VARIATION OF LIGHT ATTENUATION OF SEAGRASS HABITAT IN PENINSULAR MALAYSIA FROM SATELLITE-BASED ESTIMATION

S. Misbari, M. Hashim

Abstract

Light deprivation into the water column depends on the water clarity. Seagrass habitat is sparsely identified along the coastal area of Peninsular Malaysia. Seagrass density is affected by the amount of attenuated light into the water column, as light is essentially used for the growing process. Water along the west coast is more turbid than the south and east coast of Peninsular Malaysia. Blue spectral band (450 nm−510 nm) of Landsat 7 ETM+ satellite image that has strong penetrative power and red band (640 nm−670 nm) that is sensitive to subtle changes on seafloor features are useful to estimate variability of light penetration. A set of sampling points for both spectral bands was plotted with coastal depth. It is found that the east coast has 25% higher light penetration compared to south and west coastal regions. This condition is favourable for seagrass habitat. However, low light in deeper sea bottom and strong waves from South China Sea are among limitations imposed by east coast seagrass meadows to constantly survive.

Keywords: Penetration, Coastal, Landsat, Seafloor

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Faculty of Civil Engineering Technology, UMP Research Series: Construction Engineering and Management, Vol. 1, [insert doi here later]

Introduction

Seagrass meadows form a diverse benthic community in the tropical coastal ecosystem. It is one of the key sources of blue carbon content, and supports the productivity of adjacent coral reefs and seaweeds (Stankovic et al., 2021; Ricart et al, 2020). Dynamics of seagrass density and spatial distribution is highly affected by nutrient concentration, wave energy, water quality and light intensity. Light attenuation is one of the critical elements to significantly influence the rate of seagrass growth, both intertidal and shallow substrate seagrass habitat. In the global scenario, there is a trend of water quality and light level deterioration in coastal regions (Alsaffar et al., 2020), where they are typically inhabited by multi-species of seagrass. Tropical country that typically intensifies with at least 10 hours of intense light from 10am-6pm daily is a favourable climatic condition for seagrass habitat, proved by 10-16 species found in this region, particularly in Southeast Asia including Malaysia. However, vigorous urbanisation for marine tourism and consistent coastal alteration from more than two decades has weakened the ecosystem service of some physical elements, mainly light. Light should be responsible for seagrass growth, and density and sufficiency of light for seagrass have significant impact on the seagrass abundance and its biomass.

Decrement of seagrass occurrence, distribution, growth rate and imbalance carbon storage between above and belowground seagrass body are among the results of light derivation from air-water surface to the seafloor, where photosynthetic activity by seagrass leaf could not be efficiently carried out. Light source from the sun propagating into the water column to reach seagrass leaf measures how fit the seagrass could be to survive in such an environment. Malaysia is one of the countries whose area is mostly surrounded by sea water. Out of 6,036.7km of the total Malaysian coastline, Peninsular Malaysia is surrounded by more than 1,926km from west coast, south to east coast of continental region. Coastal region around Peninsular Malaysia could be divided into two; the east coast has good clear water whereas on the opposite, west coast and south coast have less clear and turbid water. Some countries with less clear water could not support seagrass growth (Unsworth et al., 2019; Saunders et al., 2017). Low light availability to seagrass, primarily at the deepest edge of the seagrass meadow could minimise the rate of photosynthesis (Ralph et al., 2006). Uniquely, seagrass can occupy both of these parts that signify that light penetration from intense light received by Malaysia as a tropical country is one of the critical elements for seagrass survival that is still able to supports sustainability of seagrass occurrences in this country, but it has various influences from other elements. Currently, how strong the relationship between light penetration ability to submerge seagrass in Peninsular Malaysia (PM) is still being questioned. There is limited knowledge to understand inter-relationship between light attenuation of different coastal parts in PM and seagrass distribution. Light propagation into the water column varies on each satellite scene at east, west and south coastal regions. Hence, the aim of this paper is to determine the variation of light penetration by knowing how much the light has been attenuated in submerged seagrass habitat along the coastal region of Peninsular Malaysia using a set of satellite data. Optical remote sensing sensors are effective to indicate variation of light attenuation along the coast of PM, primarily at seagrass patches area.

