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Carbon budget of leaves of the tropical intertidal seagrass *Thalassia hemprichii*

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ABSTRACT

The question of whether seagrass beds are effective carbon sinks has recently attracted much attention. Leaf production and consumption, and detrital export and decomposition were determined to quantify the carbon budget of leaf production in a southern Taiwan seagrass bed composed of the tropical intertidal seagrass *Thalassia hemprichii*, which is widely distributed in intertidal zones of the western Pacific. The influence of elevation in the intertidal zone on these processes was also investigated. Leaf production and consumption, and export of leaf detritus showed seasonal variations, with higher rates in the wet season (summer and autumn) and lower rates in the dry season (winter and spring). At the high-elevation site, leaf consumption by fish was significantly higher than that by sea urchins. At the low-elevation site, however, the proportion of leaves consumed by sea urchins was equivalent to that by fish. Leaf detritus decomposed rapidly within the first 9 days, then gradually slowed down, and stabilised after 212 days, at which only 8.7% of dry weight remained in the litterbags. The carbon budget of seagrass leaves demonstrated that 20% of leaf production was grazed by fish and sea urchins and 80% flowed to detritus. This suggests that seagrass leaves are important food sources for inhabiting herbivores. Most of the detritus decomposed (44% of leaf production) or was exported (32% of leaf production), and only 4% of leaf production or 22 g C m^{-2} yr^{-1} was stored in this tropical intertidal seagrass bed. Mass balance calculations support this tropical seagrass bed acting as a carbon sink and an outwelling system which exports organic detritus to neighboring coral reefs.

1. Introduction

Shallow coastal waters have long been recognized as some of the most productive natural ecosystems in the world (Schelske and Odum, 1962). However, there is still uncertainty as to whether primary production in coastal waters is exported or recycled (Chen and Borges, 2009). The organic carbon burial rate in vegetated habitats, including seagrass beds, mangroves, and saltmarshes, was estimated to be 0.33 Pg C yr^{-1} on a global scale (Nellemann et al., 2009). The “missing carbon sink” (1.8 $\pm$ 0.5 Pg C yr^{-1}) from the global budget may be accounted for by the existence of widespread small sinks (Schindler, 1999). There is a need to understand how these vegetated habitats function as natural carbon sinks and how they are affected by underlying factors (Laffoley and Grimsditch, 2009; Mcleod et al., 2011).

Seagrasses are widely distributed in shallow coastal waters throughout the world except the Antarctic (den Hartog, 1970). They are important in supporting the detrital food chain (Zieman, 1982), where most primary production is transferred to higher trophic levels via fallen leaves (detritus) (Cebrián et al., 1996; Pergent et al., 1997). The detritus may remain in seagrass beds and be consumed by crustaceans and snails or decomposed by microbes (Fenchel, 1970; Wittmann et al., 1981). Further, it may be transported by waves and tides to neighboring ecosystems (Fenchel, 1977; Pergent et al., 1997; Cebrián, 2002). Recently, seagrass beds were recognized as key sites for carbon storage in the biosphere (Fourqurean et al., 2012); despite this the carbon budget of seagrass ecosystems on a global scale has rarely been quantified.

Based on a compilation of available data, Duarte and Cebrián (1996) estimated that the largest part of seagrass biomass produced is decomposed (50%), with export and herbivory respectively accounting for 24% and 19%, and the remaining 16% being stored. However, numbers of field observations of herbivory, export, decomposition, and storage are very limited (Kennedy and Björk, 2009). Duarte (1999) indicated that 25% of the literature on seagrass ecology related to the ecology of just two seagrass species (*Thalassia testudinium* and *Posidonia oceanica*) with 50% of the studies conducted in the Caribbean and Mediterranean. Reliable estimates of the distribution and density of dominant seagrass

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species in all different biogeographical regions and the potential of each species for carbon storage are needed to produce an accurate global carbon budget (Kennedy and Björk, 2009; Fourqurean et al., 2012).

Thalassia hemprichii (Ehrenb.) Aschers. is one of the most widely distributed tropical seagrasses in the western Pacific (Klumpp et al., 1993; Mukai, 1993). It often occupies intertidal zones as it is tolerant of high irradiance, air exposure and their combined effects (Lan et al., 2005). This study aimed: 1) to quantify the carbon budget of leaves of the tropical intertidal seagrass *T. hemprichii* by simultaneously measuring its leaf production and consumption, and detrital export and decomposition, 2) to examine the influence of elevation in the intertidal zone on those processes, and 3) to assess whether tropical intertidal seagrass beds are effective carbon sinks.

2. Materials and methods

2.1. Thalassia hemprichii and the study sites

Thalassia hemprichii is a perennial that is capable of both clonal propagation and sexual reproduction and can colonize open areas and/or maintain existing beds (Vermaat et al., 1995). In southern Taiwan, the above-ground biomass persists throughout the year, with a unimodal pattern and a peak in June (Lin and Shao, 1998). Generally, flowering is initiated in January, peaks in February, and then declines through April. There are seasonal changes in the abundance and productivity of *T. hemprichii*, and wind speed and rainfall are the factors most responsible for this seasonal variability (Lin and Shao, 1998).

