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Water Quality Changes Using GIS-Based Approach at Seagrass Meadows Along the Straits of Johor

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Abstract. Industrialization and urbanization promote socio-economy development but they unwittingly cause environmental problems. Land use change always brings about the changes of ecological components including water quality and richness of marine communities. Rapid alteration in coastal landscape, increasing density of residential area and intensive reclamation since 2013 in Merambong coast area causes subtle changes of water quality compared to 2009 where coastal development is relatively moderate. Interaction between water quality changes and seagrass biomass changes in tropical water remains intriguing and indistinct. Thus, this study focuses to analyze water quality changes that cause intensive pollution and changes in water quality that lead to the gradual changes in seagrass biomass within a 4-year interval along the Straits of Johor. Water quality checker of the Horiba U-52 model is used during field sampling to measure seven main water quality parameters from 35 sampling points. Using Landsat 8 OLI image, each water quality parameter is visualized and interpolated using the GIS system on known points of water sampling and the accuracy is assessed. The study found that the changes of water quality of tropical water is directly proportional with the changes of seagrass biomass, primarily due to increasing turbidity from the consecutive flows of pollutant as the consequence of coastal alteration for urbanization and industrial expansion. The increment of >30% in total dissolved solids content, turbidity and dissolved oxygen is the most obvious changes in the reclamation area. Heavy load of sediment in parallel with coastal development is the most potential threat to water quality maintenance. Findings from the study are very important to support SDG 14 and as a reference for the governance of stakeholders and policy makers in providing excellent services to the coastal community, sustainable coastal planning and estimation of natural resource productivity in local scale.

INTRODUCTION

In recent years, the coastal area is populated by residential infrastructure and an increasing number of residents. Industrial waste and land use changes unwittingly cause environmental problems when pollutants enter soil, water and air through various pathways. Coastal alteration gradually shows degradation of water quality, which creates less favorable habitat for myriad aquatic organisms including seagrass. The clarity of coastal water is highly influenced by chemical compounds from various sources which are transported via different mechanisms in a hydrologic cycle including river discharge and atmospheric deposition [1]. The various types of pollutant flows into the coastal systems will be incorporated into biota and may interfere with the chemical and biological processes in the water column, mangrove ecosystem, sediment and biota. Seagrass which is prone to coastal alteration always shows quick response to the dynamic changes of the seawater. Seagrass are vulnerable to the changes of water and very sensitive to other environmental quality [2]. Hence, seagrass densities which inhabit the place where the people are fervent in urbanization and tourism have potential to bring remarkable impact on environmental health in quick or snowballing responses.

Vulnerability of seagrass towards the changes of coastal development are increasingly threatened by human activities resulting in declining trend of its global coverage [3, 4, 5]. Moreover, seagrass bed has proven to be natural engineer of coastal environment to maintain water quality [6, 7], weakening wave impact to the shoreline and reduce

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erosive rate in mangrove forest and indirectly plays the role as buffer zone to protect people who live nearby the coast and minimize devastating impact brought by strong wind events such as hurricane and typhoon [8]. Developing area of the Merambong area and increasing population in the vicinity is susceptible to degradable quality of some components in the coastal ecosystem which leads to other hazardous and non-optimal ecological services. Since the early 2000s, a number of economic-based projects have begun and without effective monitoring on the water quality in large scale, efforts in conserving natural invaluable assets like seagrass and myriad biodiversity richness in Merambong would be fruitless. In fact, effectiveness in assessing coastal ecological services to seagrass biomass using only ground-based monitoring remains uncertain and questionable, especially in presence of other potential threats.

