Greenhouse Gas Regulation by Wetlands

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Abstract

Wetlands are unique and productive ecosystems that perform essential ecological functions. They cover only 6% of the earth's surface, yet they play a crucial role in maintenance and improvement of water quality; controlling soil erosion and floods, regulating the hydrological cycle and retention of nutrients and carbon. Wetlands also contribute to local climate regulation through distribution of incoming solar energy, by transferring solar energy from latent heat flux (cooling) into sensible heat flux (warming of air). The amount of water vapour, as a greenhouse gas, found in plant stands and in the atmosphere is many times higher than the amount of CO_2 and it changes dramatically across time and space. Water exists on the Earth in three phases and its transition between these phases is linked with uptake or release of high amounts of energy. The cooling effect of evapotranspiration is introduced in terms of solar energy and water vapour fluxes. The effect of wetlands on the daily dynamic of surface temperature is shown by thermographic and visible pictures of the mosaic of a cultural landscape with wetlands. We thus demonstrate that wetlands cool

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landscape and moderate daily extremes of temperature; in this way we seek to quantify the global role of wetlands in regulation of greenhouse gases and influence on local climate.

Keywords
Climate regulation · Evapotranspiration · Greenhouse gases · Surface temperature · Transpiration efficiency · Wetlands

The Balance of Greenhouse Gases in Wetlands

There has been increased interest in understanding the role that wetlands play in the regulation of greenhouse gases. The dynamics of greenhouse gas exchange are largely determined by site-specific conditions including hydrology, soil type, vegetation, and meteorological and climatic conditions. Wetlands, just as other ecosystems, may act as carbon dioxide (CO_2) sinks in some periods, and as sources in others, depending on the meteorological conditions (Čížková et al. 2013). The emission of methane (CH_4) and nitrous dioxide (N_2O) from wetlands is similarly variable in time.

Čížková et al. (2013) provided an overview of case studies that focused on the balance of greenhouse gases in different wetland types. They found that peatlands were by far the most important of all wetland ecosystems with regard to affecting the global balance of greenhouse gases and globally represent a highly important store of carbon, sink for CO_2, and a significant source of atmospheric CH_4 (from the point of view of its importance for the greenhouse effect). In general, N_2O emissions are small in natural peatlands (Joosten and Clarke 2002). In addition to actively growing peatlands (mires), littoral wetlands with abundant plant cover such as reed (*Phragmites australis*) in Central and North Europe can be important sinks for carbon. Floodplains can also accumulate organic matter and carbon if floods are maintained and the river-floodplain connectivity allows the plant communities (especially riparian woodlands) to develop in response to the ecohydrological cycle.

Two types of impact considerably affect the greenhouse gas balance of wetlands: changed hydrology and nutrient enrichment. More frequent summer droughts increase the frequency of situations under which wetlands, especially peatlands, act as sources of CO_2 to the atmosphere due to mineralization. At the same time, CH_4 emissions decrease. There is also evidence that peatlands reclaimed for agricultural use are releasing significant amounts of N_2O because they have become enriched with mineral nutrients including nitrogen (Couwenberg 2011). Long-term nutrient enrichment of wetlands with organic soils can also promote CO_2 efflux. Eutrophication of permanent wetlands associated with standing waters can promote anaerobic decomposition processes including CH_4 production (Fig. 1).

Wetlands have been both taking up and releasing greenhouse gases continuously since their formation, and thus their influence on the atmosphere must be modeled

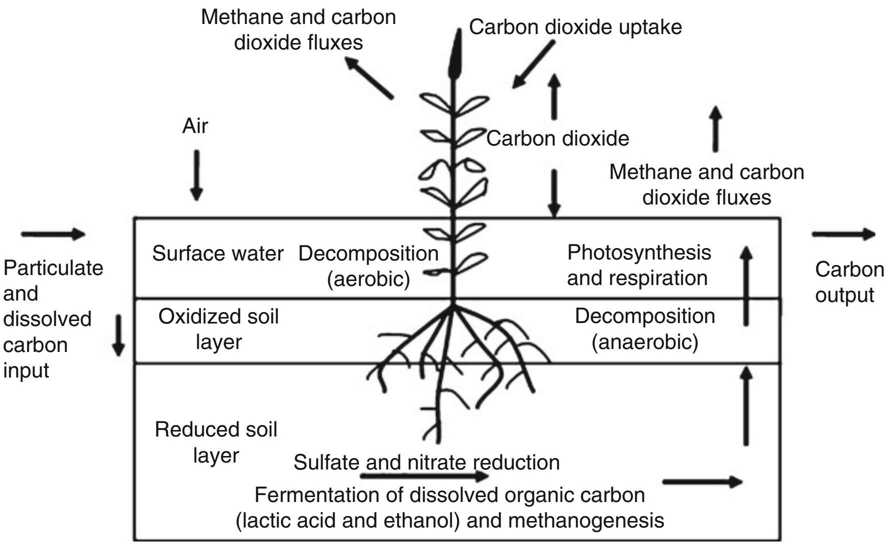

Fig. 1 Schematic diagram showing the major components of the carbon cycle and conditions in the root zone (With permission from Kayranli et al. 2010)

over time. When this is considered, the sequestration of CO_2 in peat outweighs the CH_4 emissions. In terms of greenhouse gas management, the maintenance of large carbon stores in undisturbed peatlands should be a priority.

