ABOVE GROUND BLUE CARBON SEQUESTRATION CAPACITY OF SUNGAI PULAI ESTUARY SEAGRASS MEADOWS – A SATELLITE BASED METHOD

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KEYWORDS: Landsat, blue carbon, sequestration, mapping, Sungai Pulai estuary, Malaysia.

ABSTRACT

Monitoring blue carbon (C) sequestration potential within coastal ecosystem is essential for enhancing climate change mitigation initiatives. Although remote sensing is known as a useful method for mapping benthic habitat and monitoring changes at large spatial scale compared to field survey methods, it has not been attempted for quantifying seagrass C stock. A satellite-based mapping approach, applied on Landsat imagery (acquired in 2004, 2009 and 2013) and field biomass data obtained from previous studies were used for repeat mapping of above ground seagrass C for the turbid water of the Sungai Pulai estuary, Johor Straits, Malaysia. The mapping approach has demonstrated (1) the ability to determine total above ground seagrass C sequestration capacity and identify the areas of highest C stock cover class from the spatially extensive biomass map, and (2) the spatio-temporal dynamics of seagrass C stocks that can be used to assess and monitor C fluxes and (3) informing costal managers to decide which data to be used and method to apply for monitoring climate change related activities when project demands a spatially explicit maps. According to the estimates, the highest mean C stock was in 2004 (90.68 kg C/pixel) and the lowest in 2013 (18.77 kg C/pixel) – a declining trend of seagrass cover, biomass and C stocks in the Sungai Pulai estuary. Further studies on the Sungai Pulai estuary should be conducted to identify C pools and to estimate total C stocks and fluxes in seagrass ecosystem.

INTRODUCTION

Carbon (C) stored in the coastal vegetation, such as mangroves, salt marshes, and seagrass meadows, above and belowground biomass is termed as blue C (Mcleod et al, 2011). According to UNEP's 2009 report "Blue Carbon – The role of healthy oceans in binding carbon", 50-71% of atmospheric C is captured by the coastal vegetation. Therefore, the blue C initiatives are appreciated worldwide to mitigate climate change impacts through conservation and restoration of coastal ecosystems. It offers to mobilize funds and revenue by combining best practices for coastal conservation and restoration with climate change mitigation initiatives (Ahmed and Glaser, 2016, Wylie et al, 2016). Being seagrass meadows as an important component of coastal ecosystem, and in contrast, their continued degradation will eventually result in greenhouse gas (CO_2) emissions, loss of biodiversity and ecosystem services. Seagrass blue C ecosystem services are already been recognized (Thomas, 2016, Russell et al, 2013), but still knowledge gaps are there. There is a lack of research in the following areas: (1) spatial cover and distribution, biomass of seagrass meadows have not been largely surveyed and undocumented at large spatial scale (Hossain et al, 2015b), (2) data on the seagrass blue C sequestration and storage, and rate of changes especially in Southeast Asia are limited in the scientific literature, (3) an efficient method for mapping of degraded and restored seagrass blue C estimates is unavailable that can enable inclusion of C removal (degradation) to restored (revegetation or natural recover) data in relevant databases (e.g., IPCC Database), (4) the blue C ecosystem drivers associated with degradation or loss, especially for seagrass meadows are also currently lacking.

In Malaysia, sixteen seagrass species (Bujang and Zakaria, 2011) are widely distributed in the subtidal and intertidal areas, semi-enclosed lagoons and shoals along the coasts of Malaysia (Zakaria and Bujang, 2013), providing enormous ecosystem services (Thomas, 2016), while they are experiencing a gradual decline (Hossain et al, 2015a). When Malaysia is experiencing climate change related vulnerabilities (Al-Amin et al, 2015) along with degrading seagrass resources, inventory on blue C captured by the seagrass meadows occurring in coasts of Malaysia can explicitly address the role of blue C ecosystems in climate change mitigation, predict potential C emissions from the seagrass cover changes, and enable to integrate seagrass blue C management to the over-arching coastal management strategies.

