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Metabolism and methane flux of dominant macrophyte communities in created riverine wetlands using open system flow through chambers

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ABSTRACT

Estimating net primary productivity of macrophytes is a common practice in wetland research, but much less is done regarding gross primary productivity (GPP) and respiration (R) of wetland macrophyte communities. The purpose of this project was to estimate metabolism (GPP and R) and greenhouse gas emissions (methane) of wetland macrophyte communities using an open system flow-through chamber to determine the gaseous carbon budget. Large (0.5 m^2, 1.6 and 2.6 m tall) flow-through chambers were placed over dominant macrophytes communities (2010: *Typha* spp., *Scirpus fluviatilis*, *Sparganium eurycarpum*, and *Phragmites australis*; 2011: *Typha* spp., *S. fluviatilis*, *P. australis*, and open water) in two wetlands in central Ohio, USA. Gas samples were collected over a 48-h period monthly from April through September. Samples were collected using a vial and syringe method from the chambers every odd hour between sunrise and sunset to estimate photosynthesis, and twice nightly to estimate respiration. Overall metabolism measurements were similar in the two years: 2010, GPP = 13.9 ± 1.2 g CO_2-C m^{-2} day^{-1}; $R = 12.1 \pm 1.0$ g CO_2-C m^{-2} day^{-1}; 2011, GPP = 13.9 ± 1.1 g CO_2-C m^{-2} day^{-1}; $R = 12.9 \pm 0.6$ g CO_2-C m^{-2} day^{-1}. GPP peaked in June 2010 and in July 2011 and overall was approximately 3.7% of solar radiation. GPP differed by both month sampled and plant community ($p < 0.001$ and $p = 0.002$, respectively). *P. australis* and *Typha* spp. had higher average GPP than did open water and *P. australis* had higher GPP than *S. fluviatilis*. Median methane emissions from the sample plots were 12.8 mg CH_4-C m^{-2} h^{-1} and differed by month ($p < 0.001$) and soil temperature ($p = 0.049$). Based on this study, net retention of carbon in the two experimental wetlands ranged from 160 to 195 g C m^{-2} yr^{-1}; these values compared well with other published estimates for the same wetlands.

1. Introduction

The gaseous carbon budget of a wetland depends on the carbon dioxide uptake during photosynthesis and the amount of carbon lost as either carbon dioxide from plant and soil respiration or as methane emitted by methanogenesis (Whiting and Chanton, 2001; Cornell et al., 2007; Yvon-Durocher et al., 2011). The overall limit of heterotrophic activity within an ecosystem is established mainly by the amount of carbon acquired by a system through gross primary productivity (GPP) (Cornell et al., 2007).

GPP is dependent on species present, available solar radiation, available water and nutrients, and temperature (Running et al., 2000). Many species have an optimum temperature for photosynthesis that tends to be near the mean daytime temperature of an ecosystem. If temperature is drastically different from the optimum (low or high), GPP measurements will be low. Limitation of solar radiation will also lead to low relative GPP. Respiration, unlike GPP, tends to increase exponentially with temperature, so under high temperature conditions it is possible for respiration to exceed GPP (Aber and Melillo, 2001; Yvon-Durocher et al., 2011).

Methanogensis occurs under reduced, anaerobic condition by methanogen Archaea. These conditions are likely to form under prolonged periods of hydrologic inundation within wetland ecosystems (Mitsch and Gosselink, 2007; Altor and Mitsch, 2008). Methanogens utilize organic matter within a system to produce methane (Mitsch and Gosselink, 2007). Methane emissions can be reduced by methanotrophic bacteria that oxidize methane within the soil and water, while producing carbon dioxide (Segers, 1998; Mitsch and Gosselink, 2007; Altor and Mitsch, 2008). Methanogenesis is likely linked to soil temperature, either directly or in

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combination with other environmental factors (Schutz et al., 1990; Gedney et al., 2004). A positive correlation has been found between soil temperature and methane emissions in temperate freshwater wetlands (Altor and Mitsch, 2008; Nahlik and Mitsch, 2010, 2011a; Sha et al., 2011). Soil carbon content and hydrologic gradient (slope of the water table) have also been found to have a positive relationship with methane emissions (Altor and Mitsch, 2008; Koh et al., 2009; Sha et al., 2011).

GPP may influence the amount of methane production in an ecosystem (Joabsson et al., 1999), with up to 15% of carbon fixed being released as methane (Brix et al., 2001). Root carbon exudates and litter production act as a source of organic matter for methanogen Archaea (Chanton et al., 1995; Joabsson et al., 1999; Whalen, 2005). High primary productivity leads to an increase in root exudates and litter production of a system, thereby increasing the amount of raw material for methanogens to utilize. Increases in plant density, and thereby plant productivity, have been shown to result in increased methane emissions compared to lower density sites of the same species (de Klein and van der Werf, 2013). It is also possible that root exudates may stimulate the decomposition of complex organic compounds in the soil that can then be utilized by methanogens (Bridgham et al., 2013). However, oxygen released from roots can decrease methane emissions by facilitating methanotrophy and increasing available habitat for methanotrophs (Whalen, 2005; Fauber et al., 2013).

