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Vertical carbon flux of marine snow in *Enhalus acoroides*-dominated seagrass meadows

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HIGHLIGHTS

- Total carbon budget that was exported downward can be estimated as 14.5 kiloton C yr^{-1}.
- The vertical flux contributes quadrupled decomposition + export of seagrass meadows.
- The marine snow aggregates can be categorized as autochthonous and allochthonous.
- *Enhalus acoroides* and *Thalassia hemprichii* contribute to autochthonous origin aggregate.

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ABSTRACT

Fine seagrass detritus together with fecal matter, clumps of aggregated phytoplankton, and colloidal organic matter, comprise macroscopic organic aggregates known as 'marine snow'. Seagrass phytodetritus is considered to be an important component of the carbon budget, because of the loss of carbon as fine particulate organic matter. The purpose of this study is to determine and to estimate the vertical flux of marine snow as part of the carbon budget in the seagrass meadows of Bintan Island. Average organic carbon and nitrogen fluxes were 8945.6 ± 2742.0 mg C m^{-2} day^{-1} and 737.7 ± 222.5 mg N m^{-2} day^{-1}, respectively. Considering the submerged time (5747 h in a year) also the total area (2600 ha), the vertical carbon flux of marine snow aggregates can be estimated as 557.6 g C m^{-2} yr^{-1} and 176.7 g N m^{-2} yr^{-1} throughout the year. The total carbon budget that was exported downward can be estimated as 14.5 kton C yr^{-1}. This vertical export is nearly one and a half times of the seagrass's NPP in Bintan Island. The vertical carbon flux contributes a maximum nearly quadruple the decomposition + export of seagrass meadows. This result suggests that the dynamics of the flux of marine snow aggregates may contribute valuable information. According to the stable isotope analysis, the marine snow aggregates in seagrass meadows can be categorized as: (1) autochthonous (composed mainly of fine seagrass detritus) and (2) allochthonous (composed by POM, fecal pellets, anthropogenic inputs, etc.).

1. Introduction

Seagrass meadows together with other marine vegetation have been estimated to contribute 50% of top-down carbon burial in marine sediment which is about 216 TgC per year (Duarte et al., 2005). Furthermore, it has been estimated that the global seagrass carbon pool lies between 4.2 and 8.4 PgC (Fourqurean et al., 2012). Because of the low level of nutrients, the decomposition of the seagrass tissues is slow which then leads to a low value of herbivory (Duarte and Cebrián, 1996; Enríquez et al., 1993). Therefore, it seems that the surplus of the organic carbon production will be exported or buried. It means that the seagrass ecosystems will act as a carbon sink (Duarte et al., 2013). Considering these facts, the seagrass ecosystem can be considered as an important part of global carbon cycle.

Much research elucidating the carbon cycle in seagrass beds has been conducted (e.g. Gazeau et al., 2005; Duarte et al., 2010; Lavery et al., 2013; Macreadie et al., 2014). However, some components of the carbon cycle in seagrass meadows have been neglected, such as carbon flux through grazer or benthic food webs, or the vertical carbon flux of marine snow aggregates. Kennedy et al. (2010) stated that according to the isotopic constraints, seagrass vegetation contributes only ∼50% carbon burial to the surface sediment. The another half is contributed by the allochthonous sources such as phytoplankton (a major component of marine snow) and terrestrially derived particles. In order to estimate

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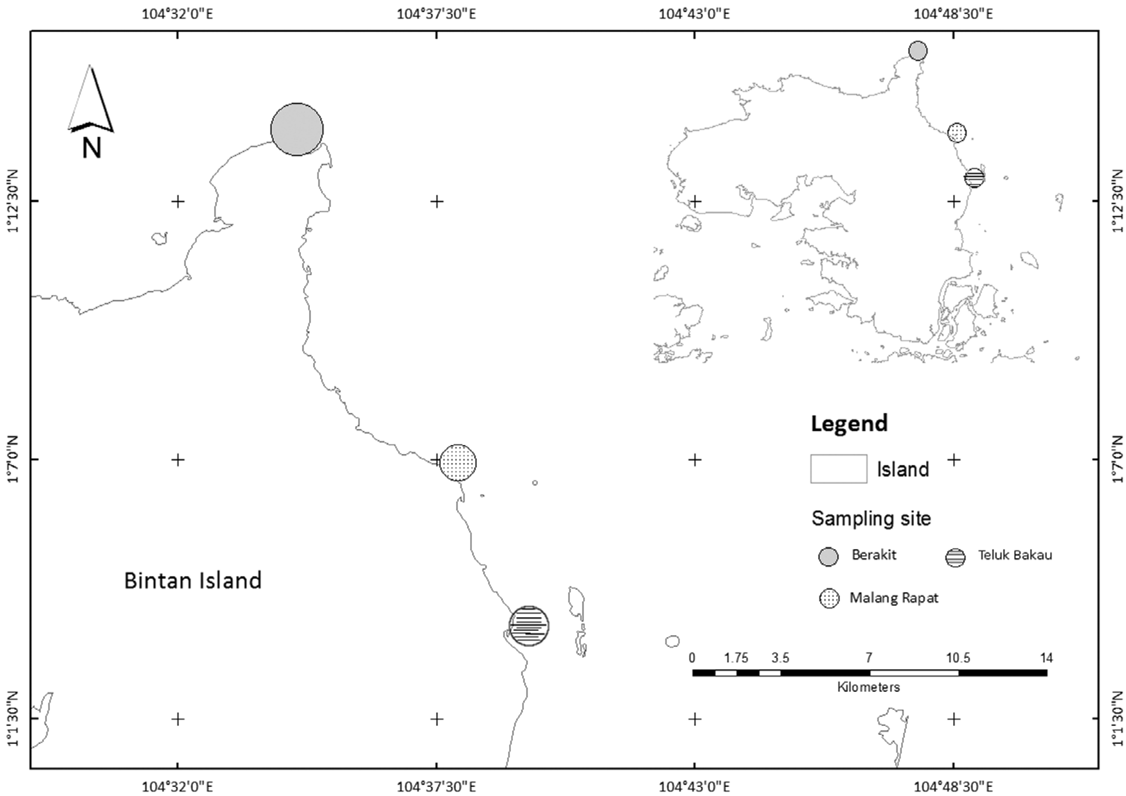