Methods to measure C sequestration from the metabolism within coastal habitat components of their air-water and water-sediment interfaces in a coastal ecosystem are complex and still not well established. In the past two decades, numerous field-based methods have been used to measure C flux in coastal vegetation such as Eddy (Hume et al, 2011), non-dispersive infrared (NDIR) spectrometry (P. Fietzek et al, 2011); each have advantages and limitations based on accuracy and costs, and ability to monitor C stocks at required spatiotemporal scale. The core incubation methods (Eyre and Ferguson, 2002), although are found suitable to assess C stock, they are limited to low spatial observations and difficult to assess C sequestration capacity at required spatial scale.

The aim of this research was to develop integrated satellite and field-based methodologies for quantifying above ground C sequestration capacity for Sungai Pulai estuary seagrass meadows.

MATERIALS AND METHODS

Study site

The study was conducted in Merambong shoal, situated in the mouth of Sungai Pulai estuary, Johor Straits, Malaysia (Figure 1). Extensive seagrass meadows of mixed species are occurring in the turbid water of the estuary (Bujang et al, 2006). Among 15 species, *Enhalus acoroides* and *Halophila ovalis* are dominant. Seagrasses are growing in typically shallow waters at a depth less than 4 m. Co-occurrence of seagrasses, seaweeds (Bujang et al, 2012a, Zakaria et al, 2014), corals and diverse benthic organisms (Idris et al, 2008) have made the estuary an interesting site for marine researches.

Satellite-based carbon stock determining method

In this study, Landsat 5 acquired on 5 August 2004, 8 February 2009 and Landsat 8 (OLI) data acquired on 27 June 2013 and, pre- and post-processing methods, ground truth data and hydrographical chart used for satellite-based aboveground biomass mapping for Merambong shoal seagrass meadows were obtained from previous studies (Hashim et al, 2014a, Hashim et al, 2014b, Misbari and Hashim, 2016), and hence was not detailed in this paper. In brief, radiometric, geometric, atmospheric and water column corrected satellite images of each date were correlated with absolute above ground seagrass biomass which were obtained by up-scaling from quadrat to per pixel size (30 m x 30 m) (Misbari and Hashim, 2016). The C within the aboveground seagrass component (kg C/pixel where each Landsat pixel is 900 m^2) was determined by multiplying the biomass by a value of 0.34 (Duarte, 1990) which was considered as C conversion factor.