The research information would be useful for marine scientists who are seeking current status of water quality and threats to seagrass communities in the future, so that effective mitigation action could be designed earlier. In addition, the civil engineers may use this information to encourage development of coastal infrastructure and technological tools or system at the most suitable places at national scale in improving coastal health, by monitoring technology at the coastal area, reducing chemical pollutants and dissolved solid into the estuary such as tide gates, and coastal monitoring system and breakwaters. Moreover, satellite is one of the advantages that covers a huge area, so the cost to investigate the light penetration is not only specified in patch and confined areas, in fact shortening the cost and manpower.

Methodology

Data Gathering: Satellite images and in-situ data collection

Two main material sets were used in this study, namely the satellite remote sensing data and ground data collection using field samples from in-situ observation. The image of Landsat 7 Enhanced Thematic Mapper (ETM+) 2014 was used to detect submerged seagrass occurrences in Peninsular Malaysia. Besides that, hydrographical chart acquired from National Hydrographic Centre of Malaysia was used to extract the depth information plus the tidal chart at the time of satellite passing to selected scene. During low tide, the seagrass sampling (extruded seagrass) was also collected, close to time of satellite passing the seagrass habitat such as Merambong shoal, Johor. Seagrass habitat found in Peninsular Malaysia is referred to previous published studies.

Meanwhile, the selected samples were then physically measured. Images with less cloud cover were selected since cloud-affected scenes potentially degrade the data quality, in fact noises on high resolution satellite data could be filtered for submerged seagrass in less clear water with better detection accuracy (Misbari and Hashim, 2014). There are two main steps comprising two main phases of data processing involved in this study: (i) data preprocessing and (ii) distribution of the seagrass occurrence. The distribution of seagrass is referred to previous documented seagrass-related studies in Malaysia. The satellite data were subjected to data-preprocessing tasks and image preparations, prior to the main data processing. These data involved in the pre-processing stage include: (i) image subset, (ii) geometric correction, (iii) atmospheric correction, (iv) image masking and (v) conversion of satellite digital number to radiance. Geostatistical interpolation technique and seagrass distribution mapping on satellite images are the main elements in the processing phase. Digital image processing software, namely ENVI version 5.3 and ArcMap version 10.8, were used to perform all the data processing tasks.

Study area

Patches of intertidal and submerged seagrass habitat are scattered along the west, south and east of coastal region in Peninsular Malaysia. Using passive satellite system, the image is acquired only during daylight where the electromagnetic energy from the sun is propagated into the water before reflected back by seagrass. As located near equatorial belt in Southeast Asia, Malaysia received high sunlight intensity for 12 hours daily, where the peak solar intensity is typically within 12pm to 1pm. Landsat ETM+ sensor would pass regularly this region from ±10.30am from Johor at south to north states, for every 16 days. A total of 10 Landsat scenes is required to cover the whole coastal region of Peninsular Malaysia. Images in Figure 1 are loaded in RGB composite, where R: red band (Band 3); G: green band (Band 2) and B: blue band (Band 1). All selected images have less than 30% cloud coverage to optimise the accuracy measurement.

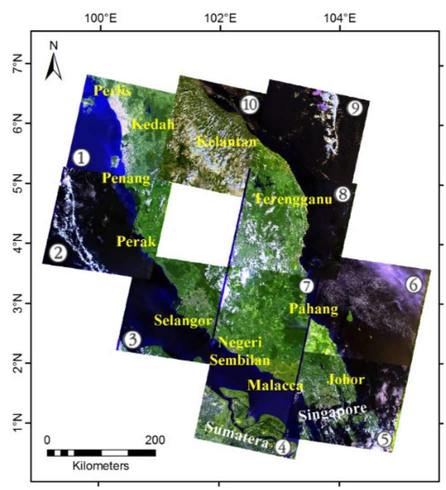

Figure 1: Mosaics of Landsat ETM+ images cover the whole Peninsular Malaysia.