Wetlands may initially accumulate organic matter at higher rate than it is decomposed, but as this material accumulates, the continued decomposition of steadily increasing amount of peat or sediment means that carbon loss is also progressively increasing (Clymo 1984). Eventually mean carbon input roughly balances the rate at which carbon is released. Marshes and swamps reach this point relatively rapidly: perhaps a few hundred to a maximum of a few thousand years. Peatlands, on the other hand, may take thousands of years to reach a “steady state” of carbon losses balanced by carbon inputs. Carbon accumulation in wetlands can be highly sensitive to environmental conditions such as temperature, precipitation, fire, or flood. Studies in Finland and Canada found that bogs and nutrient-poor fens in general accumulate more carbon (ca. 20–25 gC.m^{-2}.a^{-1}) than more mineral-rich fens (ca. 15–20 gC.m^{-2}.a^{-1}) (Tolonen et al. 1996; Robinson and Moore 1999). Nowadays, the world’s wetlands may be net carbon sinks of about 830 Tg CO_2 year$^{-1,}$ with an average of 118 g-C m^{-2} year^{-1} net carbon retention (Mitsch and Hernandez 2013).

Carbon release can be elevated by ten or more times for months to years immediately after drainage (of the order of 250–1,000 gC m^{-2}.a^{-1}, Maltby and Immirzi 1993) and decreases over time as more labile carbon compounds are decomposed and more refractory material remains. Long after drainage, for more than 60 years, for example, however, stored peat can continue to decompose.

Exchange of Water and CO_2 in Plant Stands

Most plant tissues contain large amounts of water. The biomass of non-woody tissues typically is made up of 80–95% water. Most water taken up by roots is transported through plants in the soil-plant-atmosphere continuum (SPAC) and transpired into the air.

The cooling process of transpiration is often considered a side effect rather than a mechanism to control leaf temperature (Lambers et al. 2008). Transpiration is also perceived as a rather negative process. Plant physiologists and hydrologists may use negative terms such as "transpiration loss" and "evapotranspiration losses." Transpiration efficiency (TE) is defined as the amount of water used in transpiration per unit of dry matter produced. TE normally reaches a value of several hundred kilograms of water consumed per kilogram of dry biomass produced. The amount of water molecules exchanged by plants is at least two orders of magnitude higher than the amount of carbon dioxide fixed in biomass.

The amount of water vapor, as a greenhouse gas, found in plant stands and in the atmosphere is many times higher than the amount of CO_2 as a greenhouse gas. Moreover, it changes dramatically across time and space. For example, air saturated with water at 21 °C contains 18 g m^{-3} of water vapor, i.e., 22,400 ppm. Air saturated with water at 40 °C contains 50 g m^{-3} of water vapor, i.e., 62,200 ppm. The amount of water vapor in air is often two orders of magnitude higher than that of CO_2. The content of water vapor in the atmosphere is highly variable, and furthermore, water exists in three phases (solid, liquid, and gaseous). The transitions between these phases are linked with the uptake or release of high amounts of energy and with immense change of volume (18 ml of water liquid forms 22,400 ml of water vapor). The energy absorption spectrum of water is broader than that of CO_2 (Sondergard 2009).

Cooling Effect of Evapotranspiration

Climate change and global warming are widely believed to be caused only by an increase in CO_2 concentration from 250 to 390 ppm. Novel recent research, however, highlights the dynamic role of water vapor in climate change, with its concentration two orders of magnitude higher than that of other greenhouse gases. The implication of this research is that human landscape management affects the behavior of water vapor and its role in the dissipation of solar energy, in a much more important way than formerly appreciated (Pokorný et al. 2010).

This research has focused on wet meadows in the Czech Republic, which evapotranspired about 7 mmol m^{-2} s^{-1} (i.e., 126 mg m^{-2} s^{-1}) during a sunny afternoon, converting about 315 W of energy per square meter of its surface into latent heat flux (Rejšková et al. 2010). The wetland, which covered an area of about 4 km^2, evapotranspired about 500 kg of water per second, which is equivalent to the flow rate of a small river. This invisible stream represents the latent heat flux of approximately 1,260 MW. Thus, this ecosystem regulates the temperature through energy and water fluxes with a power equivalent to that of a moderately large power station. If a wetland is situated in the middle of a dry landscape, it is predestined to function as a water funnel, and all evaporated water which runs through it is locally lost via rapid convective movement. In drained or dry landscapes, wetland ecosystems thus act as "wet islands," important both for their conservation value and for their important hydrological function (in addition to their hydrologically dependent nutrient processing).

