Understanding the Spatial and Temporal Patterns of Wetland Evapotranspiration, Primary Production, and Nutrient Cycling

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Executive Summary

Problem Statement

The mechanistic processes that control the biogeochemical budgets and evapotranspiration in California wetlands are poorly understood. We propose research at UCI's San Joaquin Freshwater Marsh to better understand the ecological controls on wetland carbon, energy and water vapor exchange. We have been using the eddy covariance technique since 1998 to measure the CO_2 exchange (F_{CO2}) and evapotranspiration (E) between the atmosphere and the San Joaquin Marsh. Eddy covariance is a non-invasive micrometeorological technique that measures the exchanges of gases and energy between the atmosphere and a few hectare patch of marsh. The marsh's CO_2 exchange and evapotranspiration fluctuated dramatically from year to year during this period, with particularly high rates of F_{CO2} and E during the 2000 and 2003 growing seasons. The interannual shifts in F_{CO2} and E occurred despite similar climatic and flooding regimes. The large year-to-year variability at the San Joaquin Marsh apparently reflects an unexpected and previously unreported phenomenon that helps to control marsh biogeochemistry and evapotranspiration. Our research goal is to understand the causes and consequences of this pattern.

Summary of Research Approach

We will focus on three questions. (1) What causes interannual variation in CO_2, energy and evaporative exchange? (2) How do the spatial patterns of plant growth change from year to year? (3) What are the consequences of interannual variation in CO_2 exchange for the nutrient budgets?

We will approach these questions with four sets of observations. (1) Continued measurements of the CO_2 exchange and evapotranspiration by the marsh, combined with new measurements of the inputs and outputs of Nitrogen and Phosphorus in surface water. (2) Replicated and controlled Mesocosm experiments to directly test hypotheses about the controls on marsh production and nutrient inputs and outputs. (3) Analyses of aerial photographs and remote sensing images (ETM+ and ASTER) to determine whether marsh production is spatially uniform, or whether it is a mosaic of high and low-growth patches that shift from year to year. (4) A large manipulation, either by a controlled burn or mowing, to further test our understanding of the causes of year-to-year variation in F_{CO2} and E.

Statement of Results, Benefits, and Information Expected

This research will contribute a more mechanistic understanding of the controls on wetland biogeochemistry and evapotranspiration. Given the lack of previous research in this area, especially as it applies to Mediterranean-climate marshlands, we have a good chance making an original contribution. This research may contribute to the improvement of management techniques for wetlands, and, in particular, high productivity marshlands that fill in over time. This research may also contribute to understanding the effect of wetlands on the chemistry of surface water, and the effectiveness of constructed treatment wetlands. Finally, this project will contribute to the graduate and undergraduate education at UC-Irvine.

Overview

Both scientists and the public recognize the importance of wetlands. Costanza et al. (1997) estimated that a hectare of wetland provides over $14,000 in goods and services each year. The citizens of California demonstrated support for wetland protection and conservation by voting for bond measures such as Proposition 50. At the same time, the basic biological, chemical and physical processes that control the carbon, nutrient and water cycles of California wetlands remains poorly understood. Searches of JSTOR and Web of Science indicate a complete lack of peer-review research on the biogeochemical and hydrological cycles of California Tule Marshes. The disconnect is obvious: both scientists and the public recognize wetlands as critically important, but understanding of the ecological processes that control the functioning of California wetlands is lacking.

We propose research at UCI's San Joaquin Freshwater Marsh to better understand the ecological controls on wetland carbon, energy and water vapor exchange. The San Joaquin Marsh is an 82-ha *Typha latifolia* and *Scirpus californicus* dominated remnant of a large historical wetland (Figure 1; http://nrs.ucop.edu/reserves/sjfm/moreinfo.html). The marsh is located on UCI's campus, allowing easy access and facilitating undergraduate and graduate student training. We have been working at the marsh since 1998, making low intensity measurements of the marsh's carbon and water budgets. Support from UC's Center for Water Resources will allow us to dramatically increase our research effort and improve on our understanding of the controls on marsh carbon, energy and water vapor exchange. Support from the Water Resources Center will also help us move toward long-term federal funding, most likely through NSF's LTREB program.