Primary Data

Bathymetry data and nautical chart

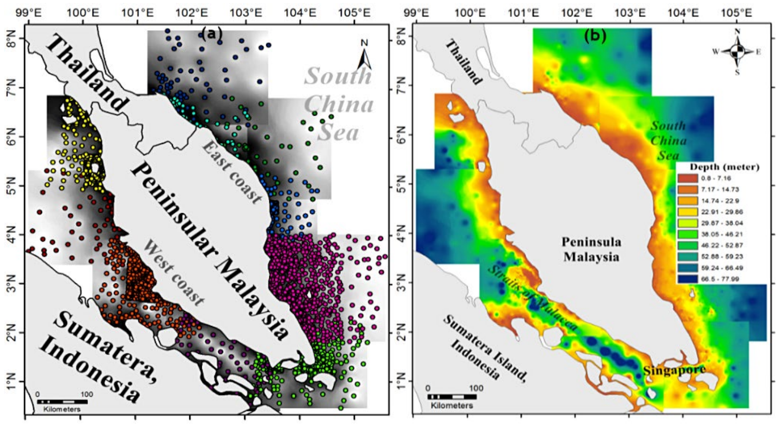

Figure 2: (a) The extraction point of depth information from official national hydrographic chart. Different colour indicates different scene boundary of Landsat; (b) An interpolated depth of coast in Peninsular Malaysia.

Time and depth were collected for calibration of tidal height during image acquisition. Depth is the actual water depth during satellite passes, derived from the corresponding nautical chart plus the tidal height during sea truth information being collected. Depth information is obtained from extraction depth values in sandy areas from the most current hydrographical chart with scale 1:10,000 to 1:25,000 produced by National Hydrographic Centre of Malaysia that covers the whole coast along Peninsular Malaysia. Interpolation of known bathymetric location using GIS processing system using interpolation function namely spline interpolation scheme. Both the extracted points and interpolated depth of sea bottom are shown in Figure 2. Sandy area is an ideal location to indicate how the light can be attenuated in the water column, after processing of the satellite scene. Nevertheless, some points of deep area have also been extracted as light penetration ability is indirectly proportional to depth.

Attenuation coefficient, K_i, measurement on satellite data could give different values from different bands. Landsat ETM+ has three visible bands and other bands are not necessarily used, since light is almost fully-absorbed in longer wavelengths. A strong penetrative power of the blue band (450 nm-510 nm) and property of the red band (640 nm-670 nm) of Landsat 8 OLI that is sensitive to subtle changes on seafloor features are used to estimate variability of light penetration. It requires input of radiance at sensor pixel (L_i) and radiance of deep water (L_{si}) of a particular band. Use of radiance in reductive measurement of light across the water column could be a water clarity measurement in seagrass-related habitat. This technique assumed that the water attenuation coefficients of each pixel in selected bands remain constant over the study area and independent from benthic types. For ground truth data collection, both intertidal and submerging seagrass samples were collected, in fact other benthic organisms (non-seagrass) information had also been collected.

Seagrass growth, distribution and abundance are highly dependent on the light availability in its habitat. It is not staggering that some species of seagrass could struggle to survive in less clear water with high light attenuation in the water column towards the seagrass area. Figure 3 shows the distribution of seagrass location found in Malaysian coastal waters by field sampling.

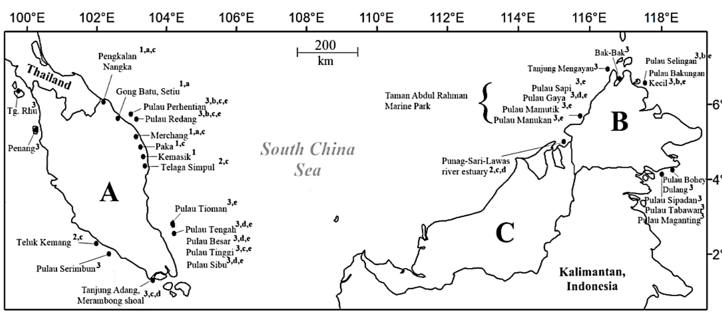

Figure 3: Seagrass habitats in Malaysia and utilisation by coastal communities in Peninsular Malaysia (A); east Malaysia-Sabah (B); and Sarawak (C). Lagoon[1], inter-tidal[2], sub-tidal[3]. Aquaculture[a], turtle sanctuary[b], traditional capture fisheries[c], dugong feeding ground[d] and marine park[e]. (Modified from: Bujang et al., 2006)

Ancillary Data

Moderate resolution satellite multi-spectral images of Landsat 7 ETM+ are used to extract processed-radian values of more than 30 selected sand pixels. In total, 10 images for the whole coast area of Peninsular Malaysia are openly accessed from the United States of Geological Survey (USGS) official website. All images were preprocessed, including stacking of RGB-band to generate a natural colour composites, cloud masking and conversion of DN-top-of-atmosphere. Then, all selected satellite scenes will be processed to obtain the radiance value of the sandy area at the coastal region, as well as some value of deep water in the middle of the straits.