Due to the anaerobic conditions found in wetlands, methane emissions compared to other types of ecosystems tend to be somewhat high, with wetlands and areas with high water tables being methane sources while most dry ecosystems are methane sinks (Smith et al., 2000; Whiting and Chanton, 2001). Wetland methane emissions account for approximately 20–25% of global methane emissions, with the remainder coming from anthropogenic sources (Mitsch and Gosselink, 2007; Nahlik and Mitsch, 2011b). The balance of carbon uptake and emissions will determine if a wetland is acting as a sink or a source of carbon (Whiting and Chanton, 2001).

Understanding carbon flux in terms of both carbon dioxide and methane is of particular importance due to the role these gases play in global climate change. Of these two gases, methane is considered to be of great concern since it has a global warming potential of 25 compared to carbon dioxide's global warming potential of 1 (IPCC, 2007). Thus, small changes in levels of methane will have a greater impact on global climate change than small changes in levels of carbon dioxide. The role of wetlands as carbon sinks or sources has been debated. It has been suggested that in North American freshwater wetlands, carbon sequestration is offset by the amount of methane produced (Bridgham et al., 2006). Other studies have suggested that over the long term (100–500 year time frame), wetlands act as carbon sinks and thus are capable of alleviating the effects of global climate change regardless of whether they emit methane (Brix et al., 2001; Whiting and Chanton, 2001; Mitsch et al., 2013). Newly created and restored wetlands are likely to act as carbon sinks, due to the rate of organic soil carbon increase, compared to natural wetlands, outweighing lower rates of methane production (Badiou et al., 2011).

Measurements of GPP, respiration, and methane emissions can be done on many different scales, from individual leaf analysis to eddy flux towers (Ruimy et al., 1995). With chamber methods, these can either be open or closed systems, both of which have their pros and cons. Open system chambers can be used for extended periods of time, but require controlled air movement through the chamber to maintain chamber temperature within range of ambient (Drake and Read, 1981; Streever et al., 1998). Closed system chamber are simple, non-mechanical structures, but can only remain in place for a short period of time due to increased temperature within the chamber which can alter ecosystem processes (Streever et al., 1998).

This paper describes GPP and respiration of the dominant macrophyte communities in 18-year-old created marshes in central Ohio, as well as methane emissions from those communities, using open system flow through chambers over the course of the growing season. It is hypothesized that there will be a significant difference between the planted and unplanted dominant species in the two wetlands, with the unplanted naturally colonizing species having generally higher GPP and respiration rates than the planted species in the wetlands. It is also hypothesized that there will be an overall net retention of carbon in the wetland communities, i.e., the amount of carbon taken up through GPP will be larger than the amount of carbon lost through respiration and methane emissions.

2. Methods

2.1. Study site

The two created experimental wetlands at the Olentangy River Wetland Research Park (ORW), Ohio State University, Columbus, Ohio were used to examine metabolism and methane emissions from dominant macrophyte communities. In the spring of 1994, an initial vegetation succession experiment was implemented in which one wetland was planted with 13 wetland macrophyte species (western basin), while the other wetland (eastern basin) was allowed to colonize naturally (Mitsch et al., 1998, 2012). The major plant communities in these two wetlands during this study were dominated by *Typha* spp. (*Typha latifolia*, *Typha angustifolia*, and *Typha* × *glauca*), *Sparganium eurycarpum*, *Scirpus fluviatilis*, and *Phragmites australis*. *S. eurycarpum* and *S. fluviatilis* were both planted in the planted wetland in 1994. *Typha* spp. and *P. australis* colonized the wetlands naturally. All four species are perennials.

2.2. Chamber design

Metabolism of the herbaceous vegetation was measured in the major plant communities of the experimental wetlands at the ORW on a monthly basis from April to September of 2010 and 2011. Chambers were set up in four dominant plant communities in 2010 and set up in three dominant plant communities and one open water site in 2011. Each community was monitored with two chambers per month, which were run for approximately 48-h each month. Sampling occurred every odd hour between sunrise and sunset to determine GPP, while sampling to measure respiration occurred once a night (after sunset) in 2010 and twice during nightly (after sunset and before sunrise) in 2011.

Each chamber consisted of a plastic bag fitted over a PVC pipe frame that sat on a wood and plexi-glass base (Fig. 1). Chamber bases covered a 0.5 m^2 area of soil and were pushed 10 cm into the soil surface. The plastic bag and PVC pipe frame were sealed to the chamber base using all-weather tape. Two different frame heights were used, 1.4 m and 2.4 m, depending on the height of the vegetation. Each chamber had an inflow pipe near the base of the chamber and an outflow pipe coming out of the top of the chamber. The inflow pipe was made of PVC pipe and semi-rigid aluminum pipe. The 1.83 m PVC pipe had a fan with a range of 1–7 m^3/min (40–250 cubic ft/min) airflow at one end, a pitot tube near the middle, and a semi-rigid aluminum pipe at the other end that connected to the chamber. A manometer was connected to the pitot tube to measure air flow through the chamber. Sampling ports were located on the inflow PVC pipe and the outflow pipe (Fig. 1). A fan was used to force air through the chamber (Oechel et al., 2000).