Impacts of Elevated Atmospheric CO₂ and Plant Species Composition on Methane Emissions from Subarctic Wetlands

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Abstract
Elevated atmospheric CO₂ may create greater methane (CH₄) emissions from subarctic wetlands. To date such ecosystem feedbacks remain poorly understood, particularly in relation to how different wetland plant species will control such feedbacks. In this study we exposed plant-peat mesocosms planted with four Cyperaceae species to 400 and 800 ppm atmospheric CO₂ concentrations and measured plant and peat properties as well as CH₄ fluxes. Above ground biomass for plants grown at 800 ppm CO₂ increased for E. angustifolium, Eriophorum vaginatum and Carex brunnescens, but the total biomass of C. acuta decreased relative to the ambient CO₂ treatment. The plant species and elevated CO₂ treatment affected both peat redox potential and pore water chemistry. There was no overall effect of the elevated CO₂ on CH₄ emissions, however, CH₄ emissions were related to above ground biomass and redox potential, both of which were significantly altered by elevated CO₂. Our study shows that species composition poses an important control on how wetland communities will respond to elevated CO₂ and that plant mediated changes of peat biogeochemical processes, in response to elevated CO₂ levels, may affect CH₄ emissions from subarctic wetlands, but any such responses will differ among species.

Keywords Methane · Subarctic · Wetland · Elevated CO₂ · Plant species

Introduction
Northern peatlands store ca. half of global soil carbon (C), much of which is held in permafrost areas (Tarnocai et al. 2009). Arctic and sub-arctic peatlands are responding rapidly to climate warming, threatening their C storage capacity (IPCC 2013). In parallel with rising temperatures, atmospheric CO₂ levels have increased from pre-industrial levels of 280 ppm to 400 ppm with future atmospheric CO₂ concentrations predicted to increase to between 426 ppm (RCP 2.6) and 936 ppm (RCP 8.5) over the next century (IPCC 2013). These changes in climate and atmospheric CO₂ concentration may result in greater Net Primary Productivity (NPP) and decomposition rates which are both controls of greenhouse gas fluxes from ecosystems including wetlands (Curtis et al. 1989; Turetsky et al. 2014).

Wetlands release ca. 80% of methane (CH₄) emission from natural sources, equating to a third of overall global emissions (Kirschke et al. 2013) with the largest CH₄ atmospheric concentrations found north of 40° N (Steele et al. 1987). Indeed, the large area of wetlands at northern high latitudes are recognised as an important component of the global CH₄ budget (Moore and Knowles 1990; Bridgham et al. 2013; Turetsky et al. 2014). Wetland CH₄ emissions are determined by temperature, substrate and hydrology (Updegraff et al. 2001; Bridgham et al. 2013). In subarctic and arctic regions, these factors are strongly controlled by permafrost. Therefore future changes to permafrost are predicted to impact on CH₄ emissions from high latitude regions (Christensen et al. 2004; IPCC 2013). For example, waterlogging of peatland soils as a result of permafrost thaw will likely increase CH₄ emissions from arctic regions both in response to the anoxic conditions per se but also due to vegetation shifts from moss-lichen woody shrub tundra to wet sedge communities (Christensen et al. 2004; ACIA 2005; Bridgham et al. 2013).

Vegetation directly impacts CH₄ emissions from peatlands (Joabsson et al. 1999; Heilman and Carlton 2001; Öquist and Svensson 2002; Ström et al. 2005; Bhullar et al. 2013a, b). The main controls of CH₄ emissions in relation to vegetation...
are; (i) release of labile organic compounds in to the root zone
which increase CH₄ production; (ii) enhancing CH₄ oxidation
due to root oxygen emissions in to the peat and; (iii) passive
transport of CH₄ through plant tissues (Joabsson et al. 1999;
Oquist and Svensson 2002). As most of the organic matter
stored in arctic peatlands is recalcitrant and substrates for di-
gestion by anaerobic bacteria are limiting (Bridgham et al.
2013; Sjogersten et al. 2016), input of labile photosynthates
in the form of litter or root exudates are an important carbon
source for methanogens (Tom and Chapin 1993; Ström et al.
2005). The diffusion of oxygen through aerenchyma from the
atmosphere into the roots and leakage into the rhizosphere
causes oxidation of CH₄ to CO₂ in the soil, substantially re-
ducing net CH₄ emissions (Fritz et al. 2011). The quality and
quantity of plant litter and root exudate as well as root O₂
inputs differs among wetland plant species, potentially creating
species specific impacts on CH₄ fluxes (Updegraff et al.
1995; Ström et al. 2005). Plant mediated transport of CH₄ to
the atmosphere can represent a major emission pathway but its
contribution to net emissions varies among plant species as the
rate of transport is strongly dependent on aerenchyma tissue
(Kutzbach et al. 2004; Bhullar et al. 2013b). Indeed, while both
Eriophorum and Carex species can emit large amounts of
CH₄ through their tissues the proportion of CH₄ emitted
through plant tissues varies strongly among species
(Bhullar et al. 2013b).

