DETECTION AND QUANTIFICATION OF SUBMERGED SEAGRASS TOTAL ABOVEGROUND BIOMASS CHANGES IN TINGGI ISLAND, JOHOR USING REMOTE SENSING DATA

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Abstract

Tinggi Island area is gazetted as Johor Marine Park while unpredictable natural phenomenon claimed as a primary threat that caused reduction of submerged seagrass total aboveground biomass (SSTAGB). This study aims to (a) detect and quantify SSTAGB in clear water of the Tinggi Island area using satellite data, and (b) assess SSTAGB changes in 2009 and 2014. Algorithm of Bottom Reflectance Index is implemented on Landsat 8 OLI image of 2009 and 2014 to detect and study spatial distribution of multi-species submerged seagrass. Field data sampling was conducted to validate the classified satellite image. A series of quadrat sampling of 0.5mx0.5m was used to quantify ground-based SSTAGB. The result found that the seagrass area and SSTAGB around the island are rigid and remarkably consistent over a 5-year interval. A strong association between ground-based SSTAGB and satellite-based SSTAGB shows that the BRI model is significantly satisfied to be implemented on moderate resolution of satellite data with overall accuracy of >70% and >0.65 of kappa statistic.

Keywords: Satellite, Reflectance, Aquatic, Case-1

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Introduction

Submerged aquatic vegetation including intertidal and submerged seagrass meadows are the dominant shallow substrate components in global coastal water. Seagrass is the only flowering aquatic plants surviving on the seafloor and offering numerous ecological services that are crucial for mitigating plan for coastal protection (Misbari, 2016a; Collier and Waycott, 2014; Hashim, 2014; Roelfsema, 2014), and natural resources maintenance including commercial fish species (Cullen-Unsworth, 2014; Beaumont et al., 2008) and carbon sequestration (Fourqurean, 2012; Constanza, 1997). In regional scale, Southeast Asia is claimed as the richest seagrass species in the world (McKenzie et al., 2021; Short, 2005) and becomes the most iconic submerged vegetation that brought significant impact on coastal health and seascape components.

Seagrasses are common in nearshore and subtidal sand habitats in tropical coastal water of Peninsular Malaysia (Ooi et al., 2011). Islands located within the gazette area of Marine Park such as Tinggi Island and Sibu Island in Johor are among the prominent places of seagrass habitat in Malaysia, especially along the east coast of Peninsular Malaysia. In the past few decades, many studies related to seagrass biomass in this region focused on the ground-based technique including diving or snorkelling observation (McKenzie, 2003; Gotceitas, 1997), underwater photographic assessment (Mumby, 1997), and less sophisticated technology have been used to monitor the activity on this submerged aquatic species. Seagrass meadows create a characteristic landscape visually identifiable using aerial photography and satellite imagery. This region supports a variety of seagrasses, predominantly from the genera *Halodule, Cymodea* and *Halophila* (Bujang, 2006; Misbari, 2016a). Among the global community, there is less considerable attention to appreciate their huge contribution as ecosystem engineers and coastal defenders from natural coastal erosion.

Unlike seagrass habitat in other climatic regions such as Mediterranean and pacific region, satellite-based quantification of submerged seagrass total aboveground biomass (SSTAGB) in clear water in tropical countries has not been explored compared to manual harvesting methods, which are destructive to the seagrass habitat. While many studies focus only on the seagrass mapping in the Southeast Asia region (Sudo et al., 2021; Fortes et al., 2018), this study extends the focus into perspective on the biomass quantification of multi-species seagrass around pristine island of Tinggi Island. Many studies had been conducted on intertidal seagrass, where the seagrass was exposed to the air at low tide, whereas this study explores the seagrass biomass changes of submerging seagrass habitat using the optical satellite image in clear tropical water. Therefore, this study aims to (a) detect and quantify SSTAGB in clear water of the Tinggi Island area using satellite data, and (b) assess SSTAGB changes in 2009 and 2014. In fact, this study reveals the changes of submerged seagrass biomass using two different years. The assessment of the biomass changes has been carried out by assessing the changes pattern of the biomass on the satellite image based on its locational changes and seagrass coverage, which in turn identify its potential stressors to the dynamics of seagrass biomass in Case-1 water. Without a destructive sampling approach, satellite and Geographical Information System (GIS) tools offer the best approach to gather relevant information about the submerged seagrass in the context of its species diversity, richness, distribution and biomass. Information on seagrass dynamics could be utilised as a defensive reason for making critical decisions for coastal managers, policy makers and related authorities such as the National Department of Fisheries Board. Due to climate change, seagrass loss is prominent in global water (Short, 2005) and expected to continue, since seagrass is vulnerable to rising water temperature, sediment load and turbidity (Phinn et al., 2008). The information is important for marine life conservation efforts and supports Sustainable Development Goal (SDG) 14 that intends to ensure marine resource sustainability in the long term. This study spurs the production of innovative shore infrastructure technology in reducing water pollutants and dissolved solids to coastal areas. Satellite has many advantages to achieve the objective of this study, which covers huge area, multi-temporal images and requires less harvested seagrass samples compared to conventional methods in attaining ground-based seagrass biomass data.

