlaid by a union algorithm to synthesize all surface distributions. The results revealed the distribution of vegetation, aquaculture and bare land. The synthesized data were overlaid to detect land use/land cover (LULC) and aquaculture farming distribution.

Results

Satellite imagery data collection

The eight scenes of Landsat 8 were selected from 2015 (January, February, November and December) and 2016 (February, March, April and May). The images were located in path 125 and row 53; UTM 48 Northern and WGS-84 were used as the projection and reference ellipsoid, respectively (Fig. 2). One scene covers approximately 185×180 km and a 30-metre spatial resolution for the multispectral bands and a 15-metre spatial resolution for the panchromatic band. Landsat 8 Level 1 product includes 11 bands, QA band and metadata file.

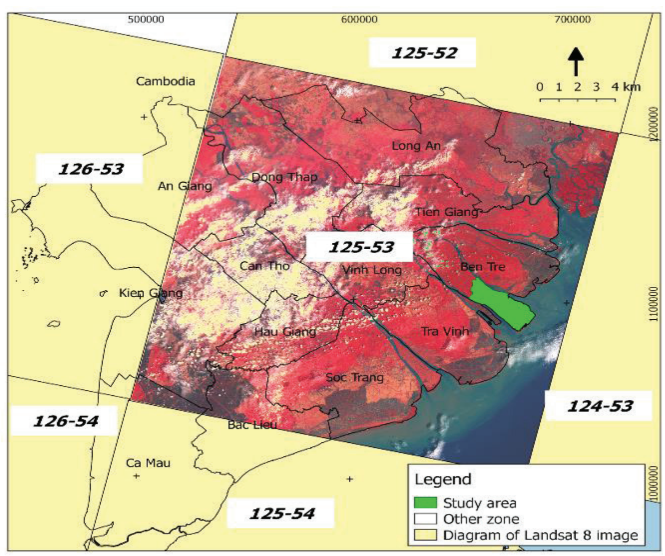
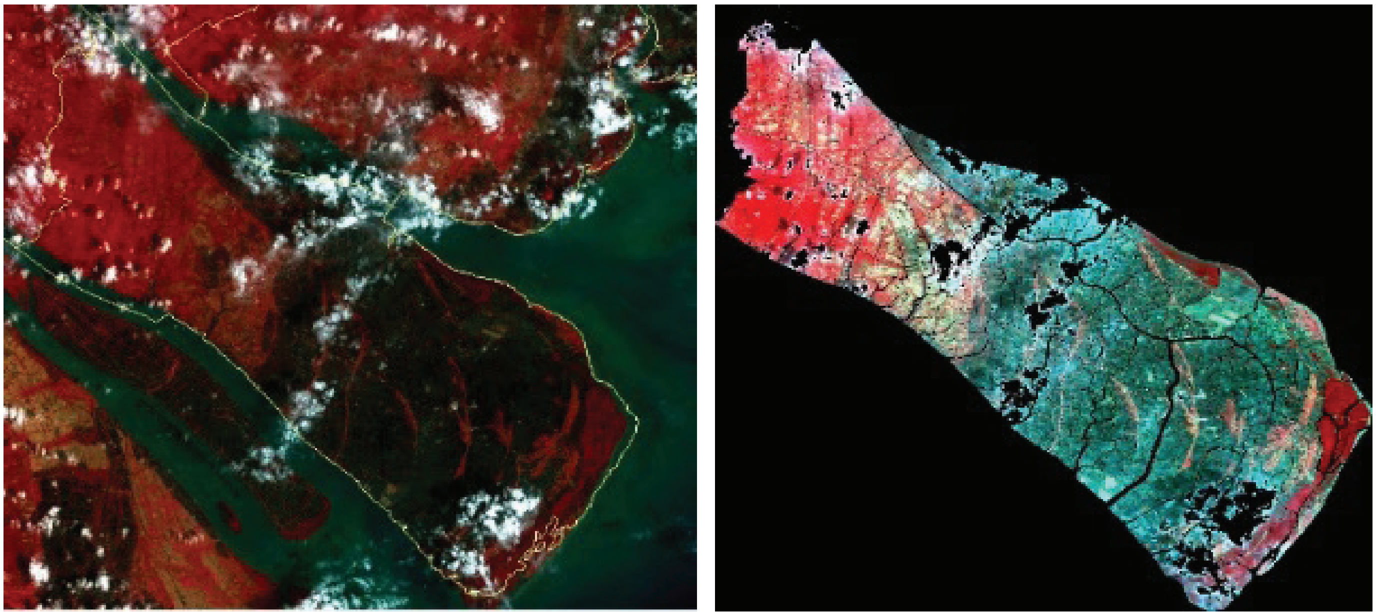