Elevated atmospheric CO₂ can influence wetland CH₄ pro-
duction through its role in plant C assimilation and allocation.
For example, greater root biomass in rice grown under elevat-
ed CO₂ concentration has substantially increased CH₄ emis-
sions from paddy rice fields (Van Groenigen et al. 2011). Greater
plant biomass and productivity in a range of wetland
species in response to elevated CO₂ have resulted in increased
CH₄ emissions from some wetland systems (Megenigal and
Schlesinger 1997; Kao-Kniffin et al. 2011; Wang et al. 2013)
while the growth of other species have not been affected
resulting in no change in wetland CH₄ fluxes (Angel et al.
2012). Such contrasting responses may, in part, be controlled
by the plant species composition of different wetlands as elev-
ated atmospheric CO₂ concentrations influence plant activity
including growth, photosynthetic rates and root exudate pro-
duction, processes which also vary strongly among species
(Lawlor and Mitchell 1991; Zak et al. 1993; Bellisario et al.
1999). These findings suggest that a more detailed under-
standing of how elevated CO₂ impact different plant species
is required in order to tease apart the controls that govern plant
mediated impacts on CH₄ emissions in response to elevated
CO₂. It is likely that if elevated atmospheric CO₂ concentra-
tions increase biomass, providing growth is not nutrient lim-
ited in the first place (Gordon et al. 2001), this will increase
labile C inputs into the peat and potentially production of CH₄.
However, greater plant biomass may also increase transport of
O₂ to the rhizosphere and CH₄ to the atmosphere (Joabsson
et al. 1999; Wolf et al. 2007; Laanbroek 2010). Taken toget-
er, the understanding of impacts of elevated CO₂ on arctic
wetland CH₄ emissions is limited at both the ecosystem and
species level, creating large uncertainties in model predictions
of the role of elevated CO₂ on CH₄ feedback mechanisms
(Ringleval et al. 2011).

Arctic and sub-arctic peatlands are currently responding
rapidly to climate warming, which has resulted in expansions
of graminoid-dominated flooded areas (Prater et al. 2007;
Åkerman and Johansson 2008). Such changes in the vegeta-
tion has lead to large increases in CH₄ emissions (Christensen
et al. 2004; Hodgkins et al. 2014). In subarctic and arctic
wetlands, graminoids (e.g. Eriophorum sp. and Carex sp.)
are known to directly impact CH₄ emissions both by transport
of CH₄ from the rhizosphere to the atmosphere (Bhullar et al.
2013b; Turetsky et al. 2014) and by impacting CH₄ produc-
tion and oxidation in the rhizosphere (Ström et al. 2005;
Koelbener et al. 2010; Fritz et al. 2011; Ström et al. 2012).
However, these effects are species specific (Christensen et al.
2004; Ström et al. 2005; Prater et al. 2007; Hodgkins et al.
2014). To explore how variation in graminoid species compo-
sition and elevated atmospheric CO₂ impacts CH₄ emissions
we established a controlled environment experiment exposing
peat mesocosms planted with either Carex acuta, Carex
brunescens, E. vaginatum or E. angustifolium to elevated CO₂ and me-
sured how this affected plant growth, peat physicochemical
properties and CH₄ fluxes. This experiment was used to test
the hypothesis that: Elevated atmospheric CO₂ will increase
productivity of Carex and Eriophorum species and subse-
duantly stimulate CH₄ emissions due to increased root inputs
of labile substrates for methanogens, with the largest effect of
elevated CO₂ on CH₄ emissions found in peats planted with
Carex acuta (the highest biomass species).

