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Baseline

Carbon stores from a tropical seagrass meadow in the midst of anthropogenic disturbance

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ABSTRACT

Seagrass meadows provide important carbon sequestration services but anthropogenic activities modify the natural ecosystem and inevitably lower carbon storage capacity. The tropical mixed-species meadows in the Sungai Pulai Estuary (Johor, Malaysia) are impacted by such activities. In this study, we provide baseline estimates for carbon stores analysed from sediment cores. In sediment depths up to 100 cm, organic (OC) and inorganic carbon (IC) stores were 43–101 Mg C ha^{-1} and 46–83 Mg C ha^{-1}, respectively, and are in the lower end of global average values. The bulk of OC (53–98%) originated from seston suggesting that the meadows had low capacity to retain seagrass-derived organic matter. The species factor resulted in some variability in OC stores but did not appear to influence IC values. The low carbon stores in the meadow may be a direct result of sediment disturbances but natural biogeochemical processes are not discounted as possible causal factors.

Vegetated coastal habitats are global hot-spots for carbon sequestration (Nellemann et al., 2009). Global level studies showed that the average quantity of organic carbon (OC) stored in soils/sediments of seagrass meadows is twice the average stored in terrestrial soils (Fourqurean et al., 2012). Carbon stored in these habitats may offset anthropogenic carbon dioxide emissions and thus offer potentials for climate change mitigation (Duarte et al., 2013). Among coastal vegetated habitats, seagrass meadows rank among the highest in terms of global loss rates, declining annually at 7% (Waycott et al., 2009). With habitat degradation, important ecosystem services such as carbon sequestration are also lost (Nellemann et al., 2009). Without any significant reductions in carbon dioxide released due to anthropogenic activities, communities at large are increasingly interested in preventing further releases of carbon already sequestered in habitats of coastal vegetation.

The intensity of carbon sequestration in seagrass meadows stem from the high primary and secondary productivity that occurs in these habitats (Tu Do et al., 2012; Duarte et al., 2005). Organic carbon (OC) produced from direct seagrass production can be stored in living seagrass tissues (Trevathan-Tackett et al., 2015; Fourqurean et al., 2012) or as detritus buried in seagrass sediments (Rozaimi et al., 2016; Trevathan-Tackett et al., 2015). Seagrass detrital matter are known to be degradation-resistant due to high amounts of recalcitrant compounds found in its tissues (e.g. Trevathan-Tackett et al., 2015; Torbatinejad et al., 2007) and forms the primary source of OC sequestered in seagrass sediments (Kennedy et al., 2010). However, the capacity for OC storage among seagrass meadows differ (Lavery et al., 2013). Organic carbon storage is influenced by biotic and abiotic factors intrinsic to a particular meadow such as depth of meadow (Serrano et al., 2016; Serrano et al., 2014), hydrodynamic environment, turbidity (Samper-Villarreal et al., 2016), and habitat composition (Lavery et al., 2013; Rozaimi et al., 2013). Other sources of OC, including seston, terrestrial plant-matter and algal-matter contributes to the sedimentary organic matter (OM) pool (Serrano et al., 2016; Rozaimi et al., 2016; Kennedy et al., 2010). The relative contribution of seagrass-derived OC to this organic pool is approximately 50% (Kennedy et al., 2010) but recent studies showed that the proportion varies from low to high contributions (4 to 82%: Serrano et al., 2016; Rozaimi et al., 2016; Miyajima et al., 2015). This indicates that characteristics intrinsic to the habitat need to be considered when accounting for the proportion of seagrass-derived OC stored in sediments of seagrass meadows.

