Phenological Indicators of Wetland Recovery in the Sacramento-San Joaquin Delta

Sophie Taddeo*, University of California at Berkeley, sophie.taddeo@berkeleu.edu
Iryna Dronova, University of California at Berkeley, idronova@berkeley.edu

Plant characteristics have been a key component of restoration monitoring in San Francisco Estuary wetlands. As they show a rapid response to site conditions, fluctuations in plant characteristics can reveal environmental stressors or an unexpected trajectory in ecosystem recovery. Yet the long-term monitoring of plant communities can generate a considerable financial burden for project managers. Remote sensing technology has the potential to expand the spatio-temporal extent of monitoring efforts at low cost, but its use in restoration ecology is still limited. We explored how landscape phenology- which studies variation in the timing of key events in a plant life cycle- can track restoration progress in wetland ecosystems. We analyzed 20 years of free remote sensing data from NASA's Landsat archive to offer a landscape-scale synthesis of wetland restoration efforts in the Sacramento-San Joaquin Delta. Through an analysis of spatio-temporal changes in plant phenology and greenness, we assessed how 25 restored wetlands across the Delta have responded to restoration treatments, time, and landscape context. We used a spline smoothing approach to generate annual phenological curves from Landsat data and identify key phenological events, including timing of peak greenness and growing season length. Preliminary results revealed a greater variability in the initial post-restoration years in both greenness and length of growing season. Sites reached phenological stability on average 4 to 7 years after restoration. More recent sites seemed to benefit from an increased availability of propagules enabling them to reach peak greenness and maximum growing season length more rapidly. These results demonstrate the potential of remote sensing-based phenological analyses to measure restoration progress and compare site trajectories for a better understanding of factors affecting wetland recovery. Phenological time-series can provide useful base data to measure a site's capacity to fulfill ecosystem services including carbon sequestration and habitat provisioning.

Student Award Competition: Yes

Keywords: phenology, remote sensing, wetlands, restoration, Landsat, trajectory

Poster Cluster Title: Variability in Land-Atmosphere Interactions of the SF Bay-Delta's Restored and Natural Wetlands: Implications for Carbon, Methane, and Water Fluxes

Biophysical Controls on Ecosystem-Scale CO2 Exchange in a Brackish Tidal Marsh in Northern California

Sara Knox, USGS, sknox@usgs.gov
Lisamarie Windham-Myers, USGS, lwindham-myers@usgs.gov
Frank Anderson, USGS, fanders@usgs.gov
Brian Bergamaschi, USGS, bbergama@usgs.gov

Carbon (C) cycling in coastal wetlands is difficult to measure due to dynamic atmospheric and hydrologic fluxes, as well as sensitivities to dynamic land- and ocean-based drivers. Few studies have begun continuous measurements of vertical and/or lateral C exchanges in these systems and as such our understanding of the key drivers of coastal wetland C cycling remains limited. Additional measurements of vertical and lateral C fluxes is critical to developing a better understanding of the drivers of C sequestration and greenhouse gas (GHG) mitigation potential of coastal wetlands. Here we present 2.5 years of eddy covariance measurements of CO_2 and CH_4 fluxes from a tidal marsh in Northern California.

CO_2 fluxes showed large interannual variability, with low net CO_2 uptake in the first year of the study (67 g C m^{-2} yr^{-1}), and much higher uptake the following year (295 g C m^{-2} yr^{-1}). Conversely, annual CH_4 fluxes were similar between years (1.2 and 1.3 g C m^{-2} yr^{-1}). With respect to the net atmospheric GHG budget, the wetland was a net GHG sink of 172 g CO_2eq m^{-2} yr^{-1} in year one, and a sink of 1004 g CO_2eq m^{-2} yr^{-1} in year two. Our results showed that tides strongly influenced CO_2 fluxes across multiple timescales; ecosystem respiration was approximately 25% lower during spring tides relative to neap tides, and flooding overall increased photosynthesis. While several mechanisms can contribute to the suppression of respiration following flooding, our results suggest that tidal effects were largely due to the suppression of CO_2 efflux from the soil as the water creates a physical barrier to gas diffusion, with implications for dissolved inorganic C losses. Further research on lateral C transport is key to investigating the influence of tides on the C balance of coastal wetlands.