Methods

Site Description

The study site is a subarctic peatland located on the southern
edge of Lake Torneträsk in Northern Sweden (68° 21’ 30.96”
N 18° 46’ 56.064”E). The mean annual precipitation is
310 mm, more than 40% of this occurs during summer. Mean
annual temperature is 0.7 °C, with a July average of
11 °C (1913–2000 average, Kohler et al. 2006). The site is a
palsa mire complex, a common peatland type in the region.
The area is made up of two distinct communities of vegetation
(Sjogersten et al. 2016). The raised, mesic area is dominated
by dwarf shrubs (Betula nana, Empetrum nigrum and
Vaccinium uliginosum). The active layer depth in these
hummocks is 30 ± 0.9 cm in summer. In the flooded
areas there are three dominant Cyperaceae species: Carex
acuta, E. angustifolium and E. vaginatum as well as the less common
C. brunnescens (Nilsson 1991; Mossberg and Stenberg 2008). On average, \( n = 5 \) C. acuta grew in locations with an active layer depth of 119 ± 21 cm below the peat surface, E. angustifolium at 122 ± 12 cm and E. vaginatum and C. brunnescens at 95 ± 21 cm. The water level depth in the flooded areas varied, averaging +34 ± 7 cm where C. acuta was found, +30 ± 3 cm for E. angustifolium and +15 ± 2 cm for E. vaginatum and C. brunnescens, note that positive values means that the peat surface was submerged. The peat pH at 5 cm depth was 4.3 ± 0.04; with conductivity of 66 ± 30.8 μS; extractable PO4^-3 of 3.9 ± 1 μg g^-1 and extractable NH4+ of 0.12 ± 0.02 μg g^-1. Peat pH and conductivity was determined following mixing peat with DI water in a 1:2 ratio by volume and analysis on a dual pH and conductivity analyser. Extractable PO4^-3 and NH4+ was determined using standard colourimetrically methods following a K2SO4 extraction of 5 g of fresh weight soil.

**Experimental Design and Analysis**

**Growth Room Experiments**

Growth room experiments were established using two walk-in growth rooms (Unigrow, UK) which had fixed atmospheric CO2 concentrations of 400 ppm and 800 ppm. Mesocosms planted with either C. acuta, C. brunnescens, E. angustifolium or E. vaginatum were established with peat and plant material collected from the field site. The degree of replication per treatment was; \( n = 10 \) for C. acuta and E. vaginatum, \( n = 6 \) for E. angustifolium, and \( n = 5 \) for C. brunnescens, this resulted in a total number of 42 mesocosms. Peat samples were collected as several 20 × 20 × 20 cm blocks taken ca. 30 cm below the peat surface from submerged areas free of vegetation with a water table depth of ca. 30 cm. The recovered plant and soil samples were transported, separated and transplanted into separate water-tight one litre pots ensuring good contact between plant roots and the peat. Care was taken that peat did not dry out prior to the experiment started, however, some oxygenation of the peat will have occurred. For C. acuta, C. brunnescens, E. angustifolium individual shoots were transplanted in to the peat while E. vaginatum was planted as small tussocks reflecting the plants growth form in the field.

As the starting biomass differed among pots the mesocosms were grouped as pairs according to biomass and then randomly allocated to a CO2 treatment. The volume of peat in the pots were ca. one litre, water levels were adjusted (using tap water) to 2–3 cm above the peat surface throughout the experiment. This water level is shallower than those in the field but where used to reduce ebullition and bubble formation on the inside edges of the mesocosm which were deemed to be a risk associated with using deeper water levels. The conditions used in the growth chambers was a day length of 16 h, day/night temperature was 21/15 °C, reflecting the conditions found at the sites during warm summers to stimulate growth and microbial activity. The relatively high temperatures compared to the average air temperature during the field sampling period of 13.3 °C. Daytime light levels were constant at 400 μmol m^-2 s^-1 and day/night humidity was 65/75%. The mesocosms were equilibrated for ca. 1 month before the measurements started to allow the system to settle from the disturbance and any remaining oxygen to be used up so that the experiment took place under anoxic conditions.

Two types of head space chamber were used for the gas sampling. A taller chamber (15 cm diameter × 100 cm height, 17.7 l volume) was used for the mesocosms with C. acuta and E. angustifolium and a smaller chamber (15 cm diameter × 25 cm height, 4.4 l volume) was used for the shorter E. vaginatum and C. brunnescens.