Fig. 2. Landsat image scene, with the study area highlighted in green.



(A) (B)

Fig. 3. (A) Landsat 8 image, (B) subset study area with removed cloud.

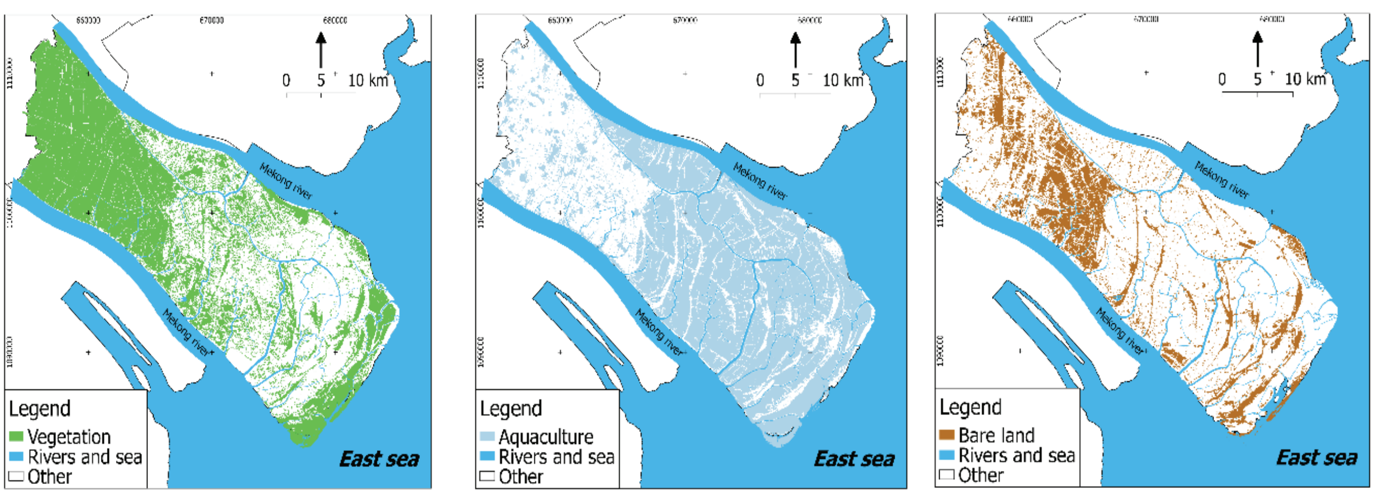
Determining the study area and removing clouds

The Landsat images were affected by clouds (Fig. 3A) and included unrelated zones, rivers and cloud. The subset study area was removed cloud to limit the confusion between water surface and aquaculture area (Fig. 3B).

Land covers distribution

Figure 4A illustrates the vegetation that was detected by NDVI index with a range of value from 0.17 to 0.57. The vegetation area is approximately 18,972.72 ha, of which roughly 1,350 ha comprise freshwater plants in the northwest, including rice crops, orchards and annual plants. The plantation is near Mo Cay Nam boundary in the communes of Thoi Thanh, Hoa Loi and Tan Phong. The vegetation also includes a mangrove forest in the coastal area of Thanh Hai commune, and it measures 1,450 ha (Fig. 4A).