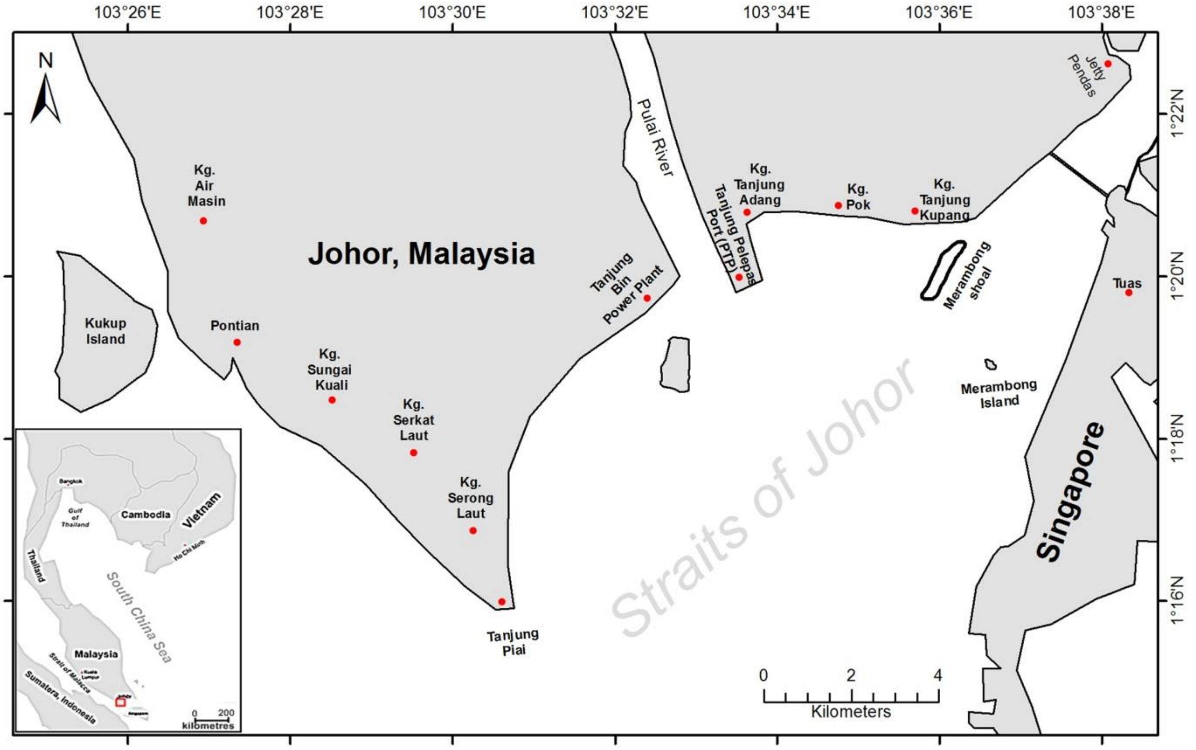

Figure 1. The study site.

RESULTS AND DISCUSSION

As the seagrass above ground biomass data were collected for the study sites per quadrat, the field data collection technique only can provide a point based assessment of C stock compared to the up-scaled image-based estimates (Figure 2) which is spatially more extensive. In general, the mapped C stock (kg C/Landsat pixel) patterns were similar to those described in Misbari and Hashim (2016) for seagrass cover. However, spatial and temporal differences in biomass resulted in variations in C stock. This was clearly visible in all the C stock maps, with areas of high cover of C stocks in 2004 than 2009 and 2013 (Figure 2). Similar overall trends in mean C stock estimates among the study dates showed that it exhibited the highest in 2004 (90.68 kg C/pixel), followed by in 2009 (33.04 kg C/pixel) and the lowest in 2013 (18.77 kg C/pixel). As a result a continuous decline of C stock is apparent from both the C stock distribution maps (Figure 2) and the annual change analysis (Table 1). This may be due to the more suitable seagrass habitat condition combined with a higher seagrass cover and biomass in 2004 compared to 2009 or 2013. Such a decline seagrass cover and distribution largely due to coastal development and sand mining for Sungai Pulai and other seagrass inhabiting areas of Malaysia have been reported in other studies (Zakaria and Bujang, 2011, Bujang et al, 2012b, Hossain et al, 2015b, Misbari and Hashim, 2016)

The results of this study indicate that Landsat image data provided spatially explicit maps of above ground C stock across the range of seagrass biomass levels around Sungai Pulai estuary. The spatial and temporal aspects of this study image and field data, should be sensibly considered to place the mapping approach in climate change impact analytical context. At the spatial scale of seagrass meadows with mixed species composition covered in the Sungai Pulai esturary, Landsat data were suitable to mapping above ground C sequestration capacity. The mapping approach could be used for biomass and C sequestration mapping for all over coasts of Malaysia where seagrasses are occurring (Zakaria and Bujang, 2013). For managers and scientists concerned with implementing projects to map, develop predictive models and model C flux attributes of coastal vegetation in seagrass ecosystem, this study results demonstrate an indication of satellite-based mapping approach under turbid water environment, and can be used to determine seagrass loss/decline and thus, to identify which areas are vulnerable to climate change risk.