Fig. 1. Study site in Bintan Island.

the seagrass contribution to carbon sequestration with the most reliable approach, the auto-/allochthonous variable should be considered.

As organic aggregates, marine snow, together with organism's fecal pellets, and phytodetritus of sinking plankton, create particulate organic matter (POM) which is exported downward from the euphotic zone (Turner, 2015). These aggregates may be formed by colloidal organic carbon, and are often combined with living organisms, inorganic matter and even decaying materials (Alldredge and Silver, 1988; Kepkay, 1994). Since the term 'marine snow' always refers to the organic material falling from upper waters to the deep ocean (e.g. Asper, 1987; Alldredge and Silver, 1988; Kepkay, 1994; Turner, 2002; Goldthwait and Alldredge, 2006), in the present paper we use the term 'aggregates' instead to refers specifically to the phenomenon when it occurs in shallow waters (i.e. seagrass beds).

There are two key points correlated to marine snow aggregates in seagrass bed. Firstly, seagrass phytodetritus, which is likely to be an important component of marine snow besides fecal pellets and colloidal organic matter, is an important element for the carbon budget, i.e. the loss of carbon as fine particulate organic matter has been estimated to be about 48% of seagrass primary production (Mateo and Romero, 1997), the fate of which is undetermined. Secondly, the aggregation process of marine snow is a process which impacts on the carbon cycle, since this aggregation has been investigated as a function of the partial pressure of CO_2 and mineral particles (Dilling and Alldredge, 2000; Passow et al., 2014). Furthermore, more than 90% of the variation of vertical flux of particulate matter in the coastal water column is due to variations in the flux of marine snow (Shanks, 2002), which is predicted to imply the total particle flux in the sea (Graham et al., 2000). Therefore, elucidating the vertical flux of marine snow aggregates by estimating the carbon content, vertical carbon flux, and the biogeochemical role of marine snow aggregates in seagrass bed areas, are the main purpose in this study.

2. Materials and methods

2.1. Study site

This research was conducted in seagrass meadows at Bintan Island (Fig. 1). Bintan Island is situated in Riau Islands province (the Riau archipelago of Indonesia) and is located at 1°04′ 36″ N 104°30′ 01″ E with about 96% of its territory being sea. A tropical climate is dominant all through the year with two distinct seasons namely the wet Northeast Monsoon from November to March and the dry Southwest Monsoon from June to October.

Seagrass meadows are located in the north and east parts of the island, longways from south to north. We conducted the observation in three sampling site, Berakit, Malang Rapat and Teluk Bakau (Fig. 1) which face the South China Sea and the Karimata Strait.

2.2. Collecting aggregates samples

Marine snow aggregates were collected by using methods modified from Itoh et al. (2007) using similar trap methods for collecting mesograzer *fecal pellet* in *Sargassum* forest. The collection was conducted in the Southwest Monsoon season (September 2014). Three cylindrical containers (i.e. centrifuge tube 50 mL, internal diameter 28 mm) were placed on cylindrical concrete blocks (15 cm in diameter and high, respectively). The three centrifuge tubes were used as replicates. Each set of traps was placed at the bottom of the seagrass meadows (50–250 cm depth). Six set of traps were placed according to a 2 × 3 matrix (100 and 83 m distances between row and column, respectively). The matrix acts as a spatially minimum representative of the seagrass area of each sampling site (Fig. 1).

Traps were set just before high tide and then recovered on the next day (about 24 h later). The content of each centrifuge tube then was filtered with 125 μm sieves to remove sand and