Methodology

Water column correction: Bottom Reflectance Index (BRI)

Satellite images of Landsat 5 Thematic Mapper (TM) of 2009 and Landsat Operational Land Imager (OLI) of 2014 were used to detect submerged seagrass occurrences in Tinggi Island, Johor. In fact, a hydrographical chart purchased from National Hydrographic Centre of Malaysia was used to obtain the depth information plus the tidal chart at the time of satellite passing at the selected scene. As seagrasses around Tinggi Island are always submerged, seagrass sampling was collected by diving and underwater video was operated to record the seagrass coverage, close to the time of the satellite passing the island.

Prior to the main data processing, the satellite data were subjected to data-preprocessing tasks and image preparations. Pre-processing tasks include: (i) image clipping, (ii) image rectification, (iii) image masking, (iv) atmospheric correction and (v) conversion of satellite digital number to reflectance unit. All the data processing tasks were performed using digital image processing software ENVI version 5.0 and ArcMap version 10.4.

Bottom Reflectance Index (BRI) algorithm Equation (1) was used to retrieve water-leaving radiance that acts as water column correction on Landsat images (Misbari and Hashim, 2016a). Using BRI, submerged seagrass mapping requires sea depth information, since the capability of BRI to detect submerged seagrass is affected by depth information.

$$BRI = \frac{Li - Lsi}{[-KgZ)]} \quad (1)$$

where L_i is measured radiance in band i; L_{si} is deep-water radiance in band i; K_i attenuation coefficient for band i,g is geometric factor to account for the path length through water and Z is sea depth (m).

Depth variation is highly significant to the detecting capability of visible spectral bands on seagrass habitat in Case-1 water. BRI can be implemented on the blue and red band of each satellite image using data of attenuation coefficient, geometric factor and depth during satellite passes. Maximum Likelihood Classification on processed-images were then used to identify submerged seagrass distribution surrounding Tinggi Island with Case-1 water.

SSTAGB processing begins after seagrass distribution mapping using the ground-based measurement on selected samples of seagrass using an underwater camera. Thus, dried-seagrass samples were quantified using super-sensitive digital weight (Figure 1). Regression of dried-biomass with BRI value was then implemented on landsat images to attain the satellite-based SSTAGB. A total of Root Mean Square Error (RMSE) also has been calculated for the SSTAGB 2009 and 2014, which indicates the accuracy of satellite-based and ground-based SSTAGB quantification.

Figure 1: (a) A snapshot of seagrass sampling video using underwater camera; and (b) Dried-biomass measurement of seagrass sample.

Study area

Tinggi Island (Figure 2) is a small isolated island in Mersing, Johor. It is located about 30km off to the city centre of Mersing and 19km from the Tanjung Leman Jetty. Water around the Tinggi Island is categorised as Case-1 water, where *chlorophyll-a* is the dominant element, with minimum sediment and dissolved solid.

As the water is very clear, myriad of benthic features including sea urchins, coral reefs, seaweed and seagrass are easily observed in shallow waters. Tinggi Island water is deeper than the Straits of Johor, as the subtidal seagrass habitat can be found as deep as 40 m. Seagrass species of the Tinggi Island area includes *Cymodocea serrulata, Cymodocea rotundata, Thalassia hemprichii, Syringodium isoetifolium* and *Halophila ovalis*. Seagrass patches around this area have various sizes. At the northern part of the island (near Kg. Sebirah Besar), coral reefs are extensively found. The Malaysian government has gazetted Tinggi Island and adjacent continental islands as Marine Park under Fisheries Act 1985 since 1994. Under this regulation, any construction work is very limited to preserve all benthic communities in the marine park, including seagrass.

