1.2 INTERACTIONS OF CARBON AND WATER CYCLES IN NORTH TEMPERATE WETLANDS: MODELING AND OBSERVING THE IMPACT OF A DECLINING WATER TABLE TREND ON REGIONAL BIOGEOCHEMISTRY

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1. INTRODUCTION

Terrestrial carbon fluxes represent a major source of uncertainty in estimates of future atmospheric greenhouse gas accumulation and consequently models of climate change. In the Upper Great Lakes states (Minnesota, Wisconsin, and Michigan), wetlands cover 14% of the land area, and compose up to one third of the land cover in the forest-wetland landscapes that dominate the northern half of the region. Worldwide, wetlands contain up to one third of the total soil carbon reservoir (Gorham, 1991). The carbon fluxes of wetland ecosystems, and especially their responses to climate forcings, are currently poorly understood.

One major source of error in wetland modeling is the lack of mechanisms for wetland biogeochemistry and hydrology. Fluxes of both carbon dioxide and methane are expected to respond to changes in water table height. Water table-carbon flux interactions represent a climate feedback mechanism of potentially great importance given the changes in precipitation patterns predicted by many climate models as part of climate change scenarios (Meehl *et. al.*, 2007). A greater understanding of the wetland response to changes in hydrology could significantly improve the accuracy of land-atmosphere interaction modeling of temperate regions. A multi-year trend of declining water table height has been observed at several sites in northern Wisconsin, providing an opportunity to study these interactions.

2. MEASUREMENTS AND DATA

Eddy covariance fluxes and related bio-and-geophysical data from three wetland sites and an upland site in North-Central Wisconsin were analyzed for this study.

2.1 Site Characteristics

Three wetland sites and one upland site in the Chequamegon Ecosystem Atmosphere Study (ChEAS; http://cheas.psu.edu) were included in this study. The wetland sites were Lost Creek, WI (LC), Wilson Flowage, WI (WF), and South Fork, WI (SF). The upland site was Willow Creek, WI (WC). All three are located in or near the Chequamegon-Nicolet National Forest in North-Central Wisconsin. Lost Creek is a shrub wetland with predominant ground cover of alder and willow. South Fork is an ericaceous bog, and Wilson Flowage is a grass-sedge-scrub fen. Willow Creek is an upland hardwood forest, predominantly maple, basswood, and ash. (Desai *et. al.*, 2008).

2.2 Observations

The data time series included eddy covariance measurements of net ecosystem exchange of carbon dioxide (NEE), momentum, latent heat, and sensible heat flux. Eddy covariance wind and tracer measurements were taken using fast-response 3D sonic anemometers and open or closed path infrared gas analyzers. Thirty minute average fluxes were calculated from 10Hz high-frequency data. The data were corrected for storage below the eddy covariance measurement height and spectral attenuation using standard established techniques (Desai *et al.*, 2008). Fluxes were also screened for low-turbulence conditions using a friction velocity criterion for each site, and anomalous data associated with a specific wind direction were discarded from WC.

Water table height (WT) was measured using a pressure transducer at the three wetland sites, and is defined in this study as height of the water surface above the soil surface. Positive WT denotes standing water above the soil, and negative WT represents a saturation level below the soil surface. The data also included time series of air and soil temperature at several heights, photosynthetically active radiation (PAR), and precipitation.

Modeled gross ecosystem productivity (GEP) and ecosystem respiration (ER) time series were calculated from NEE using a nonlinear regression based approach (Desai *et. al.*, 2008). Seven years of data (2000-2006) were analyzed from LC and WC, and two years of data (2005 and 2006) were

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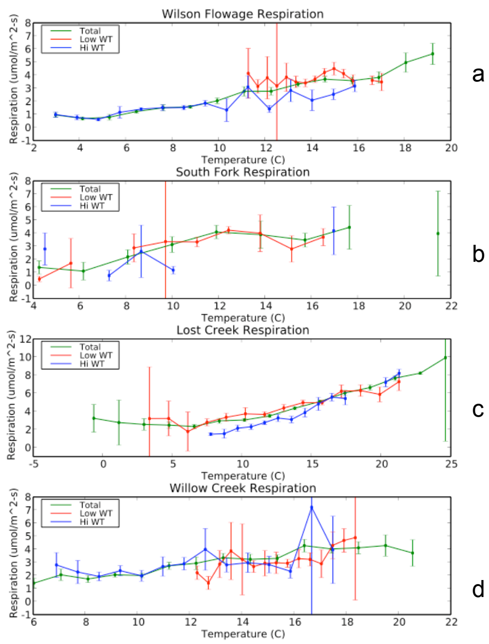

Figure 1: Summer ER plotted as a function of soil temperature for the four sites, divided according to depth of the water table. Error bars are 95% confidence intervals. Red represents low water table, blue represents high water table, and green represents the complete data. ER is lower at moderate temperatures under the high water table regime for the three wetland sites, and no significant difference is seen in the upland site. WC, an upland forest, is divided according to LC WT measurements for comparison purposes.

available from SF and WF. SF and WF were measured with a mobile flux tower. Two weeks of data were taken at a time, with a two-week separation when the tower was at the other site.

