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Temporal variations and temperature sensitivity of ecosystem respiration in three brackish marsh communities in the Min River Estuary, southeast China

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ABSTRACT

Ecosystem respiration (R_{eco}) is an important pathway for gaseous carbon loss in coastal wetland environments. However, little is known regarding the dynamics of R_{eco} and its temperature sensitivity (Q_{10}) under different tidal stages, and vegetation types. In this study, R_{eco} was measured with dark chambers for nearly 2 years in three different brackish marsh stands dominated by *Cyperus malaccensis*, *Phragmites australis*, and *Spartina alterniflora*, respectively, in the Min River estuary of southeast China. The mean R_{eco} across tidal stages and vegetation types exhibited strong temporal variations, and the Q_{10} value for R_{eco} was higher in the warm months than in the cold months. The mean annual R_{eco} was negatively correlated with electrical conductivity and soil water content, but positively correlated with both tidal water level and soil pH ($P < 0.05$). On the other hand, the seasonal variation in R_{eco} and Q_{10} was largely driven by the thermal regimes and soil salinity. Also, we found that the mean R_{eco} and Q_{s10} value were both relatively higher when the site was exposed before tidal inundation, as compared to that after tidal inundation for all the vegetation types studied ($P > 0.05$). Overall, the *C. malacensis* and *S. alterniflora* stands had the highest and lowest average rates of R_{eco}, respectively, while the mean Q_{s10} values were lower in the *Phragmites australis* stand than the other two vegetation types. Our findings point to the need of strengthening the in situ measurements of gas fluxes at multiple time scales in order to develop a better understanding of the response of R_{eco} to changing environmental conditions in the subtropical coastal wetlands. Our results also reiterate the importance of considering the influence of vegetation types in characterizing the magnitude and temperature sensitivity of R_{eco} in estuarine tidal marshes for predicting ecosystem responses to future global change.

1. Introduction

Carbon dioxide (CO_2) is a climatically important greenhouse gas (GHG) that contributes to approximately 60% of the overall radiative forcing of the atmosphere (Mosier, 1998; Myhre et al., 2013). Given that the atmospheric concentration of CO_2 has reached beyond 400 ppm in 2016 according to the long-term monitoring data from Mauna Loa (World Meteorological Organization, 2016), which is > 40% greater than the pre-industrial level (Myhre et al., 2013), the temperature of the Earth's surface has risen considerably that leads to increasing concerns about the potential environmental, economic, and social impacts of future climate change. Quantifying the potential magnitude of the CO_2 source or sink in individual ecosystems is therefore critical for accurately evaluating global carbon budgets, developing emission reduction measures, and formulating scientifically sound management strategies of ecosystems (Purvaja and Ramesh, 2001; Song and Liu, 2016).

Coastal wetlands, located at the interface between terrestrial and marine ecosystems, are widely distributed around the world ranging from arctic to tropical regions (Chmura et al., 2003). These wetland ecosystems are among the most productive ecosystems globally (Reddy and DeLaune, 2008), and are one of the important components of the global carbon budget. For example, the total carbon burial rates are estimated to be 31–34, 5–87, and 48–112 Tg C yr^{-1} for global mangroves, salt marshes, and seagrass beds, respectively, which are comparable to those of terrestrial forests (53.0, 78.5, and 49.3 Tg C yr^{-1} for temperate, tropical, and boreal forests, respectively) (Mcleod et al., 2011). While wetlands are generally considered to be long-term carbon

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sinks, they may act as net sources of CO_2 in certain periods or regions due to variations in environmental gradients (Picek et al., 2007) and human modifications (e.g. land-use changes) (Song and Liu, 2016). As one of the major mechanisms exporting C from the terrestrial carbon pool to the atmosphere (Lin et al., 2011), ecosystem respiration (R_{eco}) plays an important role in controlling the carbon balance of ecosystems and regulating atmospheric CO_2 concentrations (Valentini et al., 2000). Several studies have examined R_{eco} in coastal and estuarine marshes around the world (Hughton and Woodwell, 1980; Smith et al., 1983; Magenheimer et al., 1996; Olsson et al., 2015; Song and Liu, 2016). Although some studies have measured R_{eco} using closed chambers during the growing season over one or multiple full years, the use of eddy covariance technique has become increasingly important as it can provide a better characterization of the temporal variability of CO_2 fluxes through quasi-continuous measurements (e.g. Han et al., 2014; Knox et al., 2015; Krauss et al., 2016). Furthermore, coastal marshes are heterogeneous over both time and space that could be attributed to variations in topographic features, environmental factors, and tidal fluctuations, and are very sensitive to environmental changes and human activities (Sun et al., 2013). The high variability and temperature sensitivity of R_{eco} may lead to high uncertainties in the estimation of ecosystem carbon balance. In order to improve future predictions of atmospheric CO_2 concentrations, there is a need to better characterize the spatial and temporal variability of R_{eco} in coastal marshes, especially with respect to the variations over seasonal and annual scales, as well as the effects of tides and vegetation types.