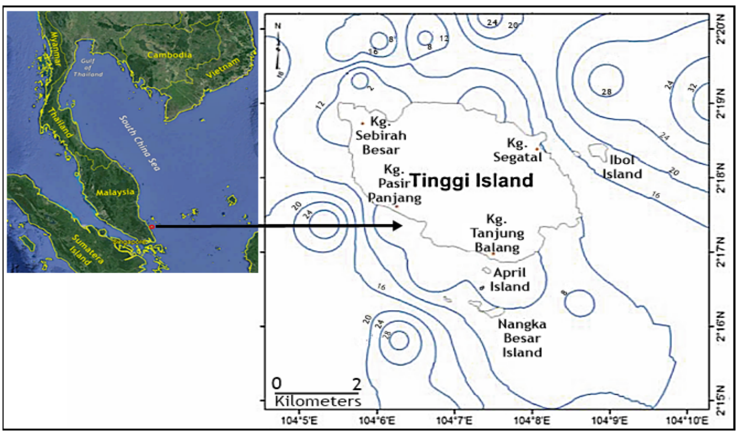


Figure 2: Location of Tinggi Island at Mersing, Johor. Depths (in meter) are shown by blue isolines. (Misbari and Hashim, 2016b)

Primary Data

The tidal height close to the time of image acquisition is calibrated using time and sea depth information. Depth is the actual water depth during satellite passes, derived from corresponding nautical chart plus the tidal height during sea truth information being collected. Depth information is obtained from extraction depth value in sandy area from the most current hydrographical chart with scale 1:10,000 to 1:25,000. Tidal height during the satellite passes is extracted from tidal chart. Interpolation of know bathymetric location with additional tidal height was undertaken in GIS processing system using interpolation function, namely spline interpolation scheme.

Table 1: Tidal height information and geographical path factor of Landsat calculated from image pre-processing phase.

Satellite Data	Date	Time of satellite pass	Tidal height	Geometric factor, *g*
Landsat-5 TM	24/04/2009	11:03:41 am	+2.10 m	2.1065
Landsat-8 OLI	14/04/2014	11:15:49 am	+0.45 m	2.0994

Ancillary Data

Two multi-spectral images from optical satellites, Landsat 5 TM and Landsat 8 OLI, freely downloaded from United States of Geological Survey (USGS) official website, were used to extract processed-radian value of more than 30 selected sand pixels for identification process. Both images were projected using Universal Transverse Mercator (UTM) coordinate system. All images were preprocessed, including stacking of RGB-band to generate a natural colour composites, cloud masking and conversion of DN to top-of-atmosphere radiance and then pixel reflectance.

There are two main steps comprise four phases of data processing involved in this study: (i) data pre-processing including geometric correction, atmospheric correction and radiometric calibration of satellite image; and (ii) detection and mapping of seagrass occurrence. The distribution of seagrass is referred to previous documented seagrass-related studies in Malaysia.

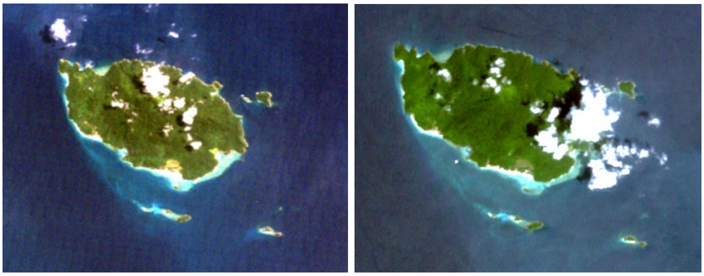
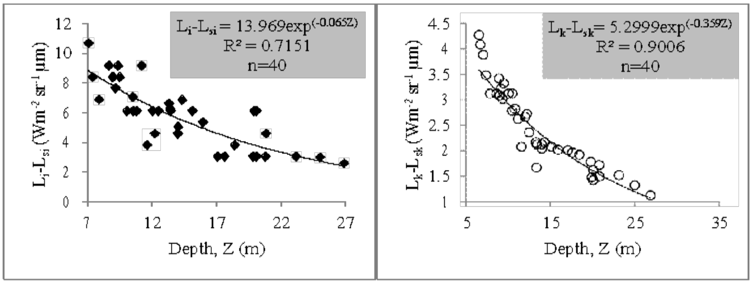