3. RESULTS

A trend of declining water table visible in the seven year LC time series (inset, Fig 4) provides a useful opportunity to investigate the connections between water table depth and wetland ER, GEP, and evapotranspiration (ET). Typically, NEE is a fine balance between the positive carbon emissions produced by ER and the carbon absorbed by GEP. Even small changes in these two components can have meaningful effects on the net exchange.

3.1 Ecosystem Respiration and Water Table

Wetlands are characterized by water-saturated, anoxic soil below the water table. Detritus from roots and plants undergoes anaerobic decomposition, a much slower process than aerobic decomposition. The slow rate of decomposition allows a long-term buildup of biological matter. It is this process that produces

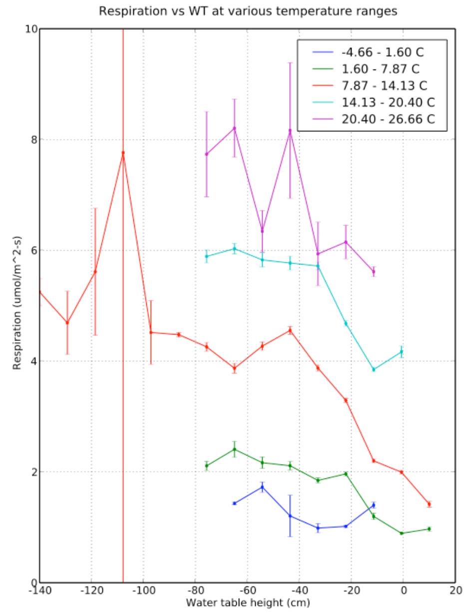

Figure 2: Lost Creek ER at different temperature ranges as a function of water table depth. The lessening of ER with deepening water table is most clear in the 7-14ºC range, and appears to have a threshold at a water table depth of about 40 cm. below the soil surface. Error bars represent 95% confidence intervals.

the deep peat reserves typical of wetlands. Soil above the water table is oxygenated and can be decomposed by faster aerobic processes. Thus, a lowering of water table makes more soil carbon available for fast decomposition and would be expected to increase the rate of carbon dioxide production by soil respiration.

Respiration rate is a strong function of soil temperature, especially in the active growing season (Fig. 1). Summer growing season is defined as June-September for LC and WC and May-October for SF and WF. A longer time period was necessary for SF and WF because less data were available for these sites. Mathematically removing the temperature dependence of ER makes it possible to identify other effects, including that of water table.

The green lines in Fig. 1 represent the mean ER of the complete data set. In WC and LC, the red lines are calculated only from data points where the LC water table depth was more than one standard deviation below the mean over the entire record, and the blue lines from data points where the water table was more than one standard deviation above the mean. WC is an upland site, but the data was divided according to LC water table measurements in order to determine if the connection with water

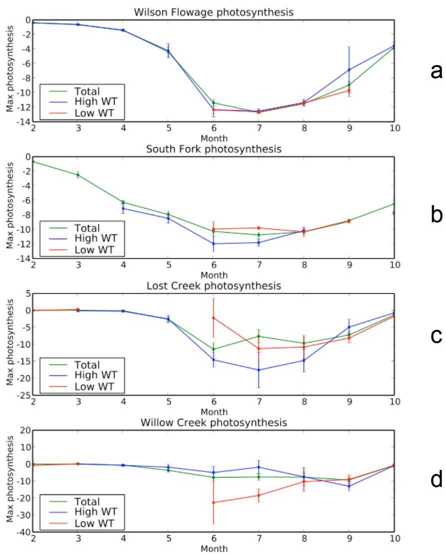

Figure 3: GEP at saturation PAR, plotted by month. Error bars represent 95% confidence limits. LC and SF show slightly lower GEP at lower WT, but WF shows no effect. WC shows higher GEP at lower WT. Whether water table has a real effect on GEP is inconclusive.

table is unique to wetland sites. In SF and WF a 0.8 standard deviation cutoff for determining high and low water table regimes was used due to the limited data.

WF (Fig. 1a) and LC (Fig. 1c) show a clear difference in ER between high and low water table regimes. LC, the site with the most available data, shows that ER at low water table is significantly lower than at high water table at temperatures less than about 18ºC, and approaches the high water table value at higher temperatures. The other two wetland sites have sparser data, but confirm this effect. WC (Fig. 1d) shows no significant difference between ER at high and low water table, confirming that this effect is specific to wetland sites.

Binned-averaged growing season LC ER at various soil temperature ranges shows respiration rate is higher at higher temperatures and also shows a decrease in ER with increasing water table height (Fig. 2). The correlation of water table with ER is most apparent at moderate temperatures, and much weaker in the highest and lowest temperature bins. The lines representing ER between about 2 and 20ºC show a threshold water table depth between 40 and 20 cm below the soil surface. Above this threshold ER drops rapidly with increasing water table depth, while below the threshold, ER has a relatively constant value.