Water surfaces were determined by the MNDWI index from 0 to 0.33. The largest water surface area was contributed by the images in the sunny season, the main season for cultivating shrimp culture. The total area of water surfaces was roughly 20,885.85 ha, including extensive-intensive shrimp farming, rice-shrimp rotational cropping and wetland area. Water surface was distributed virtually



(A) Vegetation (B) Water surfaces (C) Bare land

Fig. 4. Land cover distribution of vegetation (A), water surfaces (B) and bare land (C) on the study site.

along the coastal villages such as Thuan Phong (3,300 ha), Thanh Hai (2,800 ha), An Dien (2,400 ha) and An Nhon (2,000 ha) (Fig. 4B).

Bare land was retrieved by the NDBaI index from -0.375 to -0.001. It covered about 7,414.21 ha and achieved the largest area in January, February and March after harvesting rice crops. Bare land was mainly located in My Hung, Thanh Phu and Hoa Loi communes (i.e. harvested paddy fields), and sandy dunes located along the seaside (Fig. 4C).

Aquaculture and fallow ponds

Land use/land cover is classified into six types, namely paddy field (i.e. mono and triple crops), sandy soil, residential area, rice-shrimp rotation farming, perennial plant (i.e. orchard and mangrove forest) and aquaculture. The aquaculture area was extracted from the LULC map. It is located in the southeast part (i.e. both in the central and coastal areas) of Thanh Phu district; its distribution is denser than in the coastal zones. The total aquaculture area of 13,093.65 ha consists of extensive-intensive shrimp farming.

The fallow area was also extracted by superimposing the water surface and bare land layers. A fallow shrimp pond assumed shrimp cultivation in 2015 and halted this activity in 2016. Thus, the fallow shrimp pond was detected when its attribute data had both water-surface and bare-land in 2015 and 2016, respectively. The total fallow aquaculture area was 581.49 ha, which accounted for 4.44% of the total aquaculture area. Generally, the fallow aquaculture ponds were distributed randomly in the study area, and their distribution was almost along the seashore (Fig. 5).

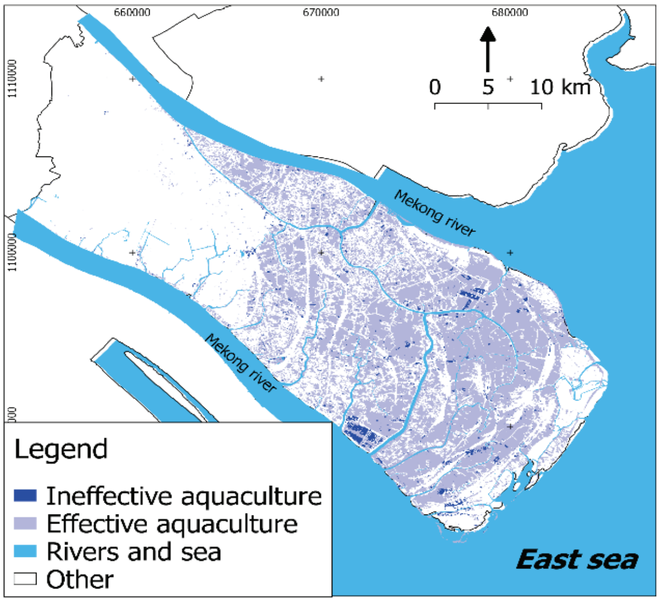


Fig. 5. Distribution map of aquaculture and fallow aquaculture ponds.

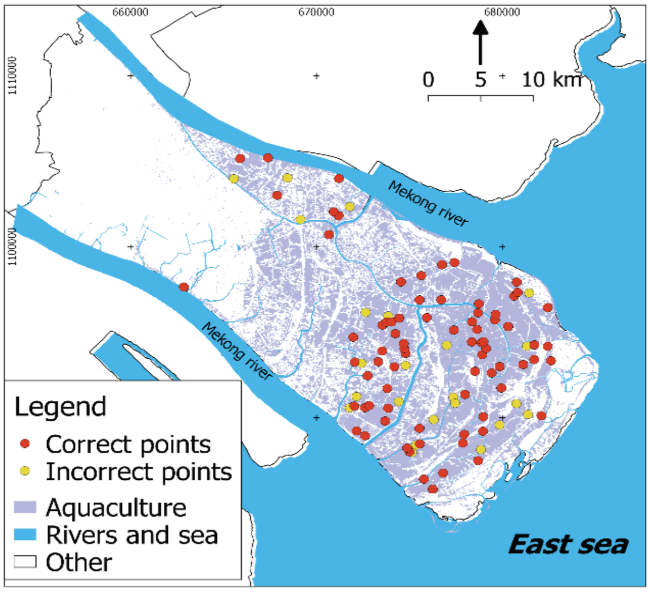


Fig. 6. Random points in the aquaculture area.