Compared to other continental regions, tropical water has its own characteristics and well adapt with most of the seagrass species in the world. Previous studies on water quality in cold water and Mediterranean coastal areas shows that water quality has a strong relationship with seagrass occurrences, distribution and density in the study area [9, 10, 11]. Significant water quality changes would obviously influence the degree of light penetration and aquatic nutrient levels. However, limited studies have effectively revealed the interaction of water quality changes with seagrass biomass changes in less clear water in tropical regions which make it remain obscured and indistinct. Hence, satellite-based seagrass biomass changes [12] is used in this study to relate those changes with water quality and other potential threat in less clear tropical water of seagrass bed in Merambong, Johor, Malaysia. Therefore, this study aims to understand the interaction between water quality changes in tropical water with respect to the seagrass biomass changes. Indirectly, other potential threats are possibly identified using remote sensing technology and Geographical Information Systems (GIS) tools. By collecting all related information, understanding on declination of total biomass of seagrass in the Straits of Johor could be used to support the agenda of Sustainable Development Goal (SDG) 14 which prioritize an effective management in protecting marine life from pollution. In fact, the findings are crucial for the governance of stakeholders, coastal engineers and policy makers to be used as ancillary and guideline to strategize annual planning on coastal health and develop technological infrastructure or digital tools to protect seagrass density despites of vigorous reclamation activity along the coast. Otherwise, risk of extreme shrinking of total seagrass biomass would remain high. In fact, the apparent devastating impact on coastal health of the Merambong area would not solely affect marine organisms, but the social-economic of the coastal-dependent community would be unstable.

MATERIALS AND METHOD

Merambong shoal

Located near the Pulai River estuary in south Johor, Merambong area is close to one of largest mangrove forests in Asia and was selected as RAMSAR site in 2003. Merambong shoal is well-known as the largest single seagrass bed in Malaysia. There are only a few villages located along the coastal area nearby to the seagrass bed which includes Kampung Tanjung Adang, Kampung Pok Besar and Kampung Pok Kechil. Most of the villagers are fishermen and some of them are involved in agriculture and palm oil plantations. Seagrass habitat in Merambong shoals located in an area known as Merambong in the Straits of Johor, Malaysia (Figure 1). It has 1.8 km from north to south and width of 200 m from east to west located in the Straits of Johor, Malaysia, centrally situated at latitude of 01^0 19.979' North and 103^0 35.965' East; which covers Tanjung Kupang and Tanjung Adang. It is the largest single tract of seagrass meadow in Malaysia, surrounded by Case-2 water. This area is home to myriad marine biodiversity and extensive development of subtropical benthic habitat features in shallow to deep waters [13]. The shoal is mostly covered by *Enhalus acoroides* and *Halophila ovalis*. Moreover, this area is now developing a coastal residential project and intensively used for many scientific research activities. Based on Figure 1, water sampling points have been illustrated which are randomly located at the seagrass meadow, Pok River and Pulai River estuary, Merambong Island, Tanjung Adang and near the Second Link Bridge.

FIGURE 1. Satellite-view of Merambong area in early 2017. Merambong shoal was separated into two parts as the result of reclamation activity.

(Source: Google Earth, 2017)

Water Quality Mapping and STAGB Quantification Using GIS

Water quality checker (WQC) model of Horiba U-52 is the main instrument to collect seven water parameters in Merambong area including sea surface temperature (SST), pH, turbidity, salinity, conductivity, dissolved oxygen (DO) and total dissolved solids (TDS) in two different dates (February 2009 and June 2013) correspond to dates of seagrass total aboveground biomass (STAGB) changes. A total of 59 sampling points was selected in both seagrass and non-seagrass area as shown in Figure 1 (blue points) to record water parameters using WQC where 35 points recorded on seagrass area while another 24 points randomly selected along the straits. Triplicate reading was recorded for each sampling point to attain its consistency and average value. Handheld GPS Garmin Montana 650 used during the field data collection to record location of seagrass location and density, point of water sampling and coordinate of fixed targets to be used as control or tie points in geometric correction procedure of satellite image during processing stage. Then, all the values of all parameters from samples (known points) have been interpolated using a GIS processing system, ArcMap 10.8. Spatial interpolation technique to assign most optimal value on unknown location in Merambong vicinity

To quantify submerged STAGB, satellite-based approach is used to: a) identify and map spatial distribution of submerged and intertidal seagrass in Merambong area; b) quantify STAGB; and c) analyze the changes of STAGB of 2009 and 2013 with respect to water quality changes as well as other potential threat present in Merambong area. All the procedures and ancillary data for submerged STAGB mapping are using two-step approach which identify seagrass using Bottom Reflectance Index on the satellite images, then quantify pixel-based STAGB of Merambong shoal as comprehensively explained by [12, 14, 15]. All pre-processing, processing and post-processing stages have been performed on the satellite images, Landsat TM 2009 and Landsat OLI 2013 using remote sensing and GIS software.