Secondary productivity in the form of calcium carbonate production adds to the carbon pool as particulate inorganic carbon (IC). Biogenic production of calcium carbonate in the meadow is retained due to the efficiency of particle retention and trapping by the seagrass canopy (Mazarrasa et al., 2015; Gacia et al., 2003). Seagrass densities influence the quantity of IC stores since the amount of $CaCO_3$ produced within the meadow correlates with the density of calcareous organisms that the seagrass biomass can sustain (James et al., 2009; Perry and

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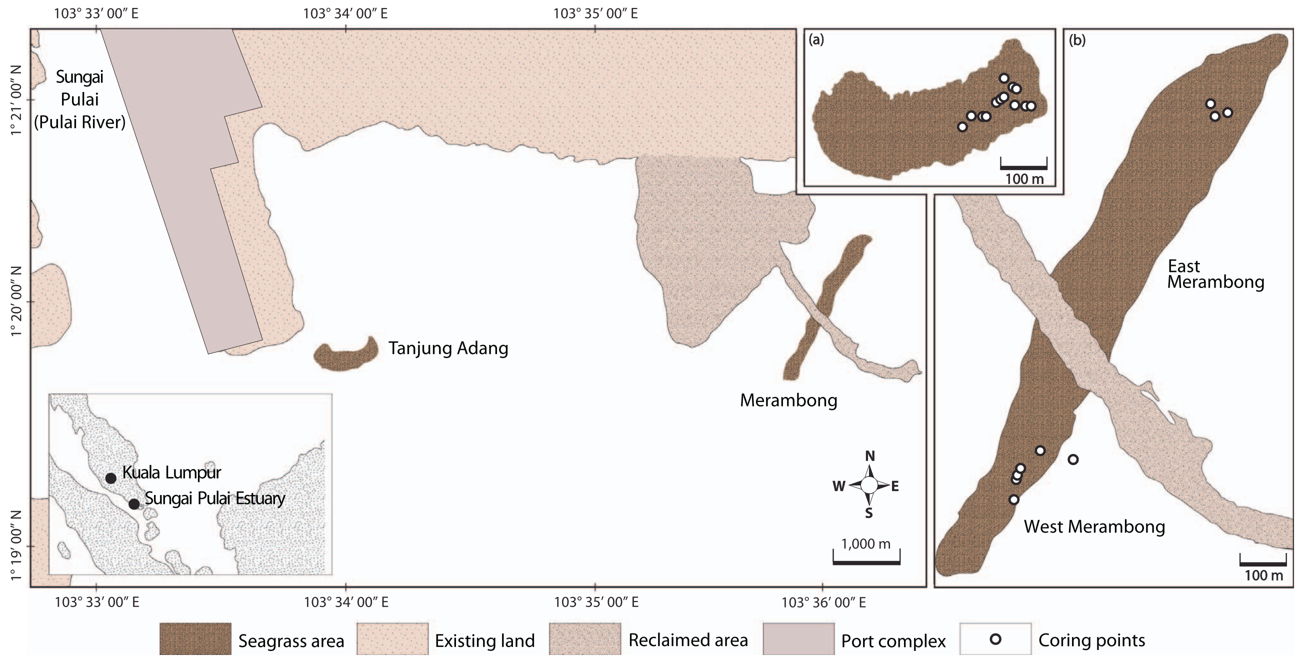

Fig. 1. Location of the coring points at the Sungai Pulai seagrass meadows. (a) and (b) are larger scale maps of Tanjung Adang Shoal and Merambong Shoal, respectively.

Beavington-Penney, 2005). Variability in $CaCO_3$ is further contributed by geographic location; productivity increases towards the lower latitudes globally and thus tropical seagrass meadows are significant storage sites for $CaCO_3$ (Mazarrasa et al., 2015). There is, however, a paucity of information in regards to carbonate productivity and inorganic carbon storage in seagrass meadows. Consequently, understanding this aspect of carbon sequestration is still lacking especially in tropical regions.