Result and Discussion

Light attenuation coefficient

In terms of geographic location, Malaysia is surrounded by Straits of Malacca in western coast, South China Sea in eastern coast and Straits of Johor in the southern region. To ensure sustainable total volume of fish landing, survival of marine life and dynamics of coastal health vulnerability, good policy and efficient management should be implemented by synergy from related agencies, authority and organisations. To monitor the quality of the seagrass habitat, conventional methodologies are required to frequently monitor the important components that highly influence coastal health. However, these methodologies have some shortcomings although the approach is accurate. This includes the inability to generalise the localised sampling location, lack of consideration of the other surrounding environments that influence the light penetration including water quality, the cost in terms of time and money. Remote sensing tools enable near-real time monitoring of such dynamic environments. Great light attenuation always creates pertinent issues in thriving of seagrass and precise identification of the seagrass patches using satellite-based approach, mainly places with complex land use and land cover categories. Table 1 summarises the K_i results from processing of Landsat images.

Table 1: Attenuation coefficient and corresponding status of water clarity of each satellite scene along coastline of Peninsular Malaysia.

Scene No.	State	Light attenuation coefficient, K_i		Status of water
		Blue	Red	
1.	Penang, Kedah, Perlis	0.0932	0.4294	Moderate
2.	Perak	0.1015	0.4925	Less clear
3.	Selangor, East Sumatera	0.1192	0.4889	Less clear
4.	Negeri Sembilan, Malacca, East Sumatera	0.0994	0.4819	Less clear
5.	Johor	0.0942	0.4656	Moderate
6.	Pahang (small)	0.0834	0.1010	Clear
7.	Pahang	0.0311	0.0413	Clear
8.	Terengganu	0.0083	0.0272	Clear
9.	Kelantan	0.0096	0.0471	Clear
10.	Kelantan (small), South Thailand	0.0214	0.0424	Clear

Based on Table 1, the clarity of Malaysian coastal water apparently is not uniform, demonstrating that light penetration varies in seagrass habitat. East coast comparatively has higher light penetration compared to west and south regions of Peninsular Malaysia, indicated by high attenuation in the blue and red band of Landsat image. It is found that the east coast that is almost covered by high water clarity has 25% higher light penetration into the water column. Based on field site inspection, light can be received by seagrass depth of ≥35m in the east coast region. Some species of seagrass such as *Halophila ovalis, halophila minor* and *halophile decipiens* could survive in low light penetration as long as the nutrients are sufficient to grow well on the seafloor. This is true for species where the seagrass leaves are small and have ramified roots, where low receiving light to be used in photosynthesis process can be compensated with ample of available nutrients. Elevated nutrients are essential for seagrass growth. However, seagrass shrinkage was strongly correlated with eutrophic waters, due to light limitation resulting from an increase in epiphytic growth or algal blooms in the water column (Dennison et al., 1993; Ralph et al., 2006). Both algal blooms and epiphytes reduce the amount of light reaching the seagrass plants (Cambridge and McComb, 1984; Short and Wyllie-Echeverria, 1996).

Attenuation coefficient, K_i, of blue, green and red band on both images shows increasing trend from short wavelength (blue band) to longer wavelength (red band). It is an indication that light is quickly attenuated when it passes through the water column at a longer wavelength. Blue band has better water penetration ability than red band of Landsat, an optical satellite image from passive remote sensing satellite (Misbari and Hashim, 2016). This shows that the medium is relatively transparent to the shorter wavelength (blue band), where seagrass leaf and its density can be determined efficiently, better than other bands. The pattern was shown in all selected scenes, while light in longer wavelength theoretically is fully absorbed by the water. Based on the plotted graph between sand points and corresponding (*Li-Lsi*) radiance, the least attenuation coefficient is blue band, followed by red band, was prone to light attenuation for selected images. It is expected that this trend is similar on visible bands of other satellite imagery; light is highly attenuated in longer wavelengths of visible bands. Compared to other visible bands, blue bands of all Landsat images are able to receive more bottom reflectance. This trend is shown on Landsat at a non-ideal condition of water clarity like the Merambong area at southern Johor, based on the data collected in 2013 and 2014, where water turbidity varies, and more turbid at seagrass shoal located very close to reclamation projects and port activity. Therefore, the light environment of a seagrass meadow in Peninsular Malaysia is influenced by consolidation of light attenuation by the water column, the bottom depth, size of seagrass leaves and its density. A change in the attenuation properties of any one of these could affect the others. In the Merambong area, it is proved that turbidity and bottom depth are the crucial factors that contribute to depletion of submerged seagrass distribution. The presence of seagrass did not affect the composition of absorbing compounds in the water column (Hill, 2014). Based on this study, inter-species delineation in the seagrass spectral reflectance was less accurate, since natural composition of the seagrass beds in highly attenuating environment.

