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Factors that control Typha marsh evapotranspiration

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Abstract

There is continuing debate about the controls on wetland evapotranspiration (E_t) and whether marshes are profligate water users. We used eddy covariance to measure the CO_2 exchange and E_t by a California Tule marsh in 2003. The marsh was dominated by Typha and Scirpus, and there was a large amount of standing litter that acted as a mulch. Canopy development was broadly related to air temperature, with rapid growth in May and senescence in October. E_t was a few tenths of a mm d^{-1} in winter, and 3–4 mm d^{-1} in summer. The midsummer Bowen ratio was $\sim$1, and the annual E_t was 49 cm. The peak rate of E_t was lower than has been reported for marshes based on lysimeter studies, somewhat lower than has been reported for marshes based on micrometeorological studies, and equivalent to, or somewhat lower than, has been reported for upland grassland. The midsummer water use efficiency was 0.0025 mol CO_2 mol^{-1} H_2O, and the $\delta^{13}C$ of foliage was $-27.1‰$, which are both typical for productive C_3 ecosystems. Transpiration accounted for 80% of total E_t. Evaporation from water standing beneath the canopy and mulch layer was only a minor component of the marsh's hydrological budget. The low rate of evaporation from standing water was a result of cool water temperatures, which remained within a few degrees of the nocturnal minimum on most days. We believe the mulch layer acted in a way analogous to an electrical diode that allowed the upward loss of heat from the water to the atmosphere at night, and shut off the flux of heat from the atmosphere to the water during daytime, resulting in cool subcanopy water and low rates of evaporation. Our observations are inconsistent with the hypothesis that Tule marshes are inefficient water users, or that their rates of transpiration and CO_2 uptake are unusual compared to upland ecosystems.

Keywords: Tule marsh; *Typha latifolia*; *Scirpus californicus*; Cattail; Evaporation; Canopy conductance; Water balance; Eddy covariance; Mulch

1. Introduction

The controls on wetland evapotranspiration (E_t) remain poorly understood despite nearly a century of investigation (Otis, 1914; Linacre, 1976; Crundwell, 1986; Allen et al., 1997; Królikowska et al., 1998; Drexler et al., 2004). A number of reports indicate freshwater marsh E_t is large and often exceeds open water evaporation (E_{open}) (Snyder and Boyd, 1987; Price, 1994; Herbst and Kappen, 1999; Pauliukonis and Schneider, 2001; Acreman et al., 2003). Other reports indicate wetland E_t is less than E_{open} (Rijks, 1969; Linacre et al., 1970; Lafleur, 1990; Burba et al., 1999) and broadly comparable to what would be expected for productive upland grassland. Efforts to understand wetland evapotranspiration have been confounded by the likelihood that different wetlands differ markedly in E_t and also by the reality that different methodologies produce widely divergent measures of E_t.

Water evaporates from marshes by several parallel pathways, including transpiration from emergent vegetation (E_{canopy}), evaporation from standing water beneath vegetation ($E_{subcanopy}$), and evaporation from open water (see Table 1 for summary of variables). Each of these fluxes is controlled by a different mechanism, and the relative importance of each pathway varies both spatially and temporally. E_{canopy} is controlled by the density of foliage, the stomatal conductance, and the meteorological conditions that determine the leaf-to-air vapor pressure deficit (Campbell and Norman, 1998). Wetland-to-wetland differences in leaf area or stomatal conductance may cause large differences in E_{canopy}. $E_{subcanopy}$ is a function of the meteorological and biophysical conditions that impact aerodynamic exchange and the water-to-air vapor pressure deficit. Wetland-to-wetland differences in litter or leaf area may cause differences in $E_{subcanopy}$. Wetlands differ in the extent of open water and the duration of subcanopy flooding, and hence the relative importance of E_{open}, E_{canopy}, and $E_{subcanopy}$. The

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Table 1
Summary of measured and derived variables

