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LANDSCAPE-SCALE DRIVERS OF CARBON DIOXIDE AND METHANE FLUX IN AGRICULTURAL AND RESTORED PEATLANDS IN THE SACRAMENTO-SAN JOAQUIN DELTA, USA.

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SUMMARY

The peatlands of the Sacramento-San Joaquin Delta in California represent the largest estuary on the Pacific coast of the Americas, but were drained in the mid- to late-19th century for agriculture. Since drainage, the Delta has experienced extreme rates of soil subsidence. Conversion back to flooded conditions may reverse subsidence by reducing soil CO_2 flux. However, land-use conversion also highlights key trade-offs between CO_2 sequestration, CH_4 emission, and increased evaporation. This study uses the eddy covariance technique to measure CO_2, CH_4, and H_2O fluxes from drained and flooded, agricultural and restored peatlands to assess changes in ecosystem fluxes with land-use conversion.

KEY WORDS: agricultural peatland, methane flux, carbon dioxide flux, restoration

INTRODUCTION

Drainage of the peatlands in the Sacramento-San Joaquin Delta (hereafter, the Delta) about 150 years ago has led to extreme rates of soil subsidence, primarily through microbial oxidation of the peat soil. The continuation of conventional agricultural land-uses (maize, alfalfa, and pasture) into the future is unsustainable, as most Delta islands are now 5-8m below sea level and continue to subside, placing considerable strain on the levees that maintain the water table below the soil surface. The conversion from drained to flooded land-use types has been identified as a promising land management technique to abate further subsidence in the Delta. However, conversion to flooded ecosystems also creates trade-offs due to the potential for higher methane production and much higher rates of evaporation. This study evaluates this trade-off by measuring the ecosystem flux of CO_2, CH_4, and evaporation from three land-use types in the Delta: a conventional drained, degraded peatland pasture, a rice paddy, and a newly restored wetland. Our first goal was to compute the net ecosystem budgets of CO_2 and CH_4 on an annual basis at each of the sites for comparison. The second goal of this work was to determine the timescale of coupling between ecosystem photosynthesis and methanogenesis by analyzing the temporal connection between CO_2 and CH_4 fluxes at each site.

MATERIALS AND METHODS

Site information

Our three study sites are a grazed degraded drained pasture (latitude: 38.0367°N; longitude: 121.7540°W; elevation: -12m), a recently converted rice paddy (latitude: 38.1087°N, longitude: 121.6530°W; elevation: -14m), and a newly restored wetland (latitude: 38.0541°N, longitude: 121.7698°W; elevation: -11m). All sites are all located in the Sacramento-San Joaquin Delta in California about 100km inland of the Pacific Ocean, and are within 4km of each other so they experience the same weather and climate conditions. The drained pasture has been maintained for at least the past twenty years in the same land-use type, the rice paddy was farmed as such starting in April 2009, and the restored wetland was converted in October 2010.

All sites experience a strong Mediterranean climate, with wet, cool winters and hot, dry summers. The soil at the three sites is composed of a top layer to a depth of about 50cm of degraded and oxidized mineral peat, which overlays a deep peat layer 5-15m thick. The water table at the degraded pasture is maintained about 60cm below the surface for the duration of the year, the rice paddy water table is maintained about 10cm above the surface but is drained twice yearly for planting and harvest, and the restored wetland is constantly flooded, where water depth ranges from 5cm to 2.5 meters across the landscape.

Eddy covariance and micro-meteorological measurements

We measured fluxes of CO_2, CH_4, H_2O and energy with the eddy covariance technique (Baldocchi, Hicks, & Meyers, 1988) at the three study sites in the Sacramento-San Joaquin Delta in California. Instrumentation at the drained pasture and rice paddy are detailed in Hatala *et al*. 2012. Briefly, a sonic anemometer (Gill WindMaster Pro) was deployed at each site to measure turbulence and the molar density of CO_2 and H_2O were measured at all three sites with an open-path LI-7500. At the rice paddy and drained degraded pasture, we used a Los Gatos Fast Methane Analyzer to measure CH_4 density, and at the restored wetland we used an open-path LI-7700 to measure CH_4 density.