The penetration ability of specific wavelength enabled the electromagnetic signal to reach submerged seagrass even though a small signal proportion was scattered back, by floating solid particles or dissolved suspended materials before reaching the seagrass physical structure. In the Strait of Malacca area, where the attenuation is high, the seagrass is possibly identified from satellite in less clear water but with correct image processing technique, and good quality of primary and ancillary data. Nevertheless, the detecting seagrass-dominated pixel of satellite data is expected to be limited only up to ≤7 m at the euphotic zone, where the turbidity level is relatively high along Malaysian coastal region.

At several seagrass habitats in the west coast, only some areas with less turbid and shallow water allow seagrass detection in coastal regions such as Langkawi Island and vicinity of Penang Bridge area. The seagrass is not identifiable from an optical satellite image including Landsat image if the sea bottom is very shallow but the turbidity is high. Seagrass at east coast like Terengganu and Kelantan around area with good water clarity can be detected since the water has low sedimentation and low light attenuation, but the bottom depth of ≥20 m is the limiting factor of seagrass to be detected due to light refraction. Under low-light conditions, the leaf size is usually decreased (Chartrand, 2012), which minimise the respiratory demand of the shoot and photosynthetic capacity of the leaves.

Radiative transfer model is an alternative to calculate the radiant loss in terms of its beam energy due to being absorbed and scattered along a defined path and the intervention of an additional gain of scattering from different light propagation paths into the defined path. The determination of seagrass bed density, distribution and productivity is really dependent on light availability (Hemminga and Duarte, 2000). Though minimum light is required by most marine macrophytes, seagrass needs a critical demand of light, and is prone to water quality deterioration and light competition from algae blooms induced by eutrophication (Ralph et al., 2006).

Light absorption or reflection by the horizontally projected leaf area defines the photosynthetic rate of seagrass. *Chlorophylls-a* and *Chlorophylls-b* are the most abundant pigments, and the only ones responsible for photosynthetic light harvesting in seagrass. In all processed-Landsat scenes, light attenuation coefficient will increase with depth, turbidity and high concentration of total dissolved solid.

Conclusion

Qualitative indication of seagrass sensitivity in variation of light attenuation and penetration in coastal water of Peninsular Malaysia could be measured using specific visible bands of satellite band. It is found that the east coast has 25% higher light penetration compared to south and west coastal regions. It has influenced seagrass distribution, abundance and vulnerability to survive in the dynamic of coastal environments, especially altered environments. In short, light can propagate in different levels in seagrass habitat of Malaysian coastal waters. The variation denotes the sources of different natural and anthropogenic factors that could affect seagrass thrive in such locations, depending on the species that vary in morphological characteristics.

In context of satellite data utilisation on high attenuated light in water, there is limitation on satellite-based detection, particularly for small size seagrass species located at areas deeper than 50m with low light penetration. Using ground collection data, the limitation of seagrass detection from satellite data could be assessed. Less clear water at most of the west coast tends to have higher light attenuation coefficient and directly proportional to deep sea bottom in seagrass habitat. In contrast, seagrass area around pristine island in the east coast is limited to bottom depth of ≥20 m with smaller seagrass physical structure than seagrass at southern part of Johor. The findings from this study are useful for the coastal infrastructure like tide gates, water monitoring system and technological tools development at the most critical place near seagrass habitat to ensure seagrass sustainability as a natural ecosystem engineer.

Acknowledgement

We would like to sincerely thank the Faculty of Civil Engineering Technology, Universiti Malaysia Pahang for facilitating researchers in the writing part of this paper for the UMP Research Series: Water, Energy and Environment. Thanks to Universiti Teknologi Malaysia for the fund from the Post-Doctoral Fellowship Scheme with the Project: "Quantification of Submerged Seagrass Biomass in Malaysian Coastal Waters Using Multi-Resolution Satellite Data".

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