Progress to date

We have been using the eddy covariance technique since 1998 to measure the exchanges of CO_2 (F_{CO2}), energy (the sensible heat flux, H) and water vapor (evapotranspiration, E) between the atmosphere and the San Joaquin marsh (Fig. 2, 3, 4). Eddy covariance is a non-invasive micrometeorological technique that measures the exchanges of gases and energy between the atmosphere and a few hectare patch of marsh (Baldocchi et al. 1988). F_{CO2} is presented with an atmospheric scientist's sign convention. Negative fluxes in Figure 4 indicate CO_2 uptake by the marsh (photosynthesis exceeds respiration); positive fluxes indicate CO_2 efflux (respiration exceeds photosynthesis). The upper envelope of points (nighttime observations) reflects the rates of ecosystem respiration; the lower envelope of points reflects the rates of photosynthesis minus respiration; the difference between the envelopes reflects the rates of whole-marsh photosynthesis.

Figure 1. Aerial View of San Joaquin Marsh. Pond 2 is in the foreground; UCI's main campus is in the background (photo from Coastal Conservancy website).

Figure 2. Tower 2 at UCI's marsh reserve. Tower 2 has been operating since May 2003.

Figure 3. Vertical aerial photo of San Joaquin Marsh (photo from Aerial Eye, 6/18/01). Tower 1 has been operating since June 1998. Tower 2 has been operating since May 2003. The towers measure the net exchange by a few-ha area that is upwind of the tower. The winds are generally from the SW (the upper left to the lower right of the photo). Pond 1 and Pond 2 refer to large areas of the marsh that are separated by dikes with culverts, and that contain both open water and vegetation.

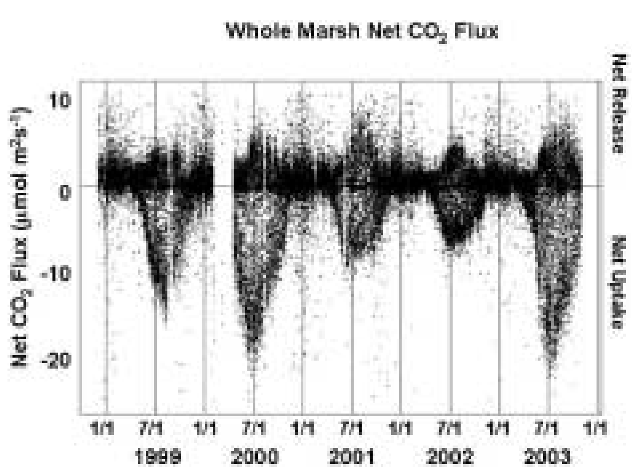

Figure 4. Five years of whole ecosystem CO_2 exchange by the marsh. The figure shows (a) the diel patterns of flux (the upper envelope of points are nighttime respiration; the lower envelope are daytime net uptake), (b) the seasonal patterns of flux (increased respiration and photosynthesis during summer), and (c) dramatic year-to-year differences in marsh function (2000 and 2003 were big years).

The marsh's CO_2 exchange fluctuated dramatically from one year to the next, with high photosynthetic uptake in 2000 and 2003, moderate uptake in 1999, and low uptake in 2001 and 2002 (Fig. 4). The midsummer rates of evapotranspiration also fluctuated dramatically from one year to the next (data not shown), with high E in 2000 and 2003, moderate E in 1999, and low E in 2001 and 2002. Photosynthesis and evaporation are positively coupled through the Leaf Area Index, the fraction of light intercepted by green leaves, and stomatal conductance. The positive relationship between F_{CO2} and E is expected; the year-to-year shifts in midsummer E and F_{CO2} are manifestations of an interannual shift in canopy structure, plant physiology, and ecosystem function.