Keywords: tidal marsh, carbon sequestration, carbon dioxide, methane, eddy covariance, Suisun

Poster Cluster Title: Spatial and temporal variability in land-atmosphere interactions of the San Francisco Bay-Delta’s restored and natural wetlands: implications for carbon, methane, and water fluxes

Evaporation versus Transpiration in Delta Wetlands: The Effect of Wetland Structure on Water Use

Elke Eichelmann, UC Berkeley, eeichelm@berkeley.edu
Kyle S. Hemes, UC Berkeley, khemes@berkeley.edu
Sara H. Knox, USGS Menlo Park, sknox@usgs.gov
Patricia Y. Oikawa, California State University East Bay, patty.oikawa@csueastbay.edu
Samuel D. Chamberlain, UC Berkeley, schamberlain@berkeley.edu
Cove Sturtevant, National Ecological Observatory Network (NEON), csturtevant@battelleecology.org
Joseph Verfaillie, UC Berkeley, jverfail@berkeley.edu
Dennis D. Baldocchi, UC Berkeley, baldocchi@berkeley.edu

The Sacramento/San Joaquin river delta is an important source of fresh water for California. To reverse soil subsidence, which is linked to draining the natural wetlands for agriculture, parts of the Sacramento/San Joaquin river delta have been restored to managed wetlands. While these restored wetlands provide greenhouse gas benefits compared to agricultural use of the land, implications for the water balance of these ecosystems, specifically evapotranspiration, are not well known.

Based on four years of eddy covariance measurements of water and sensible energy fluxes we explored the water cycling dynamics for six sites under different land use covers, three sites under agricultural use (rice and alfalfa crops and cow pasture) and three restored wetland sites, in the Sacramento/San Joaquin river delta. While the wetland and the rice sites are usually flooded for the majority of the year, the alfalfa, corn, and pasture sites have a water table that is maintained to be below ground level throughout the year. The three wetland sites also have different fractions of open water to vegetation, covering a gradient from very dense vegetation with no open water to a fairly open structure with large pools of open water.

Although the flooded sites tend to have larger annual evapotranspiration than the drained sites, the fraction of open water to vegetation affects the extent to which the flooded sites' evapotranspiration exceeds that of drained sites. Evapotranspiration at the wetland with a low fraction of open water surfaces was almost entirely dominated by plant transpiration with only very little contribution from evaporation. The closed vegetation canopy seemed to be able to inhibit evaporation from subcanopy water. On the other hand, the two wetlands with larger fraction of open water surfaces showed noticeable contribution of evaporation in addition to plant transpiration, increasing the overall water loss through evapotranspiration.

Keywords: Restored wetlands, evapotranspiration, water cycling, structure, water temperature, wetland vegetation,

Poster Cluster Title: Spatial and temporal variability in land-atmosphere interactions of the San Francisco Bay-Delta's restored and natural wetlands: implications for carbon, methane, and water fluxes

Multi-Year Greenhouse Gas Budgets of Restored Wetlands and Drained Peatlands across the Sacramento-San Joaquin Delta, California, USA

Kyle Hemes*, University of California, Berkeley, khemes@berkeley.edu
Dennis Baldocchi, University of California, Berkeley, baldocchi@berkeley.edu
Elke Eichelmann, UC Berkeley, eeichelm@berkeley.edu
Sam Chamberlain, UC Berkeley, schamberlain@berkeley.edu
Sara Knox, USGS, saraknox.knox@gmail.com
Patricia Oikawa, California State, East Bay, patty.oikawa@csueastbay.edu

Globally, delta ecosystems are critical for human livelihoods, but are at increasingly greater risk of degradation. The Sacramento-San Joaquin River Delta ('Delta') has been subsiding dramatically, losing more than 100 Tg of carbon since the mid-19th century due in large part to agriculture-induced oxidation of the peat soils through drainage and cultivation. Efforts to re-wet the peat soils through wetland restoration and flooded agricultural crops are attractive as climate mitigation activities and as part of market-based climate policies such as California's Cap-and-Trade program. While flooded wetland systems have the potential to sequester significant amounts of carbon as photosynthesis outpaces aerobic respiration, the highly-reduced conditions can result in significant methane emissions. Due largely to variability in annual photosynthesis and methane emissions, there is high uncertainty in the net greenhouse gas (GHG) budget over the lifetime of a restored wetland.

Initial comparisons in the Delta have shown that conversion of drained peatlands to wetlands can, in some cases, yield a net GHG benefit. Other studies have reported net sources, and turnover times (from a source to a sink) of greater than 500 years. This study will utilize three years (2014-2016) of continuous, gap-filled, CO_2 and CH_4 flux data from a mesonetwork of seven eddy covariance towers in the Delta to compute GHG budgets for the restored wetlands and agricultural baseline sites measured. Sustained global warming potentials will be used to model the source/sink nature of the ecosystem into the future. This work aims to describe the extent to which restored managed wetlands, compared to drained agricultural land uses, can provide a net GHG benefit and contribute to climate change mitigation in a nascent market-based system.