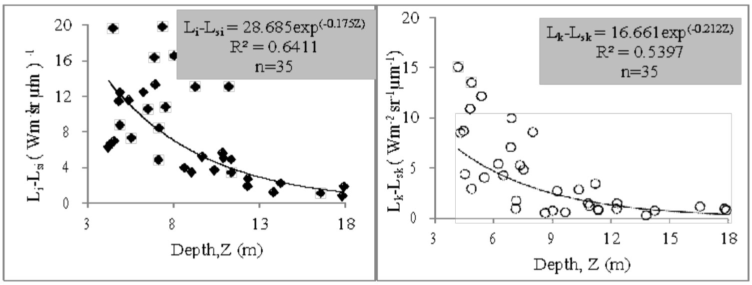
Figure 3: Tinggi Island viewed from Landsat TM (2009) and Landsat OLI (2014). Image loaded with natural composite (RGB) spectral bands.

Result and Discussion

Seagrass habitat is well adapted with tropical coastal water that receives sufficient light intensity, and hot and humid weather throughout the year, which are very important for green features survival that live under water along with other shallow substrates. Using BRI, the value of light attenuation coefficient is less because clear water at surrounding Tinggi Island allows high light propagation towards the seafloor, including submerged seagrass. Thus, detection of submerged seagrass from satellites around Tinggi Island (Case 1 water) is more efficient on satellite images but the sea bottom depth is the limitation of submerged seagrass mapping at this area. The propagated electromagnetic radiation (EMR) signal of water penetrative band (blue band) into the depth of sea floor (>55m) is unable to reach back to the satellite sensor due to signal attenuation in the water column and atmosphere.



(a) Blue band (left) and red band (right) of Landsat-5 TM at Tinggi Island

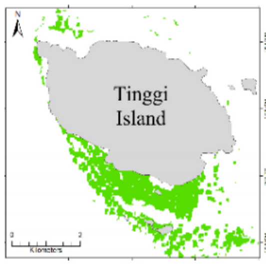
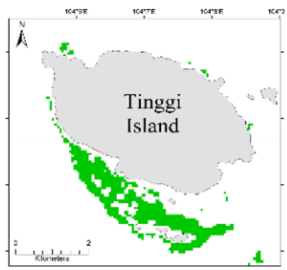
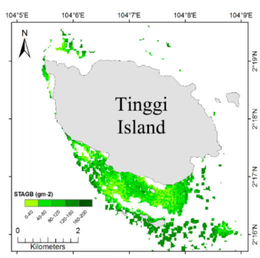
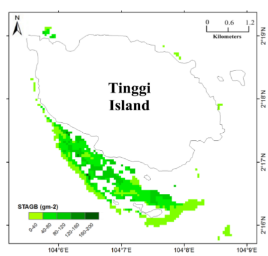


(b) Blue band (left) and red band (right) of Landsat-8 OLI at Tinggi Island

Figure 4: Computation of attenuation coefficient at Tinggi Island during image acquisition of Landsat TM (a); and OLI (b).

The result found that the seagrass area and SSTAGB around the island are rigid and remarkably consistent over a 5-year interval (Table 2). A strong association between ground-based SSTAGB and satellite-based SSTAGB (Misbari, 2016b) shows the BRI empirical model is significantly satisfied to be implemented on moderate resolution of satellite data with overall accuracy of >70% and >0.65 of kappa statistic. Green tone colour of SSTAGB map (Table 2) indicates the variation of SSTAGB being quantified; dark green indicates high biomass content and pale green shows low biomass content. Low SSTAGB remarks that the seagrass has low density at the time of satellite acquisition.

Table 2: Change of seagrass distribution and SSTAGB of Tinggi Island using BRI.