Accuracy assessment

Land use map utilized the aquaculture layer (Ben Tre DNRE, 2015) as truth data to assess the accuracy and collate the classified results and survey on 100 ground truth points. A total of 77/100 correct points (Fig. 6) demonstrated the overall accuracy achieved, with a high reliability of 77%.

Determining the fallow area in ecological regions

Thanh Phu district comprise four natural ecological regions. The detailed characteristics of each ecological region are presented in Table 2, highlighting the differences in saline concentration. Ecological region 1 has a freshwater ecosystem that is suitable for farming systems of rice crop, orchard, giant freshwater prawn and freshwater fish culture. The rest of the ecological regions (i.e. regions 2, 3, and 4) have a brackish water ecosystem that is appropriate for rice-shrimp rotation farming and shrimp cultivation such as extensive shrimp, intensive shrimp and shrimp-blood cockle combination.

Table 2. Ecological region in Thanh Phu district.

Region	ASSD (cm)	Salinity ($^{o}/_{oo}$)	Flood level (cm)	Area (ha)
1	No (<50)	<4	0-40	3,211.6
2	No	4-10	0-20	8,210.3
3	No (>50)	10-20	0-40	6,993.0
4	No	20-30	0-40	17,171.6

*Note: ASSD: acid sulphate soil depth.
Source: Ben Tre Department of Agriculture and Rural Development, 2015.

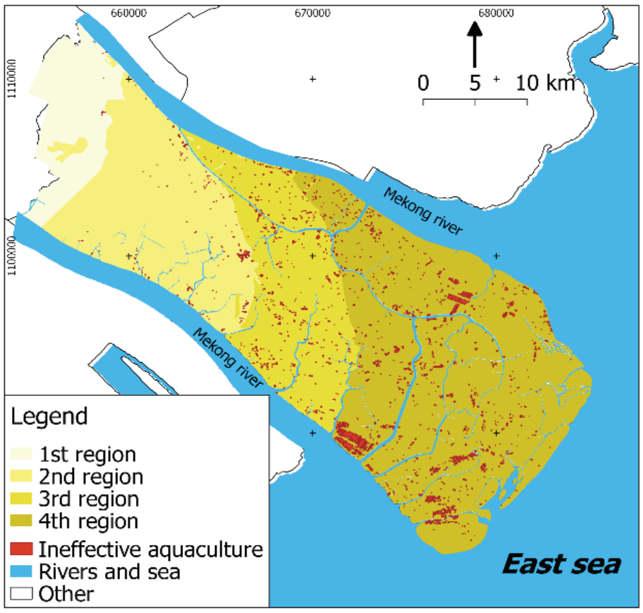


Fig. 7. Fallow ponds in each ecological zone.

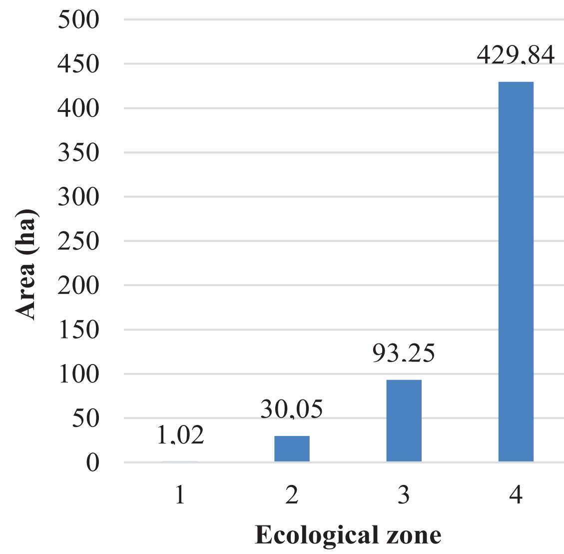


Fig. 8. Distribution of fallow aquaculture by ecological region.

