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# NET ECOSYSTEM EXCHANGE, EVAPOTRANSPIRATION AND CANOPY CONDUCTANCE IN A RIPARIAN FOREST

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## 1. INTRODUCTION

The contribution of riparian ecosystems to the water and carbon cycle are poorly described in hydrologic and land surface – atmospheric models. In addition they are difficult to measure using classical micrometeorological methods due to the normally narrow and heterogeneous coverage associated with these systems. Field data from these diverse and important ecosystems must be available in order to test model results, and the primary mechanisms that control canopy conductance, evapotranspiration, and the net ecosystem exchange of $CO_2$ (NEE) must be investigated for inclusion in these models.

Cottonwood (*Populus Fremontii*) is an important riparian tree species in the western United States both because of its prevalence and because of its potentially large transpiration and growth rates. Some evapotranspiration measurements have been taken of cottonwood trees using sap flow methods (Goodrich et al.,2000) and LIDAR (Cooper et al., 2000) but few long term eddy covariance studies have been performed on this species due to the narrow corridors where these riparian trees normally grow. The use of eddy covariance to measure the net exchange a scalar relies upon horizontal homogeneity and most riparian systems do not meet this criterion. In this study the careful use of eddy covariance within a relatively large and homogenous riparian cottonwood forest allows us to look at NEE, canopy conductance, water use, and the driving variables of the riparian microclimate over the span of several seasons. Our primary finding is the strong prohibitive effect that persistent late season flooding can have on net primary productivity and evapotranspiration.

## 2. METHODS

The field study focused on a cottonwood forest near the Cosumnes River in northern California's Central Valley. The Cosumnes River is the only un-dammed river draining from the Western Sierras into the ocean and allows us to observe riparian ecosystems under more natural flood regimes than in a dammed watershed. The forest was established in 1985 on a large sand splay that resulted from a flood event. The entire forest and the surrounding area is part of a part of a low-intervention restoration area that is subject to seasonal flooding during high river flow events. Before choosing the tower site we analyzed prevailing wind directions using historical meteorological data from several stations in the area and chose the tower site and the tower height to maximize the percentage of the flux data that would originate from within the cottonwood forest.

### 2.2 Instrumentation

A 21m tall eddy covariance tower was erected near the eastern edge of the forest and bio-micrometeorological data was recorded from January 2004 through July 2005. Half hour mean meteorological measurements included air temperature and relative humidity (Vaisala HMP 45-A), net radiation (Kip & Zonen NR-Lite), ground heat flux (Radiation and Energy Balance Systems HFT-3.1 buried 5 mm below the surface), barometric pressure (LiCor-7500 internal pressure sensor), and surface temperature (Everest Interscience infra-red thermometer model 4000.4ZL). Wind velocity and sonic temperature were measured using a Campbell CSAT3 three dimensional anemometer. Carbon dioxide and water vapor concentrations were measured using an open path LiCor-7500 infrared gas analyzer. Hydrologic measurements included ground water depth and surface water depth.

### 2.3 Calculations

The ten Hertz wind velocity, sonic temperature, and gas concentrations were post-processed to calculate mean values, turbulent statistics, and the vertical fluxes of sensible heat, water vapor, and carbon dioxide. Density corrections were applied point by point to the ten Hertz gas data before

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calculating the half hour covariances of $H_2O$ and $CO_2$ with the vertical wind speed (w).

We also calculated half hour estimates of leaf vapor pressure deficit (LVPD), vapor pressure deficit (VPD), canopy conductance ($g_c$), and the storage ($S_c$) of $CO_2$, $H_2O$, and sensible heat in the canopy below the measurement height. The equations used to calculate these values are listed below.

**Leaf vapor pressure deficit:**

$$LVPD = e_s(T_s) - e_a \qquad (1)$$

Where $T_s$ is the surface temperature measured by the infrared thermometer directed towards the canopy from the top of the tower. $e_s(T_s)$ is the saturation vapor pressure calculated from the surface temperature. $e_a$ is the vapor pressure of the air calculated from the values of relative humidity (RH) and air temperature measured above the forest.