RESULTS AND DISCUSSION

This section shows some of the results according to the objectives of study mentioned in the previous section. Water quality changes between 2009 and 2013 in the Merambong area has been analyzed based on its contributing factors and selection of which parameter that contributes a great impact on the changes of physical water characteristic. Then, the information was associated with the decrease of seagrass biomass that has been reported. In addition, potential threats in Merambong that invigorate seagrass biomass decrement was identified and elaborated comprehensively since all this information is important to strengthen endeavor and develop great concern on seagrass conservation and coastal management.

Declination of seagrass biomass is positively relative to water quality changes. Declination of seagrass total aboveground biomass (STAGB) could be considered as an alarming clock for policy makers and environmentalists to find a way to conserve seagrass from extinction in this area. Looking further on inter-relationship between STAGB and water quality changes, understanding of those elements could improve effectiveness in coastal management to control all potential threats that significantly bring negative impact on STAGB.

Based on Table 1, water quality of seagrass area shows the changes in most of the water parameters that could relate to the seagrass biomass declination, indicated by negative symbols in the column of STAGB changes. More than 70% or 25 collected sampling points on seagrass bed shows the tendency of reduction of seagrass biomass which highly corresponds to deterioration of water clarity in Merambong. Most of the collected samples show the degradation of water quality, especially parameters that are closely related to the increasing sedimentation and huge potential to reduce the clarity and light penetration into the water column. Water sampling from non-seagrass areas is important to understand the dynamics and connectivity of water characteristics with prominent marine features in the Merambong area. There is variation of values for each water parameter and Table 1 helps to initially depicts which tropical water characteristics are significant to the seagrass density. Conductivity and salinity show an insignificant relationship with the seagrass biomass in tropical regions. Changes on the water conductivity and salinity shows low correlation to the seagrass biomass changes which in turn proved that conductivity and salinity of tropical coastal water has a similar relationship with the seagrass meadow at different climate regions. Both parameters are insignificant to the seagrass coverage.

TABLE 1. Water quality parameters of some sampling points on seagrass meadow

No.	Coordinate (N, E)	STAGB changes 2013-2009 (gm^{-2})	Water quality changes (2013-2009)						
			a	*b*	*c*	*d*	*e*	*f*	*g*
1.	103°34' 7.1256"E 1°19' 55.056"N	-2850.33	2.26	0.28	3.7	2.1	4.2	0.9	-5.46
2.	103°34'42.098"E 1°20'39.885"N	-2221.02	2.08	0.34	4	2.7	4.4	1.4	-0.33
3.	103°36'0.594"E 1°20'13.0308"N	-1514.98	0.64	0.03	2.7	-2.8	3.1	-2.9	-0.16
4.	103°36'0.3312"E 1°20'14.4456"N	-668.27	1.18	-0.06	1.6	-1.6	2.6	-4.6	-1.84
5.	103°36'8.3052"E 1°20'20.6592"N	-201.78	1.05	-0.06	1.6	-4.7	1.9	-0.4	-2.25
6.	103°36'15.1596"E 1°20'29.13"N	-1596.12	0.53	0.07	3.8	0.1	1.6	-6.1	-2.09
7.	103°36'12.222"E 1°20'29.8824"N	-153.68	1.33	0	1.5	-1.3	2.6	-2.8	-1.52
8.	103°36'01.0368"E 1°20'10.0932"N	211.32	0.89	-0.08	1.3	0.1	2.2	-5	-4.18
9.	103°36'5.5872"E 1°20'21.6744"N	239.07	0.82	-0.09	1.6	-2.6	1.8	-2.7	-1.21
10.	103°36' 16.434"E 1°20' 19.7304"N	351.87	1.31	-0.1	1.1	0	1.8	-0.5	-1.12

Note: *a*: Sea Surface Temperature (^{0}C); *b*: pH; *c*: Turbidity in Nephelometric Turbidity Unit (NTU); *d*: Conductivity (mS/cm); *e*: Total Dissolved Solid (g/L); *f*: Salinity (part-per-thousand, PPT); *g*: Dissolved Oxygen (mg/L)

Figure 2 shows the seagrass biomass changes on Merambong shoal between 2009 and 2013 [12] where dark red color indicates significant decrement whereas yellow color means good recolonization of seagrass on that particular site. Unlike other climate regions, tropical water shows a stable seagrass horizontal and vertical morphological growth if no extreme weather condition or drastic environmental disturbances [7, 16]. However, coastal alteration creates survival pressure for the seagrass growth as the water parameters have shifted into non-ideal condition due to anthropogenic disturbances including activity. Higher proportion of declined seagrass biomass was shown on Merambong shoal within the period of 2009-2013 compared to recolonized area, especially area that facing-off to Port of Tanjung Pelepas (PTP) and shoreline.