Fallow aquaculture covered about 581.49 ha, and the area increased from ecological regions 1 to 4 (Fig. 7). The fallow shrimp pond area in region 1 merely accounted for 0.18%; on the contrary, the area of region 4 reached 429.84 ha and accounted for more than 70% of the total area of the fallow area (Fig. 8).

Discussion

Remote sensing in aquaculture classification

In terms of the satellite resolution and land use map scale for district level, a district with the total area larger than 12,000 ha should be mapped in the scale of 1:25,000 [15]. Hence, in theory, Landsat 8 imagery with a 30-metre spatial resolution merely achieves the map scale of 1:60,000 [16, 17], and it is merely suitable for provincial maps. However, the Thanh Phu district area is approximately 40,000 ha (i.e. nearly four times the size of the standard). Thus, the result map could be accepted in the context of freely high-resolution imagery is not available. The research period was from 2015 to 2016; hence, Sentinel-2 imagery with a 10-metre resolution was unavailable at the beginning of the research period. In further studies, the resolution of Landsat-8 imagery could be enhanced by combining multispectral bands and panchromatic band to obtain a higher spatial resolution of 15 metres (corresponding to the scale of 1:30,000).

The research identified the highly accurate aquaculture area including effective shrimp and fallow shrimp farms. The fallow shrimp pond (fallow pond) was objectively detected through the integration of spectral indices instead of visual classification [18]. However, the research was able to detect only the shrimp ponds where farmers had lost income, that is, fallow ponds in 2016. The other ineffective ponds that were still covered by water surface would not be recognized on the remotely sensed imagery. Similarly, the intensive and extensive aquaculture systems could not be distinguished through the imagery. The remote sensing technique could detect both the general aquaculture areas and the fallow ponds. However, some of LULC types mixed together-triple rice-orchard and rice shrimp rotation-mangrove forest-could not be classified in more detail using a single Landsat image. The use of a multi-series imagery could improve this limitation. High-resolution imagery and object-based image analysis via object texture are expected to distinguish extensive and intensive shrimp farming (i.e. industrial shrimp farming).

Ineffective shrimp in Thanh Phu district

According to the published references, the giant tiger prawn *(Penaeus monodon)* adapts to salinity from 5 to 31‰ [19], whereas the white leg shrimp *(Penaeus vannamei)* adapts to salinity from 7 to 34‰ [20]. Thus, brackish shrimp culture could be effectively cultivated in ecological regions 2, 3, and 4. However, the region with the highest salinity (i.e. region 4: 20 to 30‰) is the most vulnerable region. The prolonged sunny season (e.g. 2016) and lack of freshwater increased the water salinity in shrimp ponds and exceeded the highest level of salinity to which shrimps could effectively adapt. Therefore, high water salinity influenced the survival rate and productivity of shrimp and adversely affected the incomes of farmers. Finally, the area of the fallowed aquaculture ponds located in region 4 was rationally higher than the rest of the ecological regions.

Aquaculture cultivation in Thanh Phu district continues to encounter obstacles emanating from adverse weather conditions in the dry season, which increases temperatures and water salinity levels. Moreover, heavy rain, high salinity, pH and alkalinity change rapidly affect water quality, which consequently slows down shrimp growth. Market prices are the most serious problem in Thanh Phu district where selling prices are lower than product prices. The prices of aquatic fingerlings are relatively high. Thus, merely 50% of the farmers used quality aquatic fingerlings for their farming, whereas other farmers had no stocks of aquatic fingerlings on their farms. Hence, the randomly identified fallow shrimp pond was presented in the context of the farmers' decision to halt the cultivation.