**Vapor pressure deficit:**

$$VPD = e_s(T_a) - e_a \qquad (2)$$

$e_s(T_a)$ is the saturation vapor pressure calculated from the air temperature.

**Canopy conductance:**

$$g_c = \left\{ \frac{\rho \cdot C_p \left[ e_s(T_a) - e_a(T_a) \right]}{\gamma \cdot LE} - r_a \right\}^{-1} \qquad (4)$$

where $r_a \approx r_h = \dfrac{(T_s - T_a)\rho \cdot C_p}{H}$ (5)

$H$ is the sensible heat flux and $g_c$ is canopy conductance. $r_a$ is the aerodynamic resistance, which is assumed to the aerodynamic resistance to heat transfer and the aerodynamic resistance to water vapor transfer. There may be some small errors associated with this assumption, but in the defense of this method we estimate the aerodynamic resistances every half hour based on observed half hour micrometeorological variables which are physically tied to the aerodynamic resistance. This is preferable to using a parameterization such as mixing length or a Penman-Monteith based derivation to solve for the resistances. Differences in the source locations of heat and water vapor and non-local turbulent transfer could cause errors in these estimations.

**Storage:**

$$S_c = \frac{(c_t - c_{t-1800s})\alpha \cdot h}{\Delta t} \qquad (3)$$

$S_c$ is the storage of any scalar (temperature, $H_2O$, or $CO_2$). $c_t$ is the concentration of a scalar measured above the top of the canopy during the half- hour being considered. $\Delta t$ is 1800s. $\alpha$ is the scaling factor for the profile. $c_{t-1800s}$ is the mean concentration of the scalar from the previous half hour. $h$ is the measurement height.

Surface temperature was not recorded during the first seven months of the campaign. As a result canopy conductance and LVPD were only calculated using equation (1) for the latter 10 months of the period. A regression between LVPD taken from the latter ten months was used to look at equivalent LVPD during the time when surface temperature was not available.

## 3. RESULTS

### 3.1 The Effects of Flood

Figure 1 shows clear differences in NEE and LE from the same time period in 2004 and 2005. During the winter of 2004 the forest experienced flooding only in February and early March. The longest duration of a flood during this period was less than two weeks, and there were still no leaves on the trees when the last floodwaters left the forest. In 2005, by contrast, the forest was flooded various times, and surface water was present until the end of May. The forest was flooded 50% of the time from January 1 through May 31 of 2005 and some of these floods persisted for close to a month. As a result of this flooding we hypothesize that the roots of the cottonwood forest suffered from high redox potential in the soil.with limited available oxygen