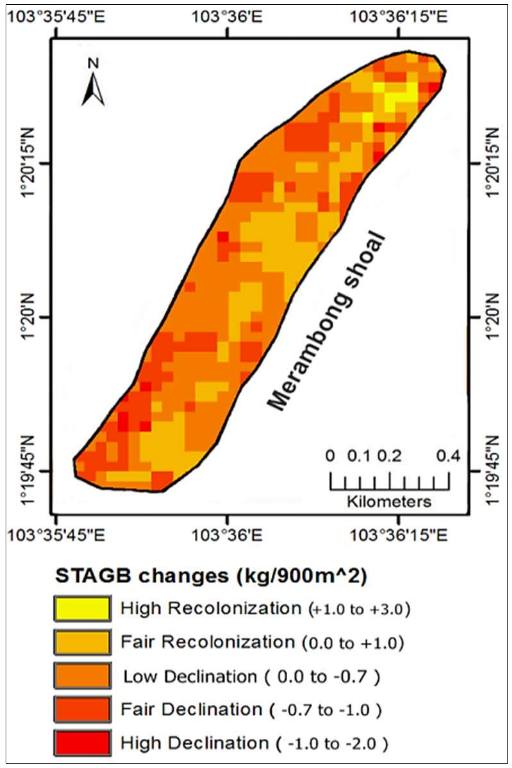

FIGURE 2. Seagrass biomass changes on Merambong shoal [12].

Seagrass distribution has quickly responded to the changes of its surrounding environment. Obviously, disappearance of a huge tract of seagrass bed which has dominated by *Enhalus acoroides* and *Halophila ovalis*, is the result of reclamation activity nearby the PTP and a mega commercial residency project which causing significant impact to seagrass biomass on Merambong shoal as shown in Fig. 2. The loss of seagrass was inevitable, especially the part that directly facing-off the developing land and PTP. Areas close to the coastal development and seagrass area are turbid where the re-suspension of nutrients from the seafloor frequently occurs due to water turbulence in the water column that brings them up to surrogate to other surrounding places. Increase of suspended material and light attenuation caused decline in shoot density of seagrasses at Cape Bolinao, Philippines [17], and productivity and abundance of *Posidonia oceanica* in Spain [18].

Among all water parameters collected, only four parameters which are DO, TDS, pH and turbidity are highly relative to seagrass biomass decrement as shown in Figure 3. Figure 3 shows the interpolated map of four water parameters and its relativity to the changes of STAGB on Merambong shoal. Based on these linear relationships, clearly it proved that turbidity is the most affected parameters (R^2=0.8025, $p \leq 0.05$) from alteration of coastal area in Merambong area that associated with seagrass biomass decrement compared to other parameters, followed by TDS and pH. Meanwhile, DO shows less negative impact on the seagrass biomass decrement, proved by a fair level of correlation of its changes with respect to the STAGB changes (R^2=0.5283, $p \leq 0.05$). Turbidity in Merambong coastal water has increased between 2009 and 2013, primarily due to erosion of coastline nearby mangrove forest. In the Merambong area, gradual loss of mangrove forest which naturally acts as buffer zone may contribute to such conditions as the result of massive propel sediment loading and siltation to seagrass bed located near the Pulai River estuary.

The remaining parameters are stable with a fluctuating pattern, including sea surface temperature, conductivity and salinity which did not bring significant impact to seagrass abundance in Merambong area.