Conclusions

This research examines the spatial distribution of aquaculture and fallow aquaculture ponds in Thanh Phu district, Ben Tre province by using the three indices of NDVI, MNDWI and NDBaI. The accuracy is assessed at 77%, which indicates the capacity of remote sensing in general aquaculture detection.

Moreover, fallow aquaculture ponds are commonly distributed in ecological region 4 (more than 70% of the total aquaculture area). High water salinity also affects this ecological region. The research reveals the aquaculture zones and fallow ponds, which correspond to water salinity by ecological region.

The suggestions for further research are related to the improvement of techniques and reduction in risk in the ineffective aquaculture region.

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The authors declare that there is no conflict of interest regarding the publication of this article.

REFERENCES

[1] Trai. N. Van (2013), *Detailed plaining of Aquaculture on Binh Dai, Ba Tri and Thanh Phu district to 2020*.

[2] Ben Tre People's Committees (2011), *Impact assessment, detailed climate change scenarios in Ben Tre and recommend response solutions*.

[3] Ben Tre People's Committees (2010), *General report the overall planning of economic - social development in Ben Tre Province in 2020*.

[4] Prime Minister (2011), *Decision 83/QD-TTg: Approving the master plan of economic - social development in Ben Tre province in 2020*.

[5] Khoa. L. Van, N.T.C. Su, V.Q. Minh, P.T. Vu (2013), "Agro-ecological zoning according to hydrology, pedology and present land use for coastal districts in Ben Tre province", *Can Tho University Journal of Science*, **26**, pp.227-236.

[6] Thanh Phu People's Committees (2010), *Review Report about economy and society in Thanh Phu district in 2005, 2006, 2007, 2008, 2009, and 9 beginning months of 2010*.

[7] US. Geological Survey (2013), *Landsat Quality Assessment Band*, http://landsat.usgs.gov/qualityband.php.

[8] B. Kim, Y. Han, Y. Kim (2012), *Generation of cloud-free imagery using Landsat-8*.

[9] C.J. Tucker (1979), "Red and photographic infrared linear combinations for monitoring vegetation", *Remote Sensing of Environment*, **8(2)**, pp.127-150.

[10] S.K. McFeeters (1996), "The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features", *International Journal of Remote Sensing*, **17(7)**, pp.1425-1432.

[11] H. Xu (2006), "Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery", *International Journal of Remote Sensing*, **27(14)**, pp.3025-3033.

[12] R. Bouhennache, T. Bouden, A.A. Taleb, A. Chaddad (2015), *Extraction of urban land features from TM Landsat image using the land features index and Tasseled cap transformation*, http://www.inase.org/library/2015/barcelona/bypaper/ELECTR/ELECTR-22.pdf.

[13] A.R. As-Syakur, I.W.S. Adnyana, I.W. Arthana, I.WW. Nuarsa (2012), "Enhanced built-up and bareness index (EBBI) for mapping built-up and bare land in an urban area", *Remote Sensing*, **4(10)**, pp.2957-2970.

[14] N. Horning (2004), *Overview of accuracy assessment of land cover products Version 1.0*, American Museum of Natural History, Center for Biodiversity and Conservation.

[15] Ministry of Natural Resources and Environment (2007), *Decision 22/2007/QD-BTNMT: Issue regulations on establishment of land use map*.

[16] W.R. Tobler (1987), "Measuring spatial resolution", *Land Resources Information Systems Conference*, pp.12-16.

[17] W.R. Tobler (1988), "Resolution, resampling, and all that", *Building Data Bases for Global Science*, pp.129-137.

[18] N. Van Thao, N.D. Cu, and N.X. Thanh (2012), "Maping and detecting fallowed area of cultivated tiger shrimp ponds of coastal provinces by using remote sensing data", *J. Mar. Sci. Technol.*, **12(3)**, pp.34-45.

[19] The National Fisheries Promotion Center (2006), *Cultivation techniques for intensive giant tiger prawn (Penaeus monodon)*, Publishing house of Agriculture.

[20] Agricultural Extension Center Hochiminh city (2009), *Handbook: Whiteleg shrimp cultivation (Penaeus vannamei)*.