The interannual shifts in F_{CO2} and E occurred despite similar climatic and flooding regimes. The marsh is intentionally flooded in December or January of each year. The marsh dries by June or July, and remains dry from June/July to December/January of each year. The air temperature is generally consistent from year to year. Previous long-term studies of the CO_2 exchange by forests have established that forest CO_2 exchange is generally consistent from year to year (Goulden et al. 1996, 1997). Previous studies above grassland and shrubland have revealed year-to-year variation in association with the direct effect of drought. Both of these patterns are fundamentally different from what we have observed at the San Joaquin marsh (Fig. 4). We are unaware of any previous long-term studies of marsh CO_2 or water vapor exchange, and Figure 4 reflects an unexpected and previously unreported phenomenon. Our research goal is to understand the causes and consequences of this pattern.

Research Questions

Hypothesis 1. *What causes interannual variation in CO_2, energy and water vapor exchange?*

We suspect the interannual variation is caused by a negative feedback between the accumulation of plant litter and the rates of whole-ecosystem photosynthesis and Net Primary Production. Years with high rates of CO_2 uptake cause a high rate of Net Primary Production and the input of a large amount of leaf litter at the end of the growing season (see Fig. 2). This litter shades the next year's growth and causes a reduction in CO_2 exchange during the subsequent year. The litter gradually decays over the next few years, increasing the light penetration and allowing increased production in a subsequent year. The overall effect is an oscillation between high and low production years, with a period that is determined by the time it takes plant litter to decay and fall.

Hypothesis 2. *What is the spatial pattern of interannual variation in exchange?*

We suspect the year-to-year variation in CO_2 and energy exchange is a result of a shifting mosaic of high and low production patches. In a given year there will be patches that do not have a thick layer of litter and are conducive to high rates of primary production, and other patches that have a thick layer of litter and low rates of production. We predict these patches move from year-to-year, with a given location cycling from a high production patch to a low production patch. Hence, we suspect the high evapotranspiration and photosynthesis years (e.g., 2000 and 2003) had a greater proportion of high production patches in the area directly upwind of the tower.

Hypothesis 3. *What are the consequences of interannual variation in CO_2 exchange for the nutrient budgets?*

We predict the year-to-year variations in CO_2 exchange will result in associated year-to-year shifts in the marsh's nutrient budgets. Nutrients, such as Nitrogen and Phosphorus, are stoichiometrically related to Carbon (Sterner and Elser 2002). We expect the marsh will lose P in years with suppressed production and a net carbon loss (e.g., 2001 and 2002). Likewise, we expect the marsh will sequester P in years with enhanced production and a net carbon gain. We predict that N will follow a broadly similar pattern, though denitrification and possibly fixation may confound the trend.

<u>Methods, Procedures and Facilities</u>

Continued measurements of the exchange by Pond 1.

We will continue the eddy covariance measurements in Pond 1. We predict the year-to-year variation will continue to follow the general pattern observed from 1999 to 2003. We expect that summer of 2004 will have relatively low rates of photosynthesis and evapotranspiration, and that these rates will recover by 2006. Additionally, we will begin measurements to characterize the nutrient budgets and vertical distribution of litter. We will measure the nutrient budgets by installing and calibrating Doppler flow meters at the inflow and outflow to pond 1, and sampling the concentrations of P and N flowing in and out of Pond 1 with an ISCO auto sampler. The concentrations of inorganic nutrients will be measured with a Bran-Luebbe AutoAnalyzer 3. The concentrations of organic nutrients will be measured following micro-Kjheldahl digestion. The vertical distribution of litter will be measured in the dormant season with a LiCor LAI 2000 canopy analyzer.