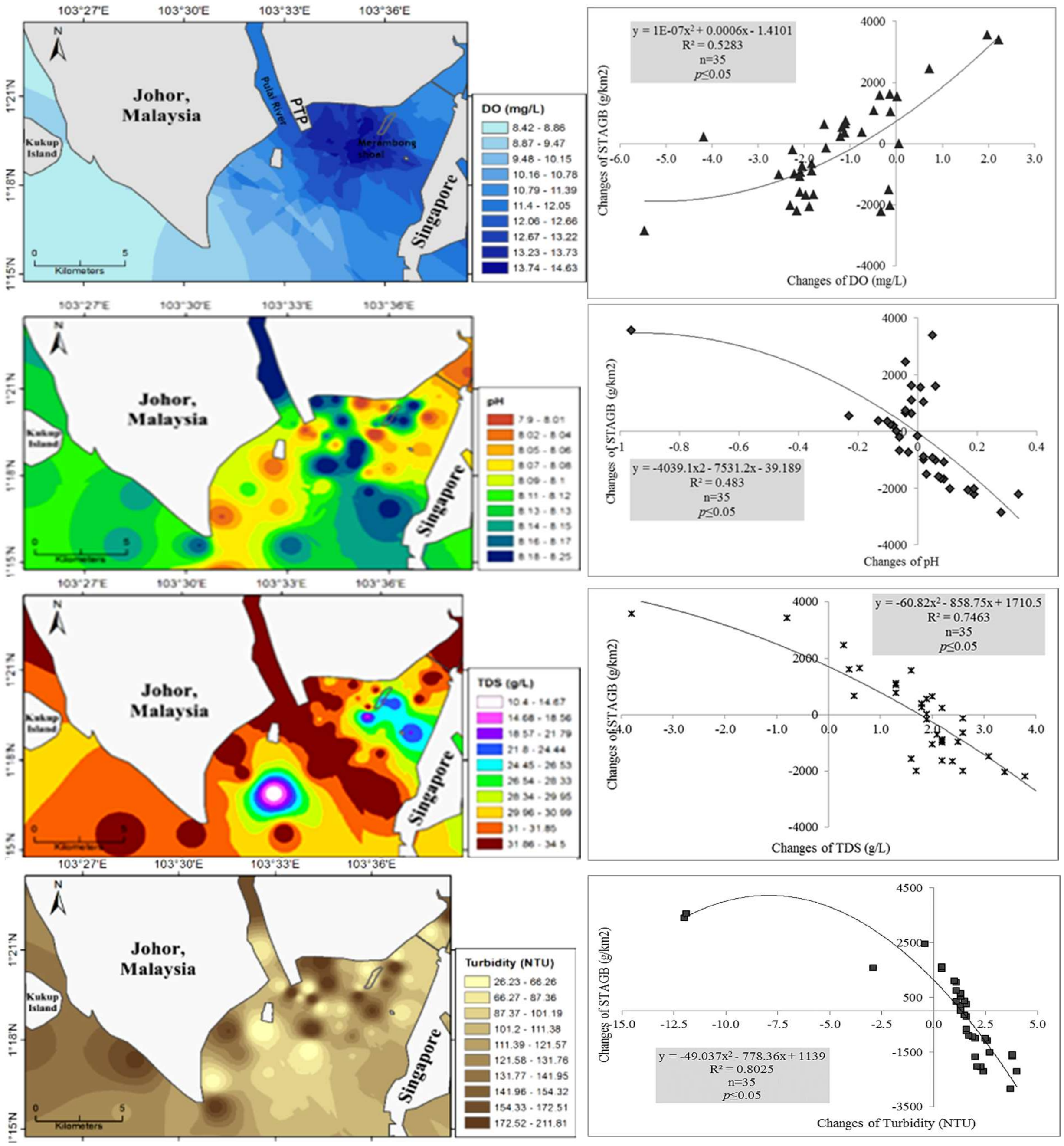

FIGURE 3. Interpolated map of water quality parameter in 2013 and its corresponding correlation with respect to seagrass total aboveground biomass (STAGB) changes in Merambong area.

Increasing human populations associated with port expansion, urbanization, industrial development and agricultural activities along the Johor Strait especially at Pulai River have raised a great intention on the risk of those activities to the estuaries and coastal. Active agricultural activity, development of power plant and industrial building, port expansion along with the increasing of coastal residence at Gelang Patah district, nearby Merambong causing the alteration of physical landscape of Merambong area which indirectly contributes to chaining effect of coastal physical parameter including degradation of water quality and increasing coastal erosion. River is the mobile medium that is responsible for pollutant and nutrient flux from land into the coastal area. According to the turbidity map in Figure 3, the area nearby the Merambong shoal, close to PTP and the area of the Straits of Malacca is more turbid than other places along the Straits of Johor. Water turbidity and depth effects submerged seagrass detection ability from satellite data. Extreme turbid class was considered as coarse sand bottom type in submerged seagrass biomass quantification through satellite-based approach.