This study was conducted in an intertidal seagrass bed of *Thalassia hemprichii* (21°57'N, 120°44'E) at Dakwan on the west coast of Nanwan Bay, located at the southern tip of Taiwan (Fig. 1). Southern Taiwan has a tropical climate, with distinct dry and wet seasons. The maximum air temperature (about 28 °C) often occurs in July, and the minimum (about 20 °C) occurs in January (data from the Central Weather Bureau, 1981–2010). Seasons were defined as spring (26.70 ± 0.74 °C, March–May), summer (28.77 ± 0.33 °C, June–August), autumn (27.47 ± 0.73 °C, September–November), and winter (24.75 ± 0.15 °C, December–February), according to the water temperature in Nanwan Bay (data from the Central Weather Bureau, 2008–2009). Generally, summer and autumn coincide with the wet season, and winter and spring coincide with the dry season. In the wet season, average monthly rainfall frequently exceeds 320 mm, and typhoons and southwesterly monsoonal winds bring considerable quantities of rain. During the dry season, when northeasterly monsoonal winds prevail, the mean monthly rainfall normally does not exceed 60 mm. Incident irradiance is ca.1500 μmol quanta m^{-2} s^{-1} in winter and 2000 μmol quanta m^{-2} s^{-1} in summer.

The studied seagrass bed is 214 m long and 18 m wide, covers about 3800 m^2, and is a homogeneous *Thalassia hemprichii* community. The seagrass bed is partly protected from wave action by a 5–10 m wide zone of elevated fringing coral reefs, and the substrata are covered by at least 10 cm of coral sand and debris. The mean coverage is about 28%, with a high value (47%) in autumn and a low value (15%) in winter (Lin and Shao, 1998). The coastline at Nanwan Bay is subjected to a mixed and predominantly semidiurnal tide. In order to consider the influences that the elevation level and tidal exposure have on the processes (Kuo and Lin, 2010), two sites, identified as high- and low-elevation sites (1.19 and 0.99 m, respectively, above the chart datum which was based on the mean sea level of the tide gauge station at Keelung, northern Taiwan) were studied. During low tide, seagrasses at the high-elevation site may be exposed to air and direct sunlight. The duration of seasonal low-tide exposure during daylight for *T. hemprichii* averaged 7.63 h (Lan et al., 2005), compared to 0.75 h for the low-elevation site. Water column salinity varied within a small range of 32.6–34.7 psu (Lin and Shao, 1998). The light extinction coefficient (k) in the water column ranged 0.59–1.26 m^{-1}.

2.2. Carbon budget of seagrass leaves

In this study, the carbon budget of leaves of the tropical intertidal seagrass *Thalassia hemprichii* only addressed the particulate components. Daily rates of leaf production and consumption, and detrital export were primarily determined in June (summer) and October (autumn) 2008 for the wet season and February (winter)

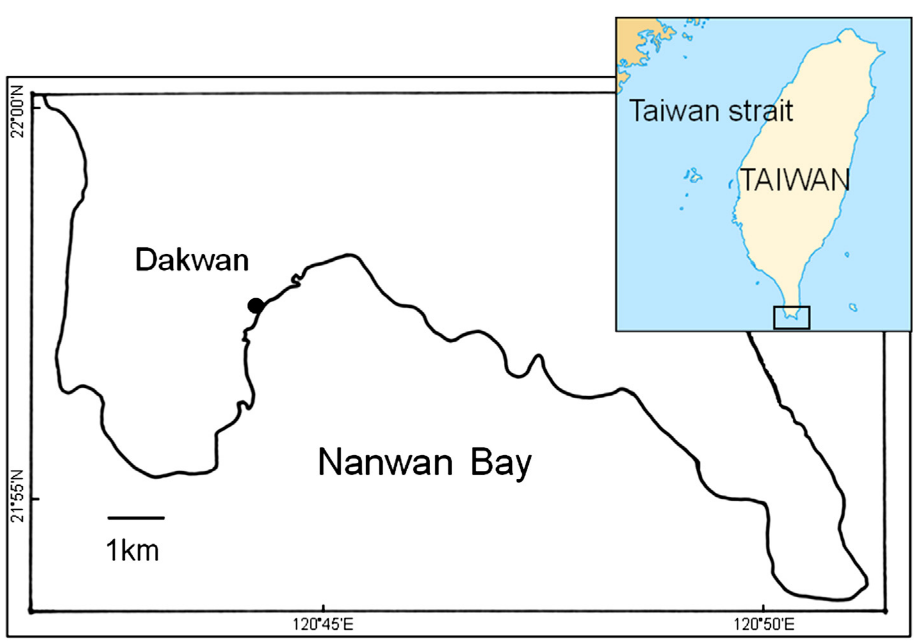

Fig. 1. Study site of *Thalassia hemprichii* at Dakwan, southern Taiwan.