Mesocosm experiments

We will use mesocosms to further explore the controls on plant production and nutrient balance. We will construct eighteen 2.4-m x 2.4-m mesocosms in the marsh using vertically oriented 4' x 8' sheets of marine-grade plywood. The mesocosms will be isolated from each other by sinking the plywood sheets ~6" into the sediment. The mesocosms will be plumbed to allow us to circulate marsh water throughout the facility during normal periods, and to isolate individual mesocosms during short periods to measure the nutrient budgets. We will determine the rates of plant growth and nutrient dynamics for six replicate mesocosms exposed to three treatments (removed litter, doubled litter, and control). Production will be determined by end of growing season harvest. Nutrient budgets will be determined by periodically measuring the flow and concentration difference between water flowing into and out of isolated mesocosms, and by analyzing the chemical composition of harvested tissue.

Analyses of spatial patterns using GIS and remote sensing.

We will use existing aerial photographs and remote-sensing images to investigate the spatial patterns of plant growth from year to year. We have identified commercially available vertical photos of the marsh for most of the summers from 1999 to 2003. We will use these photographs to determine whether the mosaic of green (green leaves) and tan (litter) patches move from year to year (see Fig. 3). We will make a similar analysis with Landsat ETM+ and ASTER images. We have identified suitable ASTER images for summer 2000 and 2003 and suitable ETM+ images for summer 2001 and 2002 (ASTER has 15 m resolution, ETM+ has 30 m resolution). We will use these images to determine how the spatial patterns of the Normalized Difference Vegetation Index (NDVI; a measure of plant production) change from year to year.

Manipulation in Pond 2.

We plan a large manipulation in Pond 2 to further test our understanding of the causes of year-to-year variation in exchange. We installed a tower in Pond 2 in May 2003 in preparation for this manipulation. The measurements at the two towers show similar temporal patterns, though summer photosynthesis was about 20% lower in Pond 2 compared with Pond 1. We plan to continue the measurements at both towers for another growing season to determine whether the interannual variation is similar. We then plan a manipulation in Pond 2 to test whether the interannual variation in gas exchange is caused by the accumulation of standing litter. This manipulation will be done within the context of the overall management of the marsh, as directed by Bill Bretz (wlbretz@uci.edu), the marsh steward. The manipulation will involve either a controlled burn or mowing during late 2004. Bill is currently seeking permission for a controlled burn, though air pollution issues may be prohibitive. As a fall back, we will mow Pond 2 at the end of the growing season. We expect the reduction in standing litter, either by burning or mowing, will dramatically decrease shading and increase marsh photosynthesis, evaporation, and nutrient sequestration during the 2005 growing season relative to the undisturbed control in Pond 1.

Student Training

Our entire budget will be used to support Adrian Rocha, a Ph.D. graduate student in Earth System Science at UCI. The research program described above was developed with Adrian, and the work will serve as Adrian's dissertation. Adrian has made excellent progress since entering UCI's Earth System Science Department in September 2003. Before coming to UCI, Adrian received a B.S. in Earth Systems Science and Policy from Cal State Monterey Bay (3.6 GPA) and a M.S. in Environmental Science from Ohio State. Adrian is interested in ecosystem ecology, plant physiology, hydrology, and micrometeorology. Adrian will begin active research after completing the Department's comprehensive examination in early July 2004.

The research we are proposing has several aspects that make it an attractive Ph.D. project. Our research has reached the point where we have identified, but not tested, several specific hypotheses. The research will be done at a nearby secure and stable site, where we have an excellent working relationship with the other members of the marsh advisory committee. The research draws together several techniques (micrometeorological, hydrological, remote-sensing/GIS) and disciplines (plant physiology, environmental biophysics, nutrient cycling).

In addition to graduate training, we will further build the San Joaquin Marsh into the undergraduate instruction at UCI, both through a class in field methods that Prof. Goulden teaches at the marsh each spring, and through the direct involvement of undergraduates in research.

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