We recorded 10Hz measurements of turbulence, CO_2, CH_4, and H_2O density, and converted these measurements into half-hourly fluxes after correcting measurements for density fluctuations and spectral attenuation (Detto & Katul, 2007; Hatala et al., 2012). We partitioned CO_2 flux measurements into gross ecosystem photosynthesis (GEP) and ecosystem respiration (R_{eco}) at each site (Reichstein *et al.*, 2005) after gap-filling CO_2 fluxes with meteorological data (Papale & Valentini, 2003). In this study positive flux indicates a flux from the ecosystem to the atmosphere, so R_{eco} is positive and GEP is negative. Further instrumentation and data analysis details are outlined in (Hatala, et al., 2012).

RESULTS

CO_2 fluxes and budgets

Net CO_2 flux (net ecosystem exchange, NEE) follows a similar annual temporal pattern for all sites, which is governed by the strong Mediterranean climate of the Delta with high rates of gross ecosystem photosynthesis during the warm and sunny summer months and much lower rates during the cooler, cloudier winters (Fig. 1). The net CO_2 flux is highest at the drained degraded pasture site due to the oxidation of peat soil at the surface that results from the relatively low water table (about -50cm below the surface year-round). The largest CO_2 uptake of the three sites occurs during the summertime at the rice paddy, when strong photosynthetic uptake occurs. The newly restored wetland experiences intermediate levels of CO_2 flux, as its flooded status impedes soil oxidation, but ecosystem-level photosynthesis is lower than that of the rice paddy, due to a heterogeneous and discontinuous plant canopy.

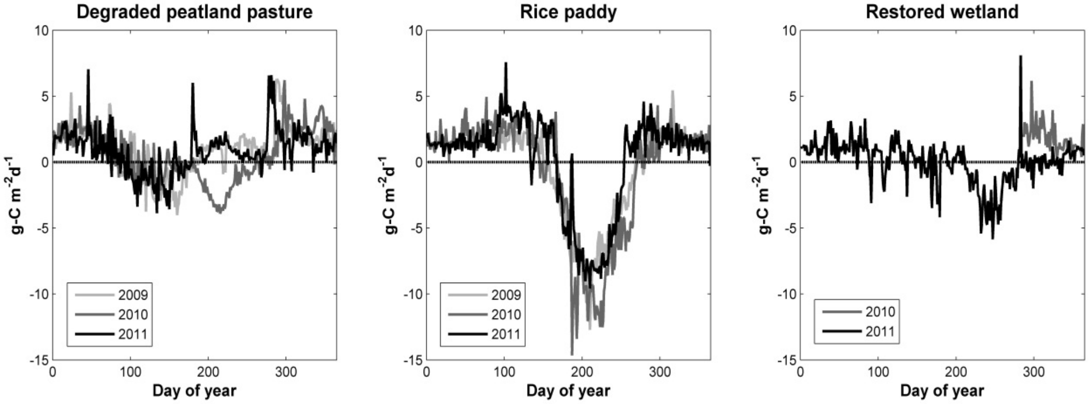

Fig. 1: Net ecosystem exchange. Net ecosystem exchange (NEE; net CO_2 flux) at the pasture is generally low during spring and early summer due to plant growth, with peaks in autumn due to rain pulse events following the summer drought. The rice paddy has a strong seasonal crop cycle, with high rates of photosynthetic uptake during the summer. The restored wetland was near carbon neutral in the first year following restoration, with increased CO_2 uptake toward late summer due to the infilling of plants at the site.

The degraded pasture released between 186 and 349 g-C $m^{-2}yr^{-1}$ as net ecosystem exchange (NEE) in 2009-2011, the rice paddy captured between -84 to -290 g-C $m^{-2}yr^{-1}$ in 2009-2011, and the newly restored wetland released 120 g-C $m^{-2}yr^{-1}$ as NEE in the first year after flooding. While the rice paddy is an atmospheric sink for carbon as measured by eddy covariance, if we consider the ecosystem flux perspective and also account for the loss of carbon through grain harvest, this calculation indicates that the ecosystem is losing carbon on a net basis.