To define individual plant-mediated methane-controlling mechanisms over the experimental period, CH4 flux, redox, and plant extension growth measurements were measured fortnightly during daytime conditions. These measurements were taken at five time points over a 10 week period between January and April 2015. Methane fluxes were determined using static headspace chambers (Denmead 2008) with samples collected over 20 min. Air in the chambers was circulated using small computer fans. The air samples were stored in 12 ml exetainers (Labco, Lampeter, UK). CH4 concentrations were determined by gas chromatography (GC-2014, Shimadzu UK LTD, Milton Keynes, UK) using a single injection system with a 1 ml sample loop that passed the gas sample using H2 as carrier, the flow rate was 30 ml min^-1. The oven temperature was 40 °C and the column was a molecular sieve, the injector temperature was 80 °C. Flame ionization (detector temperature was 250 °C) detectors were used to measure CH4. The analytical error was ca. 5%. Methane fluxes were calculated using the ideal gas law (e.g. Mangalassery et al. 2014) and were expressed as both per unit area and peat dry weight.

Peat redox potential was measured in three points in each pot using a redox probe (General Purpose ORP Electrode, Van London Phoenix, Randburg, South Africa) connected to a millivolt pH meter. To assess plant growth, three leaves of each individual plant were labelled and extension growth measured. At the end of the experiment, pore-water samples were extracted from each mesocosm using rhizon samplers (Rhizosphere Research Products, Wageningen, Netherlands). In the soil solution we determined the E4:E6 ratio, which is an indices of the humification capacity of dissolved organic carbon in the solution, using a spectrophotometer (Cecil CE1011 1000 series) set at 465 nm and 665 nm (Worrall et al. 2002). TOC-TN analysis (Shimadzu TOC-V CPH; TNM-1) was used to measure the total dissolved organic carbon (TOC) and total dissolved nitrogen (TN) content of the water with the ratio of TOC:TN reflecting the lability of carbon in the pore water (Kokfelt et al. 2009). Above and below ground
biomass of plant samples was separated, roots were picked from the peat using tweezers and then washed. The biomass samples and the remaining peat were dried at 60 °C for 72 h then weighed to calculate total above and below ground biomass and peat dry weight.

Data Analysis

Data analysis was carried out using GenStat (15th Edition). Treatment effects on plant extension growth and biomass production, pore water chemistry and CH4 fluxes was assessed using linear mixed models. In the model we used the CO2 treatment, species treatment and time as fixed factors while individual mesocosms were used as the random factor. Statistics reported are the F-value, which is the ratio for between group variance and within group variance, numerator (i.e. fixed) degrees of freedom and denominator (i.e. residual) degrees of freedom, the P value indicating significance when <0.05. When required, data were transformed to meet the normality assumption. Linear regression was used to determine relationships between variables (e.g. CH4 fluxes, biomass, pore water chemistry).

Results

Extension growth differed among species with the greatest extension growth found for C. acuta (species effect: F3, 53 = 11.32, P < 0.001), the growth rates of the other three species was in the same range (e.g. 24 ± 2, 12 ± 2.8, 13 ± 2.6, 11 ± 2.0 mm week−1, respectively for C. acuta, C. brunnescens, E. angustifolium, E. vaginatum at the start of the experiment). The elevated CO2 treatment caused a significant overall reduction in extension growth (CO2 treatment effect: F1, 53 = 12.11; P < 0.001; Fig. 1) with a particularly strong negative impact for C. acuta. At the end of the experiment, above ground biomass differed significantly among species with the lowest biomass found for C. brunnescens (F3,52 = 8.34, P < 0.001; Fig. 2a). The elevated atmospheric CO2 levels tended to increase above ground biomass in E. angustifolium, E. vaginatum and C. brunnescens but decreased above ground biomass in C. acuta (near significant species × CO2 treatment interaction: F1,52 = 3.58, P = 0.064; Fig. 2a). Below ground biomass differed among species (Fig. 2b; F3,52 = 8.31, P < 0.001); furthermore the CO2 treatment affected belowground biomass differently among the four species (species × CO2 treatment interaction: F3,42 = 2.58, P = 0.063) as below ground biomass declined in the elevated CO2 treatment relative to ambient CO2 for E. angustifolium and C. acuta. As a result of the contrasting above and below ground biomass responses among species to the CO2 treatment, the response of the shoot:root ratios to elevated CO2 differed among the species (Fig. 2c; species × CO2 treatment interaction: F3,52 = 6.45, P < 0.001). Specifically the shoot:root ratio increased for all species apart from C. brunnescens.

The plant species treatment strongly affected CH4 fluxes with the greatest emissions from E. angustifolium and the lowest emissions from C. brunnescens (Fig. 3; F3, 52 = 5.57, P = 0.002). In contrast, the CO2 treatment did not affect the CH4 fluxes (F3, 52 = 0.79, P = 0.39).