Variable	Definition	Method
Surface flooding	Presence or absence of standing water at the meteorological tower	Recorded during periodic site visits
K	Incoming solar radiation	Measured at SJFM
H	Sensible heat flux	Measured by eddy covariance at SJFM
F_{CO_2}	Net CO_2 exchange	Measured by eddy covariance at SJFM
T_{air}	Air temperature	Measured at Santa Ana Airport or at SJFM
T_{canopy}	Effective canopy temperature	Calculated from inverted Penman–Monteith equation
T_{water}	Temperature of water beneath the canopy	Measured by submerged thermocouples
q	Specific humidity of ambient air	Measured at Santa Ana Airport
E_t	Total evapotranspiration	Measured by eddy covariance at SJFM
E_{canopy}	Transpiration from plant canopy	Measured by eddy covariance during periods when marsh surface was dry
$E_{subcanopy}$	Evaporation from water beneath the canopy	Measured by eddy covariance during periods when marsh surface was wet and no appreciable canopy
D_{canopy}	Difference in vapor pressure between ambient air and inside of leaves	Calculated as the difference between specific humidity and the saturated vapor pressure at canopy temperature
$D_{subcanopy}$	Difference in vapor pressure between ambient air and water beneath canopy	Calculated as the difference between specific humidity and the saturated vapor pressure at the water temperature
G_{canopy}	Conductance for water vapor transport from inside leaves to outside of leaves	Calculated from inverted Penman–Monteith equation
$G_{subcanopy}$	Conductance for water vapor transport from beneath canopy to atmosphere	Calculated by dividing $E_{subcanopy}$ by $D_{subcanopy}$

existence of multiple evaporation pathways undoubtedly contributes to large wetland-to-wetland differences in E_t, and argues that the debate should shift from generalizations about the relative rates of evaporation by vegetated and open water surfaces, and toward the development of a mechanistic understanding of what controls wetland E_t.

Many of the reports of high rates of wetland E_t were based on lysimeter studies, which may be biased by horizontal energy advection (Allen et al., 1997) and the absorption of light on the sides of plants at low solar elevation (Idso and Anderson, 1988). Allen et al. (1997) and Drexler et al. (2004) discussed the methodologies available for quantifying wetland evapotranspiration and concluded that eddy covariance is a particularly promising tool. Eddy covariance is a micrometeorological technique that can provide half-hour observations of the net exchanges of water vapor and CO_2 between a few hectares of wetland and the atmosphere (Baldocchi et al., 1988). Recent advances in the reliability of eddy covariance instrumentation have allowed the collection of long-term eddy covariance data sets above a range of vegetation types (c.f., Wofsy et al., 1993; Hollinger et al., 1994; Goulden et al., 1997), including wetlands (Souch et al., 1996; Acreman et al., 2003). Analysis of eddy covariance observations provides information for identifying which physiological and physical processes play dominant roles in controlling water vapor and CO_2 exchange.

We used the eddy covariance technique from 1999 to 2004 to continuously measure the CO_2 exchange (F_{CO_2}) and evapotranspiration by a Typha- and Scirpus-dominated Tule marsh in Southern California (the San Joaquin Freshwater Marsh, or SJFM). Tule marshes were once common in California, covering 750,000 ha of the Central Valley (Küchler, 1964; Barbour and Major, 1988; Schoenherr, 1992). Nearly all of these marshes were drained for agriculture and few Tule marshes remain. In this paper we focus on the seasonal and diel controls on E_t. We emphasize two questions: (1) What are the relative rates of E_t, E_{canopy}, and $E_{subcanopy}$ and how do they vary diurnally and seasonally? (2) What controls and limits E_t, E_{canopy}, and $E_{subcanopy}$? We restricted our analysis to data from 2003 because the data set was comparatively continuous during this period, with fewer gaps than in other years, and because the diel patterns, seasonal patterns, and relative rates of E_t, E_{canopy}, and $E_{subcanopy}$ during 2003 were similar to those observed during the other years. The absolute rates of E_t observed during 2003 were similar to those observed in 2001 and higher than those observed in 1999, 2001 and 2002. The interannual variability in E_t and F_{CO_2} will be the subject of a second paper (Rocha and Goulden, 2007).

2. Methods

2.1. Site

We investigated the controls on E_t in the San Joaquin Freshwater Marsh (SJFM, Schoenherr, 1992), an 82 ha Tule marsh (Mason, 1957; Küchler, 1964) in the Bulrush-Cattail Series (Sawyer and Keeler-Wolf, 1995) that is located on the University of California's Irvine campus. The SJFM is in coastal Orange County at 3 m above sea level (a.s.l.) and 8 km northeast of the Pacific Ocean (33°39′44.4″N, 117°51′6.1″W). The SJFM is protected and managed for research and education as a component of the University of California's Natural Reserve System.