CH_4 fluxes and budgets

The CH_4 fluxes at the three sites all follow distinct temporal patterns. The CH_4 fluxes at the drained degraded pasture are consistently low, after removing the effects of cattle from the fluxes. However, there are some spikes in CH_4 emissions from the drained pasture during the winter when drainage ditches at the field are flooded (Teh et al., 2011). At the rice paddy, CH_4 emissions follow a strong seasonal pattern, with a late-summer peak in CH_4 fluxes around September. Emissions at the flooded but fallow rice field are generally low during the winter, with sporadic high fluxes due to ebullition events. The CH_4 emissions from the newly restored wetland were tightly coupled with the development of plants within the tower footprint by late summer. Additional years of data at the wetland will help to reveal meteorological drivers of CH_4 fluxes.

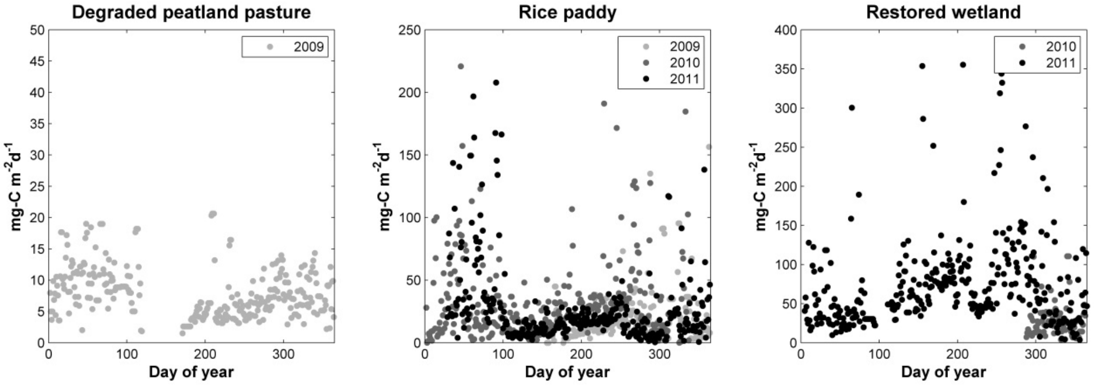

Fig. 2: Net CH_4 Fluxes. CH_4 fluxes from the drained pasture are generally much smaller than the other sites, and do not demonstrate a strong seasonal cycle. The CH_4 fluxes at both the rice paddy and restored wetland follow a seasonal cycle, with the highest growing season fluxes occurring in late summer and early fall. This seasonal peak in CH_4 flux corresponds with both soil temperature and the peak biomass during the plant growing season. The rice paddy also experiences high sporadic CH_4 fluxes during the winter, as the fallow field is flooded and sporadic ebullition is the dominant transport pathway during this time.

Temporal connectivity between photosynthesis, soil temperature, and CH_4 flux

In addition to the seasonal temporal pattern in CO_2 and CH_4 flux at the rice paddy and wetland sites, both sites demonstrated strong diurnal variability during the growing season. At both sites, the peak in diurnal fluxes occurs during the daytime, with lower CH_4 fluxes overnight.

By analyzing the wavelet coherence spectrum ecosystem photosynthesis, soil temperature, and CH_4 flux, we determined that this diurnal pattern in CH_4 flux was strongly coherent with both patterns of ecosystem photosynthesis and soil temperature. On longer timescales (~2 weeks), the temporal pattern in CH_4 flux over the growing season is highly correlated with soil temperature.