Student Award Competition: Yes

Keywords: greenhouse gas, wetland restoration, eddy covariance, Delta

Poster Cluster Title: Spatial and temporal variability in land-atmosphere interactions of the San Francisco Bay-Delta's restored and natural wetlands: implications for carbon, methane, and water fluxes

Using Remotely Sensed Phenology to Understand Wetland Composition and Dynamics at the Estuary Scale

Iryna Dronova, University of California Berkeley, idronova@berkeley.edu
Sophie Taddeo, University of California Berkeley, sophie.taddeo@berkeley.ed
Sara Knox, U.S. Geological Survey, saraknox.knox@gmail.com
Patricia Oikawa, CSu East Bay, patty.oikawa@csueastbay.edu
Kyle Hemes, University of California Berkeley, khemes@berkeley.edu
Dennis Baldocchi, University of California Berkeley, baldocchi@berkeley.edu

Phenological information on seasonal change in wetland vegetation may provide important clues about ecosystem functioning, such as uptake of atmospheric carbon, quality of supported habitats and responses to climatic variability, disturbance and invasions. Such information, however, is difficult to collect in the field in a comprehensive and spatially explicit manner to inform regional-scale wetland management and restoration. Alternatively, time series of high temporal frequency remote sensing data can be used to assess and evaluate landscape-level phenological cycles manifested in seasonal trajectories of spectral reflectance from different plant communities. Our study demonstrates the potential of such remotely sensed phenology to elucidate differences in vegetation characteristics, ecosystem properties and wetland management among a set of natural and restored marshes in San Francisco Bay and west Sacramento-San Joaquin Delta using 2015-2016 satellite data at medium (30m) and high (3-5m) spatial resolution. We use these satellite image time series to construct spatially explicit phenological trajectories and compare their key parameters among different types of wetlands, emergent plant communities and where possible, dominant species, including some of the common invasives. We further consider limitations associated with spatial scale and tidal effects on wetland spectral signatures and discuss the potential of such approaches for cost-effective and repeated monitoring of wetlands in the study region and beyond.

Keywords: remote sensing, phenology, vegetation, carbon, monitoring, dynamics, landscape-scale, marsh

Poster Cluster Title: Spatial and temporal variability in land-atmosphere interactions of the San Francisco Bay-Delta’s restored and natural wetlands: implications for carbon, methane, and water fluxes

Ozone Depleting Emissions from a Mesohaline Saltmarsh Heavily Invaded by *Lepidium latifolium*

Malte Julian Deventer, University of California, Berkeley, mjdeventer@berkeley.edu
Yi Jiao, University of California, Berkeley, jiaoyi@berkeley.edu
Robert Rhew, University of California, Berkeley, rrhew@berkeley.edu

Natural emissions of methyl bromide (CH_3Br) and methyl chloride (CH_3Cl) from terrestrial ecosystems might explain the observed missing source of methyl halides to the atmosphere. Both compounds are a major source of halogens into the stratosphere, where Br and Cl act as catalysts in ozone depleting reactions. Real-world measurements of their exchange fluxes are limited and usually involve intrusive techniques. To improve the current understanding of the net budget and to provide a solid foundation for up-scaling purposes, the surface-atmosphere exchange for both methyl halides has been studied during 2016/2017 in a year-long field campaign at Rush Ranch (38.2004 °N, 122.0265 °W), a 4.6 km^2 large brackish saltmarsh in the San Francisco Bay National Estuarine in Suisun Bay (CA, United States), using the non-intrusive micrometeorological Relaxed Eddy Accumulation (REA) technique. With REA measurements, a large area of the salt marsh (multiple acres) can be studied without disturbance.

Concurrently, static flux chamber incubations were conducted over different vegetation species, to identify their relevance in terms of methyl halide emissions.

Our results demonstrate that the saltmarsh ecosystem at Rush Ranch is a substantial source for methyl halides. A rough global extrapolation of these results yields an annual net flux of 52 Gg yr^{-1} for CH_3Cl and 8 Gg yr^{-1} for CH_3Br, respectively, which is close to estimates from chamber based observations from southern California saltmarshes.

Chamber incubations at Rush Ranch revealed that the invasive *Lepidium latifolium* emits a significant amount of methyl halides, less than the native alkali heath (*Frankenia salina*) but much more than the native pickleweed (*Salicornia* spp.) Due to aggressive invasiveness its capability to form dense monospecific patches, *L. latifolium* is the main driver of halide emissions from Rush Ranch. If *L. latifolium.* invasion of *Salicornia*-dominated marshes continues, natural emissions of ozone depleting substances may increase in the future.

Keywords: Methyl halide, flux, micrometeorology, invasion, flux, ozone depletion

Poster Cluster Title: Spatial and temporal variability in land-atmosphere interactions of the San Francisco Bay-Delta's restored and natural wetlands: implications for carbon, methane, and water fluxes