The CO2 and species treatment affected soil properties. Specifically, redox potential was consistently lower in the 800 ppm treatment (F1, 53 = 3.39, P = 0.07, Fig. 4). Redox also differed among the plant species treatments (F3, 52 = 27.01, P < 0.001) with the two Carex species having the highest redox potentials. The redox potential was negatively related to above ground plant biomass (Fig. 5a; F1, 7 = 4.27, P = 0.08). The elevated CO2 treatment had a contrasting effect on total dissolved organic carbon (TOC) for the different plant species ((species × CO2 treatment interaction, F3, 52 = 2.82, P = 0.048), Fig. 6a). Specifically, E. vaginatum and C. acuta differed in their response to elevated CO2, with pore water in the 800 ppm treatment exhibiting 0.9 mg L−1 more organic carbon in E. vaginatum but 1.5 mg L−1 less in C. acuta when compared to ambient CO2 conditions. In contrast, TOC levels for E. angustifolium and C. brunnescens were not affected by the CO2 treatment.

Total dissolved nitrogen (TN) (Fig. 6b) was not significantly influenced by treatment or species effects. The TOC:TN ratio differed among species and was highest in E. vaginatum (F3, 52 = 7.91, P < 0.001, Fig. 6c) out of the planted treatments but was not affected by the CO2 treatment. Pore water in the two species of Carex display the highest E4:E6 ratio (i.e. relatively more low molecular weight compounds) (F3, 52 = 6.05, P = 0.001, Fig. 6d) but again there was no significant difference between the CO2 treatments.

Although the CH4 fluxes were not directly related to plant biomass, redox potential, which was influenced by the above ground biomass, was negatively related to CH4 fluxes (Fig. 5b; F1, 7 = 5.75, P = 0.05). In contrast, the pore water chemistry was not related to the CH4 fluxes.

Discussion

The increase in above ground biomass for three of the four study species in response to the elevated CO2 treatment (Fig. 2a) supported the hypothesis, which predicted greater biomass production under high CO2 conditions. The different responses of above ground biomass of the study species to increased CO2 concentrations (Fig. 2a) suggest that wetland plant species will respond in contrasting ways to rising CO2 concentrations. Previous studies support the notion of species specific responses to elevated CO2. For example, following two years of experimental CO2 treatments (ambient +340 ppm) different biomass responses was reported for
Schoenoplectus americanus and Spartina patens in a salt marsh ecosystem (Langley et al. 2013). This was also the case for above ground biomass of Typha species (T. angustifolia, T. glauca and T. latifolia) exposed to 350–390 (control) to 550–600 ppm (treatment) CO₂ (Sullivan et al. 2010). The lower extension growth under elevated CO₂ indicates that greater above ground biomass is likely due to increased tillering and number of leaves. However, of the Typha species investigated by Sullivan et al. (2010), all increased their below ground biomass in response to the elevated CO₂ treatment. This differs to our study in which above ground biomass of E. angustifolium, E. vaginatum and C. brunnescens was higher in the elevated CO₂ treatment while below ground biomass only increased for two of the study species (E. vaginatum and C. brunnescens (Fig. 2b)). No below ground responses for Schoenoplectus americanus and Spartina patens was also reported by Langley et al. (2013) after two years exposure to elevated CO₂. Species specific responses to atmospheric CO₂ are well known, with fundamental differences in stomatal numbers and size being observed (Woodward et al. 2002; Lomax et al. 2014), which can then influence physiology and ultimately impact on biomass.

This study has demonstrated that different plant species control the amount and quality of substrate found in the pore water, with elevated atmospheric CO₂ influencing TOC concentrations in planted treatments (Fig. 6a), largely reflecting trends in biomass (Fig. 2). This correlates with data from temperate salt marshes exposed to elevated CO₂ (Marsh et al. 2005; Keller et al. 2009). In addition, the trend of lower root biomass, lower TOC and TN concentrations and lower CH₄ emissions in the 800 ppm C. acuta treatment suggests a link among these parameters. Indeed, contrasting above/below ground carbon allocation and quantity and quality of root exudates (e.g. Ström et al. 2005; Koelbener et al. 2010; Ström et al. 2012) may drive some of the species specific responses to elevated CO₂ and the subsequent impact on CH₄ emissions. The contrasting porewater chemistry with regard to the E4:E6 and TOC:TN ratios (Fig. 6 c and d) suggests that species composition alters rhizospheric organic matter inputs, likely due to differences in the concentration and lability of root exudates, with implications for CH₄ fluxes (King et al. 2002; Ström et al. 2005; Dorodnikov et al. 2011). Furthermore, root exudates have been found to enhance degradation of older recalcitrant soil organic matter which may further increase substrate availability for CH₄ production (Basiliko et al. 2012). The study was too short to measure how elevated CO₂ may alter litter chemistry, however, larger biomass as a result of elevated CO₂ (namely in C. brunnescens and E. vaginatum, Fig. 2) is likely to increase inputs from freshly produced litter which may also increase CH₄ production (Curtis et al. 1990).