3.2 GEP and Water Table

GEP is strongly dependent on PAR. In temperate ecosystems it is also controlled by the seasonal cycle of the growing season (Fig. 3). To observe

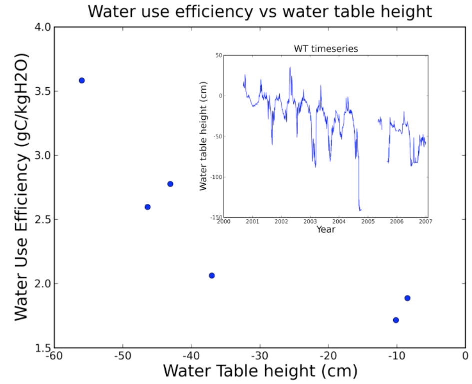

Figure 4: LC growing season water use efficiency (WUE) as a function of water table height. WUE is expressed as grams carbon absorbed per gram water transpired. Transpiration decreased with lowering water table while GEP was not strongly affected. The result is a strong dependence of WUE on water table. Inset is the time series of daily averaged LC water table height, showing the declining trend.

the possible effects of water table on GEP, it is necessary to separate out these effects. The PAR dependence exhibits a saturation effect at high PAR, so this saturation value is a good measure of the peak photosynthetic efficiency.

Photosynthesis requires plants to release water vapor in exchange for carbon dioxide, so under dry conditions plants would be expected to photosynthesize less in order to conserve water, lowering saturation GEP. In the LC (Fig. 3c) and SF (Fig. 3b) wetland sites, low water table appears connected with lower saturation GEP during summer, as expected, but the dependence is very weak, and the effect is not visible in WF (Fig. 3a). In the WC upland (Fig. 3d), low water table is connected with higher photosynthesis, but the difference exceeds 95% confidence limits only at two points. Another study has identified a slight increase in ecosystem production in response to sinking water table (Cook *et. al.*, 2008), but the results of the analysis described here are not significant enough to confirm that result.

3.3 Water Use Efficiency and Water Table

One view of photosynthesis is as a process where plants trade water for carbon. Leaves acquire carbon dioxide by opening stomata, a process that releases water. The amount of water lost in exchange for an amount of carbon dioxide is the water use efficiency (WUE). This is generally considered a property of a plant, which cannot easily change in response to environmental conditions. WUE can be measured as the ratio of transpiration to GEP. Transpiration was calculated by subtracting a simple model of soil evaporation from the measured latent heat flux.

Summer transpiration was found to decrease with decreasing water table height (data not shown), while summer GEP did not exhibit a significant response to water table (Fig. 3). This resulted in WUE increasing with the declining water table (Fig. 4), suggesting a possible fast response adaptation mechanism in this wetland to drought, though more research is needed to confirm this result.

4. DISCUSSION AND CONCLUSIONS

The results of this study show that changes in water table height primarily affect wetland ecosystem respiration and water use efficiency, with little effect on photosynthesis at three sites all experiencing a similar subboreal climate. These results suggest that a declining water table could be expected to result in a net decrease in annual carbon sequestration, or possibly in a shift to net carbon emission. However, our initial work on the response of WUE to the declining water table also suggests that the wetland plant community may be resilient when faced with variable hydrological conditions, though threshold responses are possible. This result is based primarily on a single wetland plant community. Future study will be required to determine whether this relationship holds for multiple wetland types.

The response of methane emissions to water table dynamics is another important factor in predicting the future effects of wetlands on climate scenarios. Wetland methane emissions are primarily produced by anaerobic decomposition below the water table, so a rising water table could result in an increase in methane emissions that would offset the effect of decreasing carbon dioxide emissions from soil respiration. Ongoing work by collaborators on regional methane emissions and our plans to develop a model for anaerobic decomposition will provide bounds on this process.

More sophisticated analysis of CO_2-CH_4-water interactions in wetlands would be possible using a numerical ecosystem model. We have adapted the Terrestrial Regional Ecosystem Exchange Simulator (TREES), a numerical model of ecohydrology (Mackay *et al.*, 2003), for wetland aerobic and anaerobic carbon exchange. We intend to use TREES to test model mechanisms and constrain model parameters using the observed data to further refine water-carbon interactions and test potential climatic effects on wetland carbon exchange.

Our observational and modeling results will help us refine our understanding of wetland carbon interactions in face of regional water table variability under future climate and water management scenarios. Model predictions of future precipitation patterns are highly variable, but many predict an increase in precipitation in temperate zones where many wetlands are found (Meehl *et. al.*, 2007). If wetland water tables rise in response to these patterns, the decreased ecosystem respiration predicted by this study could be a negative climate feedback. Alternatively, if water management and surface flow dominate water table dynamics, then future behavior may be more difficult to predict. Future work will hopefully shed more light on the roles of these two processes (climate change and natural resources management) and their effects on regional biogeochemistry.

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