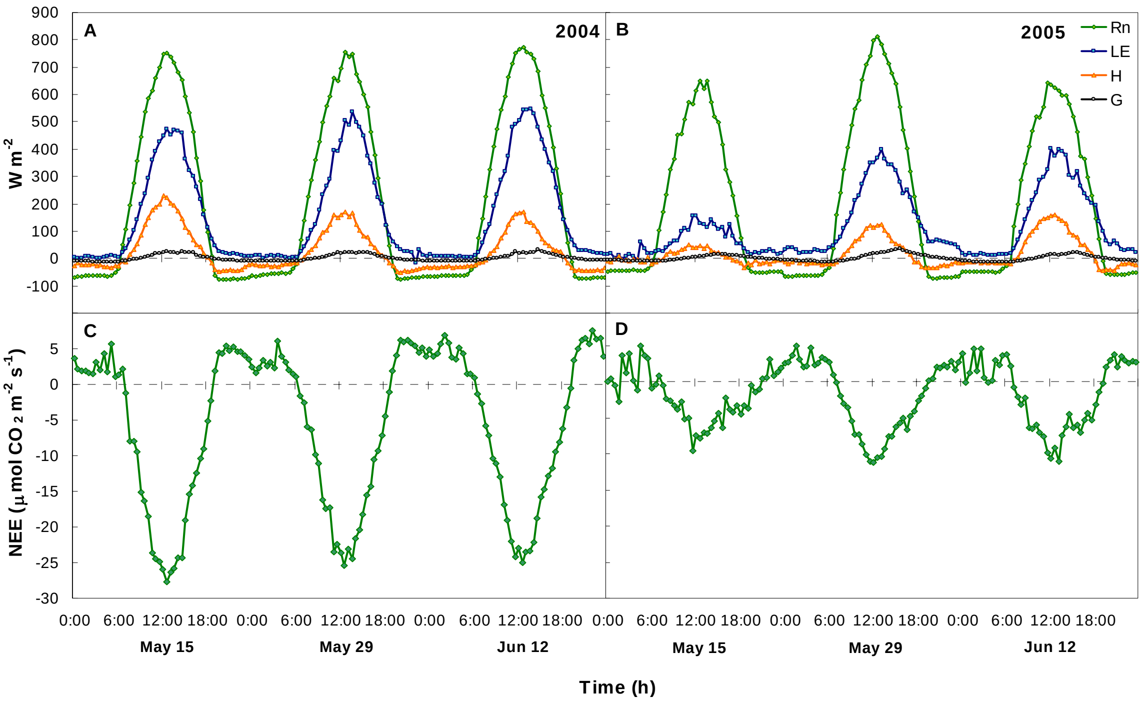


**Figure 1: (A) 15 day diurnal averages of the primary energy budget variables from spring 2004 and (B) the flooded spring of 2005 (C and D) Net ecosystem exchange averaged diurnally during the same period as above.**

We did not measure soil conditions, leaf potentials, or stomata resistance directly, but we infer from the measurements we have that the trees are suffering from some type of stress. Research has shown that persistent flooding can hinder photosynthesis in plants and can cause increased stomata control (Pezeshki, 2001; Kozlowski, 2002).

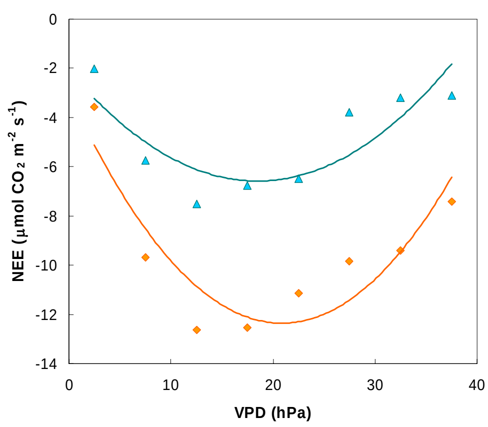


**Figure 2: Half hour values of NEE binned by VPD. Flooded data from 2005 is in blue with triangles and non-flooded data from 2004 is orange with diamonds.**

As illustrated in Fig 2. the flooded forest of 2005 responds to VPD differently than it does in 2004. Both show a response to VPD, but during the flooded spring NEE is greatly reduced.

### 3.2 Energy Budget

As illustrated in Fig. 1 (B) energy budget closure is poor during the flooded spring of 2005. LE is much lower than the previous year, even though the forest is flooded. We believe the change in LE is because stomata are closed, limiting the exchange of water in the canopy. In addition the water below the canopy is cool, averaging 10°C over the 2005 season, and has the capacity to absorb a large amount of energy as it flows through the forest. This energy was not accounted for in the measurements of ground heat flux, sensible heat, and latent energy. We will be including estimates of this term in future analysis.

## 4. Discussion

Cottonwood trees are a riparian species, adapted to survive flooded conditions, but not to thrive during extended periods of flood. During the spring of 2005, the trees reached their full summer values of LAI before the floodwaters receded, whereas in the spring of 2004 there was no surface water present during the time that leaves were emerging on the trees. The eddy covariance data shows evidence of stomata closure, which we suggest is caused by stress on the trees from high soil redox potential. Further analysis will include an estimation of canopy conductance which relies upon measured parameters that do not depend on surface temperature data. The data suggests that a comparison of canopy conductance from the 2004 and 2005 seasons will show that canopy conductance is much lower when the forest is flooded. The authors looked carefully into the turbulent statistics but could not find any suggestion of instrument failure as the cause for the evident difference in the 2004 and 2005 seasons.

Without taking into account energy stored and advected away in the surface water of flooded plant communities we cannot close the energy budget in flooded systems.

**4. Acknowledgements**

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