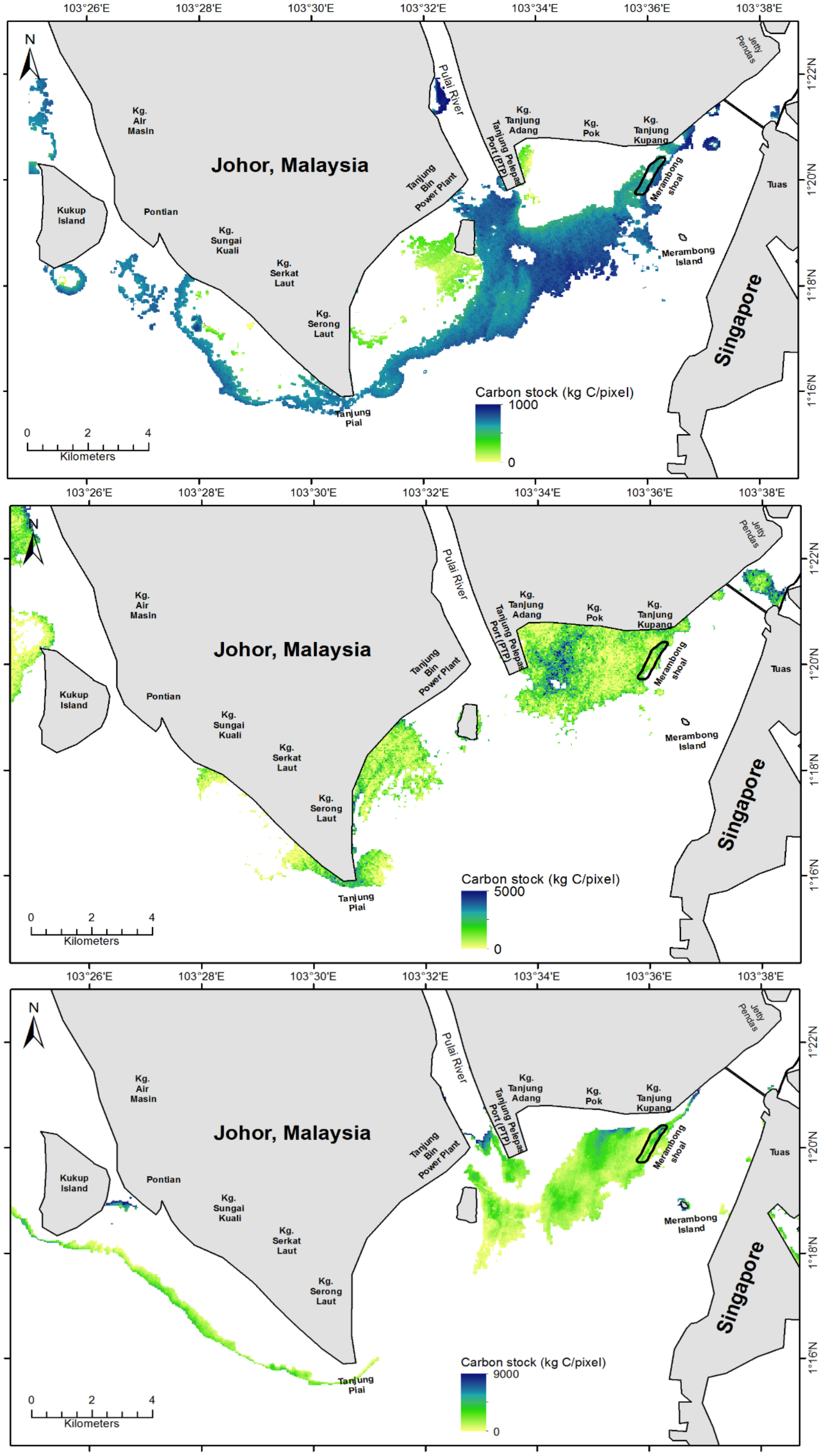

Figure 2. Living seagrass aboveground C sequestration capacity in 2004 (a), 2009 (b), and 2013 (c) for Sungai Pulai estuary, Johor Straits, Malaysia

Table 1. Annual change in seagrass aboveground carbon stocks; (-) indicates a decrease.

Year	Carbon stock		
	Total (tonne C/pixel)	Difference between years (tonne C/pixel)	Annual change (tonne C/pixel/year)
2004	30,405.23	-	-
2009	10,443.21	(-) 19,962.02	(-) 1,738.87
2013	7,306.60	(-) 3,136.61	(-) 1,208.80

CONCLUSION

The findings of this study demonstrate what is possible with integration of satellite image and field data sets for above ground blue C stock mapping technologies. Although the results of this study extend our previous studies which highlighted Landsat sensors and water column correction prior to mapping seagrass distribution, cover and biomass estimates with acceptably accuracy, it shows that C stock estimates is also possible and results are comparable to investigate changes being same image processing technique applied on multi-temporal images (Roelfsema and Phinn, 2013). It still need further study if these data sets are suitable for total C stock estimate and for climate resilient assessment and monitoring. This study is part of larger research work where we have developed satellite based seagrass mapping across a range of water turbidity levels and depths in tropical coastal environments by a correlation between water column attenuation corrected pixel to field survey data. The mapping approach presented here would aid biodiversity conservationists in deciding which sensor (Landsat being free to acquire) to use and how to process satellite images with similar spatial and spectral resolution for mapping C sequestration potential within marine ecosystem.

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