Year	2009 (Landsat TM)	2014 (Landsat OLI)
Seagrass distribution map		
Seagrass extent	5.81 km^2	3.31 km^2
Overall accuracy	71.3%	75.86%
Kappa statistic	0.6516	0.6699
SSTAGB map		
Quantified SSTAGB (± RMSE)	239±34.7 kg	227±17.4 kg
SSTAGB accuracy	93.4%	94.6%

Based on Table 2, BRI proved its high robustness in clear water surrounding Tinggi Island for seagrass detection and mapping using satellite data. Landsat-8 OLI (RMSE: 17.4kg) produces better accuracy of SSTAGB quantification compared to TM image (RMSE: 34.7kg), indicated by lower RMSE value; when both results were compared with field-based SSTAGB quantification (harvested). The findings revealed that for satellite-based SSTAGB, quantification at clear water is the most suitable by using Landsat-8 OLI. OLI image has very high radiometric resolution (16-bits quantisation level) compared to other optical images, which enables SSTAGB to be quantified based on reflectance-retrieval details on the pixel-basis using BRI as the devising method.

Based on the results, insignificant change of seagrass extent has been shown in Case-1 water of the Tinggi Island area from 2009 to 2014. Aligned with this trend, the empirical quantification revealed that there are no remarkable SSTAGB changes within the same time-frame. Based on Table 2, only seagrass habitat facing the South China Sea is exposed to high risk of SSTAGB decrement. Continuous strong wave exposure from the South China Sea and dynamic changes of water quality, especially the water temperature (Duarte et al., 2018) along the open sea side are expected to be the main reasons for that implication. Less seagrass density in this particular coastal part denotes less SSTAGB is quantified from satellite images. Dark green colour on SSTAGB map indicates high SSTAGB and higher seagrass density, as retrieved on Landsat TM 2009 compared to Landsat OLI 2014, mostly at the southwest part of the Tinggi Island, as shown in Table 2. Apart from natural elements, the continuous number of domestic and foreign visitors annually to Tinggi Island is a contributing factor for the slight change in the water quality and causes seagrass loss due to slow adaptation to the new changing environment, even though the changes are minimal in this area. At most of the seagrass habitat in Tinggi Island, the SSTAGB remains high. Preservation effort should be continued to mitigate sudden natural phenomenon that could bring tremendous changes of SSTAGB in Tinggi Island.

Reduction of anthropogenic-driven activity that could minimise seagrass loss could assist in mitigating seagrass restoration around Tinggi Island, to ensure sustainability of coastal ecosystem, and equilibrium of blue carbon emission and sequestration. Current and huge waves of South China Sea have accounted as the main potential factor of seagrass death and SSTAGB decrement, since the species has ramified roots that are easily pulled off when the water turbulence hits the submerged seagrass. At the local scale, improved coastal management and infrastructure with exclusionary protection zones may provide good policy for survival of many seagrass species and consistency of density over the years.

Conclusion

Spatial and radiometric resolution of satellite image gives significant impact to the submerged seagrass mapping and SSTAGB quantification in clear tropical water. Pristine seagrass habitat at Tinggi Island produces higher accuracy of SSTAGB quantification compared to turbid water of Merambong area (Misbari and Hashim, 2015). High water transparency enables BRI to be more robust and relevant in presenting seagrass spatial coverage in deeper coastal areas.

The SSTAGB change between 2009 and 2014 is inconsequential because Tinggi Island has an ideal coastal environment and less water pollution. Johor National Park Department has the utmost responsibility to maintain the health of the seagrass habitat and the richness of marine ecosystem in Tinggi Island through dugong and green turtle conservation project, and protections of coral reefs and fish load. Less coastal alteration and anthropogenic disturbance in Tinggi Island have contributed to the seagrass sustainability. For recommendation, satellite images of high spatial resolution (less than 2m) such as PlanetScope, GeoEye-1 and Worldview-3, with low cloud coverage and shadows, are preferred to attain more information on SSTAGB, as well as to preserve the natural marine wealth in a long term. This information would be indirectly used by not only coastal managers, engineers and local authority, but also important for marine scientists and those involved in ecotourism who are seeking for seagrass status in the study area where seagrass is an important indicator of water clarity, diversity of aquatic species and survival of endangered marine species such as dugong.

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