Hydrological conditions (e.g. water table depth, soil moisture content, etc.) play an important role in governing R_{eco}, since they determine the relative thickness of aerobic and anaerobic zones in the soil profile which in turn affect the decomposition rates of soil organic matter (Clymo, 1983; Juszczak et al., 2013). Tidal fluctuations (i.e. flooding and ebbing) are important physical processes that can strongly govern the hydroperiod or hydrological regime of coastal wetlands (Neubauer, 2013). Significant differences in water table position and degree of soil water saturation have been observed before the flooding stage and after the ebbing stage, although the wetlands are exposed at both periods (Guo et al., 2009). These differences in antecedent conditions are likely to influence ecosystem processes and functions, and, ultimately, R_{eco}. Unfortunately, most of the previous researches have focused on R_{eco} only before the flooding stage (Zhou et al., 2009; Zhou et al., 2015; Song and Liu, 2016), while few studies have simultaneously measured R_{eco} before flooding and after ebbing for making comparative assessments. Moreover, the response of R_{eco} to temperature under different tidal stages remains unclear. Quantification of the variability of R_{eco} for both before flooding and after ebbing stages can improve our existing knowledge on the mechanisms controlling R_{eco}, as well as our prediction of future impacts of global change on the carbon balance of coastal wetlands.

Vegetation type is another important variable that can affect the temporal and spatial variations of carbon fluxes in coastal wetlands through its influence on a number of biotic and abiotic factors (Han et al., 2014; Xu et al., 2014). Different types of vegetation can lead to differences in photosynthesis rates, which in turn cause significant variations in plant biomass, carbon allocation, and substrate supply to plant roots and soil microbes (Högberg et al., 2002; Han et al., 2007; Metcalfe et al., 2011). The difference in the structure of aerenchyma tissues among various plant species can create large variations in the oxygen transport efficiency and thus the speed of soil organic matter decomposition (van der Nat et al., 1998; Xu et al., 2014; Yamori et al., 2014; Shrestha et al., 2016). Furthermore, soil chemical properties (i.e. pH, salinity, and nutrient contents) are shown to vary considerably among different vegetation types (Han et al., 2014). These differences may alter the dynamics of both autotrophic and heterotrophic respiration, and, ultimately, R_{eco}. Previous studies have shown significant differences in soil respiration rates among different vegetation types (Wigand et al., 2009; Han et al., 2014; Bu et al., 2015; Zhou et al., 2015; Hu et al., 2016), yet there is still a paucity of studies that measure respiration rates at the ecosystem scale from different vegetation stands in marshes. The effects of vegetation type on the temperature sensitivity of R_{eco} in costal marshes also remain poorly understood.

It is generally acknowledged that temperature is an important factor governing the emissions of CO_2 from wetlands to the atmosphere. The Q_{10} coefficient has been commonly used to describe the temperature response of various microbial-mediated processes by standardizing temperature-related differences in reaction rates to proportional changes per 10 °C rise in temperature (Inglett et al., 2012; Wang et al., 2015). Meanwhile, recent studies have suggested that the Q_{10} value determined in the field can only reflect the apparent temperature sensitivity of the underlying microbial processes involved in CO_2 production, with the actual fluxes being affected by a series of factors such as temperature, plant phenology, organic matter quantity and quality, moisture conditions, and some other unknown variables (e.g. Davidson and Janssens, 2006; Subke and Bahn, 2010). Therefore, it is necessary to determine how Q_{10} varies over the time in association with changes in the hydrological conditions (e.g. soil moisture, tidal stages), temperature, and vegetation types in the coastal wetlands.

In this study, we continuously measured R_{eco} for nearly 2 years in three different brackish marsh stands dominated by *Cyperus malaccensis, Phragmites australis*, and *Spartina alterniflora*, respectively, in the Min River estuary of southeast China. The objectives of this study were to: (1) determine the temporal variations of R_{eco} in tidal marsh ecosystem; (2) examine the influence of vegetation communities on the annual mean R_{eco} and its temperature sensitivity within those vegetation types; and (3) compare R_{eco} and its temperature sensitivity between two different tidal stages (before flooding and after ebbing).

2. Materials and methods

2.1. Description of study sites

The study sites were located in the Shanyutan wetland (26°00′36″ to 26°03′42″ N, 119°34′12″ to 119°40′40″ E), which is the largest tidal wetland (ca. 3120 ha) in the Min River estuary of southeast China (Fig. 1). The area is affected by a subtropical monsoonal climate, with annual average temperature and rainfall of 19.6 °C and 1350 mm, respectively, and a wet season during the springtime (Tong et al., 2010). Semi-diurnal tides are typical in this region in which the soil surface is submerged during the two periods of tidal flooding. Ebbing occurred for about 7 h over a 24-h cycle, while the soil surface is completely exposed at other times. On days with neap tide, the soil surface can be exposed for the full 24-h cycle (Tong et al., 2013). During the tidal inundation period, the soil surface is usually flooded by 20 to 150 cm of water. The average salinity (± 1 standard deviation) of the surface tidal water is 4.2 ± 2.5‰ between May and December (Tong et al., 2010). The sampling sites were located in the central-western portion of the Shanyutan wetland (26°01′46″N, 119°37′31″E), where there are three adjacent macrophyte marsh stands dominated by the native species *Phragmites australis* (common reed), *Cyperus malaccensis* (shichito matgrass), and the invasive plant *Spartina alterniflora* (smooth cordgrass), respectively. The maximum height of *C. malaccensis* was about 1.5 m, and the average heights for *P. australis* and *S. alterniflora* ranged from about 1.5 to 1.8 m tall. The soil physicochemical properties and plant community characteristics for the three marsh communities are listed in Table 1.

2.2. Gas sampling and measurement

Monthly R_{eco} measurements were made between April 2008 and December 2009 for a total of 21 times. Three replicate chambers each separated by about 5 m were deployed in each of the three marsh stands (*P. australis*, *C. malaccensis* and *S. alterniflora*) for gas sampling. The closed, static chamber technique (Song et al., 2009; Mäkiranta et al.,