The reduction in redox potential under the elevated CO₂ treatment (Fig. 4), together with the negative relationship between above ground biomass and soil redox potential (Fig. 5a), suggests that plant-mediated shifts in soil redox
Fig. 2 a Above, b below ground biomass and c shoot-root ratio for all Cyperaceae species at the 400 and 800 ppm atmospheric CO₂ treatments. Mean, standard errors of the mean and S.E.D.s for significant Species, CO₂ Treatment and Species×CO₂ Treatment effects are shown.

Fig. 3 CH₄ fluxes across four plant species treatments and under 400 and 800 ppm atmospheric CO₂ treatments showing methane per unit area. Means across the experimental period, standard error of the means, and S.E.D for the significant CO₂ Treatment and Species effects are shown.

Fig. 4 Mean redox potential with standard error of the mean for the four plant species treatments across 400 and 800 ppm atmospheric CO₂ treatments. S.E.D for the Species and CO₂ Treatment effects are shown in the figure.
potential in response to elevated CO₂ may impact soil processes. As soil redox potential is a strong driver of CH₄ production and oxidation (Fritz et al. 2011) such changes may impact CH₄ fluxes. Effects of elevated CO₂ on soil redox potential were also demonstrated in mesocosms with Phragmites australis grown under ambient and elevated CO₂ (+330 ppm CO₂) (Mozdzer and Megonigal 2013). We speculate that the lowering of the redox potential is caused by greater release of...
organic material into the rhizosphere contributing to microbial respiration and depletion of electron donors (Yavitt and Seidman-Zager 2006; Laanbroek 2010). Our findings and those of Mozdzer and Megonigal (2013) contrast with those of Wolf et al. (2007) who demonstrated higher soil redox potentials in mesocosms planted with Scirpus olneyi due to greater root O2 inputs reflecting greater root biomass in the elevated CO2 treatment. The differing impact of plant species on the soil redox conditions, possibly in response to different levels of root exudation among species and/or differences in gas exchange via aerenchyma, suggests that plant species composition is a key control of the redox environment and by extension CH4 production and oxidation (Bridgham et al. 2013).

In contrast to our hypothesis, which predicted increased CH4 production in the elevated CO2 treatment, there was no significant effect of the elevated CO2 treatment on CH4 fluxes (Fig. 3b). However, the negative relationship between above ground biomass and redox potential, and redox potential and CH4 fluxes, demonstrates the important role of the vegetation as a control of redox and CH4 fluxes (Fig. 5). Our lack of direct responses of CH4 fluxes to elevated CO2 contrasts with studies on Taxodium distichum and Orontium aquaticum mesocosms exposed to an experimental increase in CO2 levels from 350 to 700 ppm (Vann and Megonigal 2003) and mesocosms planted with Typha angustifolia when CO2 levels were increased from 380 to 700 ppm (Kao-Kniffin et al. 2011), where increased root growth under elevated CO2 translated into greater CH4 emissions. However, limited or no impact of elevated CO2 on CH4 emissions was found in two sedge dominated salt marsh communities (Marsh et al. 2005) illustrating that CH4 responses to elevated CO2 may vary strongly among species and ecosystems depending on the physiological responses of the plant species to elevated CO2. Furthermore, limited responses to elevated CO2 by some species may be linked to nutrient limitation (Mozdzer and Megonigal 2013).

In conclusion, we have demonstrated that elevated atmospheric CO2 increased above ground biomass production in E. vaginatum, E. angustifolium and C. brunnescens but not in C. acuta. Our study suggests links between plant biomass, soil redox potential and CH4 production but no direct impact of elevated CO2 on CH4 emissions. Our study demonstrates the importance for improved mechanistic understanding of how wetland plants species respond to elevated CO2 before assumptions can be made with regard to impacts on elevated CO2 on CH4 emissions from wetlands.

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