Tropical seagrass meadows, notably in South-east Asia, are unique compared to temperate meadows due to the dominance of mixed-species meadows (Short et al., 2007). Because of relatively few studies done in SE Asia, the influence of such mixed-assemblages of seagrasses in a single meadow to carbon storage remains unclear. Existing studies from the SE Asia region showed that in the top 100 cm of sediment, OC stores range from 31 to 293 Mg C ha^{-1} (Alongi et al., 2016; Miyajima et al., 2015; Phang et al., 2015) but IC storage capacity is still not explored in depth apart from few studies (e.g. Ooi et al., 2011). In SE Asia, meadow degradation from anthropogenic activities are increasingly reported (e.g. Grech et al., 2012; Short et al., 2011; Halpern et al., 2008). Ecosystem disturbance invariably reduces carbon sequestration capacity of seagrass meadows and potentially releases the sedimentary OC stores as CO_2 emissions (Alongi et al., 2016; Rozaimi et al., 2016; Russell et al., 2013). Furthermore, disturbance could shift the proportion of seagrass- and non-seagrass derived OC to the sedimentary organic pool (Rozaimi et al., 2016; Marbà et al., 2015; Pendleton et al., 2012;) while simultaneously lowering the capacity for retention of particulate carbon (Macreadie et al., 2014). Such correlation between disturbance and reduction in ecosystem service capacity had been reported from temperate seagrass meadows (e.g. Macreadie et al., 2015; Marbà et al., 2015) but the impacts of such disturbances on carbon storage in tropical meadows are still unclear.

Ecosystem services can resume with the cessation of anthropogenic activities (Cullen-Unsworth et al., 2014; Greiner et al., 2013) but at a scale of decades before any indicators of recovery can be evident (e.g. Marbà et al., 2015). It is thus important to provide a baseline of pre-disturbance, during disturbance and post-disturbance recovery in ecosystem services (Jones and Schmitz, 2009; Fraterrigo and Rusak, 2008). This is, however, an ideal to approach to quantifying ecosystem services. More often, studies into ecosystem disturbances are usually during disturbance, or post-disturbance stages (White and Jentsch, 2001). If indeed cessation of disturbance can return the ecosystem services, than it could potentially be reflected by the carbon sequestration potential of the particular habitat in question.

In this study, we investigated a disturbed seagrass meadow from the Sungai Pulai Estuary (Johor, Malaysia; Fig. 1) to account for the during disturbance phase in carbon storage and ecosystem services. In Malaysia, many seagrass meadows are facing pressures from anthropogenic activities, especially meadows in the Sungai Pulai Estuary. This estuary is on the western part of the Straits of Johor and consists of mangroves and discontinuous mixed-species seagrass meadows. Large areas of seagrass beds had been lost due to port development and reclamation activities (Japar Sidik et al., 2006; Japar Sidik and Muta Harah, 2003). The ensuing water turbidity and sedimentation subsequently resulted in decreases in biodiversity and modified the dominant macrophytic assemblage (Japar Sidik et al., 2016; Ponnampalan et al., 2015). Notably, marked decreases in seagrass cover at Tanjung Adang shoal was reported in the early 2000s (Japar Sidik and Muta Harah, 2003). Currently, seagrasses have recolonised this meadow but the central portion of the meadow at Merambong Shoal had recently been reclaimed resulting in a distinct West and East Merambong meadow (Fig. 1).

To assess the spatial variability of sedimentary carbon characteristics, sediment cores (30 cm, n = 22) were collected from the seagrass meadows located at the three shoals (Tanjung Adang and West/East Merambong Shoals) from Aug 2015 to Jan 2016. Coring points were selected based on the seagrass species that grew at that point and was done during low tides when the shoal was exposed from submersion. At Tanjung Adang, a set of 3 cores were each collected from *Enhalus acoroides*, *Cymodocea serrulata*, *Halophila ovalis* and *Halodule pinifolia* patches. In addition, one reference core from unvegetated sediment was also collected (after Serrano et al., 2016). From West Merambong, cores were collected from *Enhalus acoroides* and *Thalassia hemprichii* patches, while only *Enhalus acoroides* patches were selected for coring from East Merambong. Cores were collected by manually hammering plastic pipes (50 cm length) onto the seagrass bed. After transporting to the lab, the sediment was extruded and sub-sampled into 1 cm-wide slices. Alternate slices (5 cm intervals) were selected for biogeochemical analysis, oven-dried at 60 °C to constant weight and then calculated for sediment bulk density. These slices were then ground to a fine powder using a ball-mill grinder.