Potential threats to STAGB decrement

Apart from water quality, STAGB decrements on Merambong shoal and vicinity might also come in various ways. In tropical coastal waters of Merambong, rampant coastal alteration may bring economic benefits but at the same time may permit imbalance demand of seagrass and human survival thrive. Identified potential threats to STAGB decrement in Straits of Johor consist of (i) populated coastal communities, (ii) regular shipping traffic in and out of port and (iii) mangrove loss due to coastal erosion.

Increasing coastal community: Increasing human population alongside the coastal region [19, 20] might cause excessive nutrients into seagrass habitat through river discharge. Land to coastal transfer of strange compounds is making seagrass unable to quickly adapt in such changes and causes negative effect in growing rate and spatial distribution of their presence. Coastal communities have increased dramatically for tourism and permanent residency land where waste from accumulated wastes from many connected drainages could reduce seagrass biomass as some chemical compound is strong enough to cause seagrass declination. Pulai River and other narrow channels of small rivers transport waste and chemical compounds from industrial, residential and agricultural land to the sea that may cause nutrient surplus, re-suspension and sedimentation on seagrass habitat to inhibit its normal growing rate.

Hectic shipping traffic in Merambong area: Beginning to operate in the end of 1999, PTP recently claimed Malaysia’s Most Advanced Container Terminal which is located at the mouth of Pulai River and administered under Iskandar Development Region (IDR). Geographically, PTP is very close to Singapore Port, which is well-known as one of the busiest ports in the world which guarantees a good opportunity to become a port of call for ships passing through these waters. In fact, the location nearby Danga Bay is protected from natural wind hazards and a depth of 4m-12m of sea floor is suitable for shipping lanes to the port. Recently, PTP has successfully set a world record as the fastest growing port where Pulai River mouth is connecting port from East to West region and the confluence of the international trade lanes which become a stop-over point of one of the world's busiest route, the Straits of Malacca [21]. With all these factors, it is not surprising that the Merambong area has very hectic shipping traffic in and out of the PTP and one of potential threats to seagrass biomass decrement in such an area. Hectic shipping lane also indirectly reduced the number of dugong sightings in this area [22, 23] that frequently seek seagrass as one of their main nutrient sources. From this aspect, seagrass habitat would slightly have received indirect impact from the ship mobility, excluding small boatmen of local fishermen which is insignificant to bring harm to the seagrass bed and marine biodiversity. Water turbulence in this area accelerates coastal erosion rate that brings the grain and fine soil into the coastal region which directly increases water turbidity at the surrounding area of seagrass habitat.

Deforestation and erosion of mangrove forest: The loss of mangrove areas for human-made development may distract the balance of optimal ecological services demand for sustainability of seagrass occurrences and abundance. It acts as bio-filter for sediment and nutrient from direct loading on seagrass bed become a threat since high sedimentation will not increase turbidity of water column but directly invigorate algae blooms event that will further impede photosynthesis process [24]. Light attenuation in the water is an effective indicator of light penetration power in the water column [9]. These include the natural biophysical parameters that regulate the physiological activity and morphology of seagrasses such as salinity, waves, currents and depth and the anthropogenic inputs that impact plant resources such as excess nutrients and sediment loading. Combinations of these parameters will permit decrement of seagrass biomass, density and species richness.

CONCLUSION

In conclusion, using remote sensing and GIS approach by interpolation of water quality, this study proved that changes of water quality have directly proportional to the changes of STAGB in tropical coastal water. Turbidity has the most significant influence on seagrass biomass in the Merambong area, indicated by high correlation (R^2=0.8025, $p \leq 0.05$). Increase in water turbidity caused by many contributors including reclamation activity for port and residential development, water pollution from the nearby river and coastal erosion. Other potential threats relevant to STAGB decrement in Straits of Johor are populated coastal communities, regular shipping traffic in and out of port and mangrove loss due to coastal erosion. Mitigating action and active enforcement of coastal law should be done to ensure sustainability of coastal health and minimize STAGB reduction. Effective and efficient satellite-based monitoring and seagrass restoration plan should be initiated immediately.

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