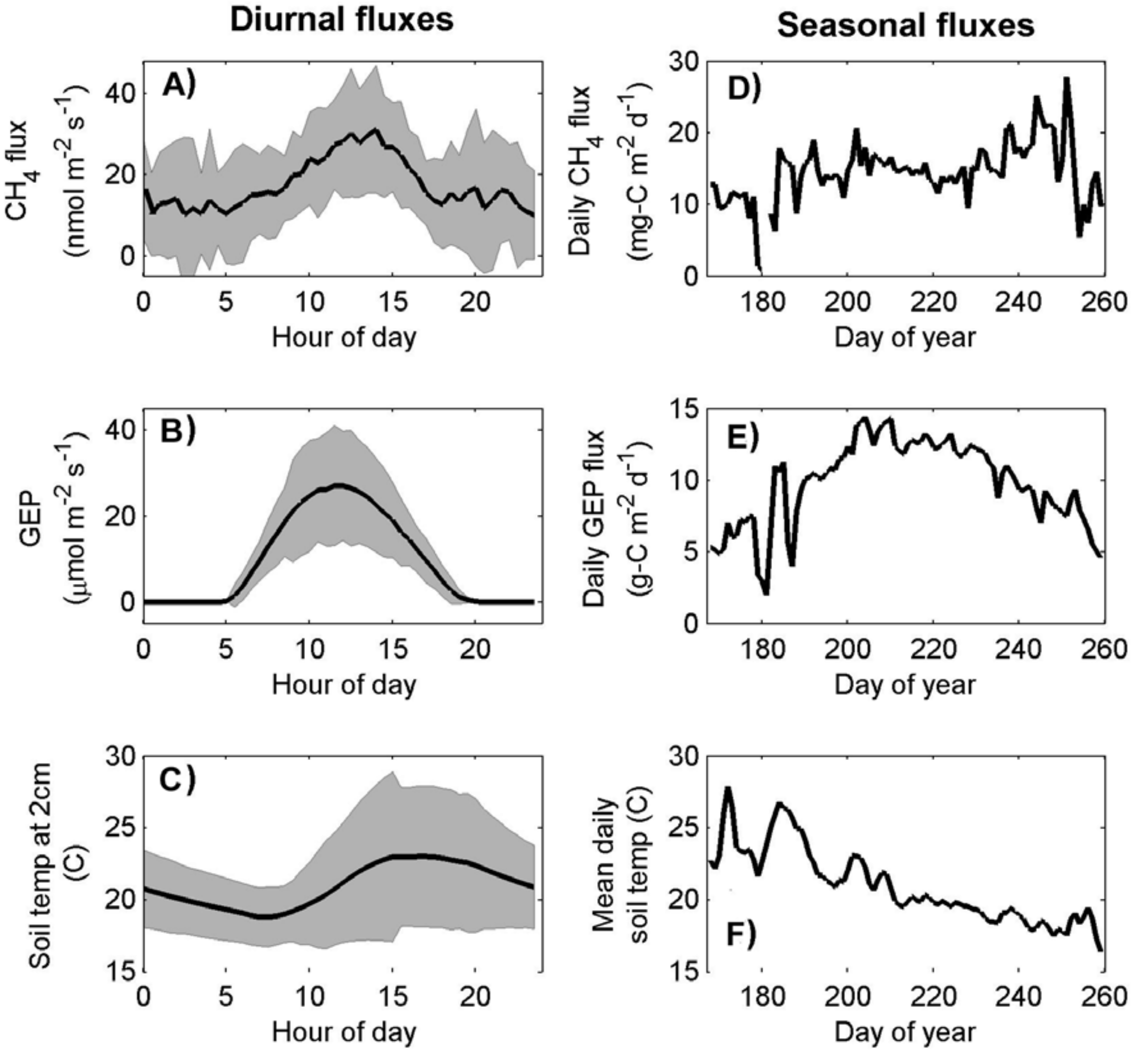

Fig. 3: Diurnal pattern in CH_4 Fluxes at the rice paddy. Ecosystem photosynthesis, CH_4 fluxes, and soil temperature at the rice paddy demonstrate a strong diurnal pattern throughout the growing season, where photosynthesis leads CH_4 flux, and soil temperature lags both of these variables.

CONCLUSIONS

The pasture and newly restored wetland were both net sources of CO_2 and CH_4 during the measurement period. While the rice paddy was a net CO_2 and CH_4 sink from an atmospheric perspective (from eddy covariance flux measurements alone), considering the harvest of rice grain as a carbon loss from an ecosystem perspective, the rice paddy was a net source of carbon in all years. Although the restored wetland was a net source of carbon in this first year, we predict sequestration in the future as more plant populations fill in at the sites, increasing CO_2 uptake. Our spectral analysis reveals a tight coupling between ecosystem photosynthesis and CH_4 flux at both the rice paddy and restored wetland. Data collection at all three sites will continue for at least five additional years, providing valuable information about how the carbon dynamics at these three sites are altered following conversion to flooded land-use types.

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