The drainage of large areas of natural vegetation and the loss of their latent heat function causes surprisingly large amounts of sensible heat to be released into the atmosphere. A drop in evapotranspiration by 1 L m^{-2} (equivalent to about 700 Wh) is capable of increasing the daily flux of sensible heat about 40 times more effectively (by 70 W) than the quoted effect of greenhouse gases [radiative forcing, Intergovernmental Panel on Climate Change (IPCC)]. For example, a drop in evapotranspiration of 1 mm over the territory of the Czech Republic (79,000 km^2) within a single day, releases an amount of sensible heat comparable to the annual production of electric energy from all Czech power plants (about 60,000 GWh).

The Czech study also measured the daily dynamics of radiation surface temperature and air temperature of different land cover types in a temperate, "cultural" landscape and their consequences for the local climate (Hesslerová et al. 2013). Seven localities with different land cover types were chosen in Trebon Biosphere Reserve, Czech Republic, Central Europe. A combined method of airship thermal scanning of Ts (radiation surface temperature) and ground measurement of thermodynamic Ta (air temperature measured in a meteorological screen at 2 m height) was used (Fig. 2). The localities differed markedly in both the values and the dynamics of Ts and Ts–Ta. In the early afternoon, the difference in Ts between the different land covers reached almost 20 °C. Ecosystems with nonfunctional or no vegetation largely resembled the asphalt surface, whereas ecosystems covered with dense, bushy, or tree vegetation showed relatively well-balanced daily temperature dynamics with low temperature extremes and a slow temperature morning increase or afternoon decrease. Ts−Ta at the peak solar irradiance ranged between −1 °C at the forest and 14–17 °C at the dry harvested meadow and the asphalt surface, respectively (Fig. 3). Therefore surface radiation temperature (Ts) can be considered as a measurable indicator of ecosystem and landscape functioning, and the importance of functional vegetation for local climate should also be considered.

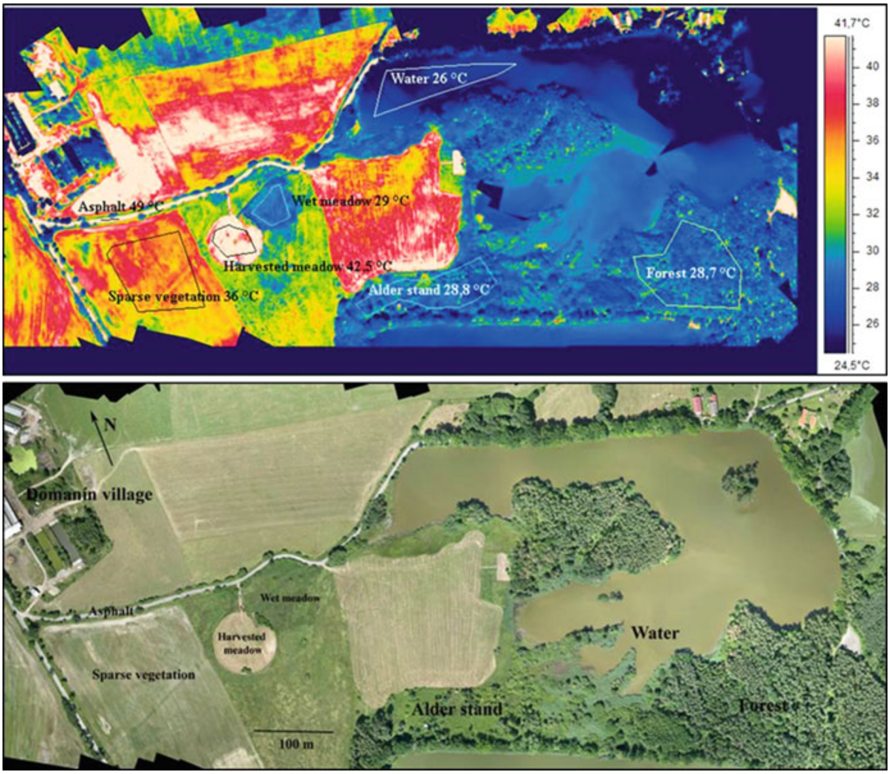

Fig. 2 Surface temperature of a “cultural” landscape on summer sunny day in Třeboň Biosphere Reserve (Czech Republic) at 2 PM, taken by thermographic and visible cameras carried by an airship

Future Challenges

The feedback between vegetation, surface temperature, water, and climate are crucial in landscape management with important implications for climate regulation and climate change. The importance of wetlands for the regulation of greenhouse gases and local climate regimes has long been assumed; the exact extent and effect have not, however, largely due to the absence of specific measurements, such as those referred to above. The measurements that have been undertaken illustrate the important role that wetlands have in regulating greenhouse gases and climate. We strongly suggest that wetland restoration, as mitigation for the predicted impacts of climate change, be placed on the agenda of climate scientists as well as conservation scientists.

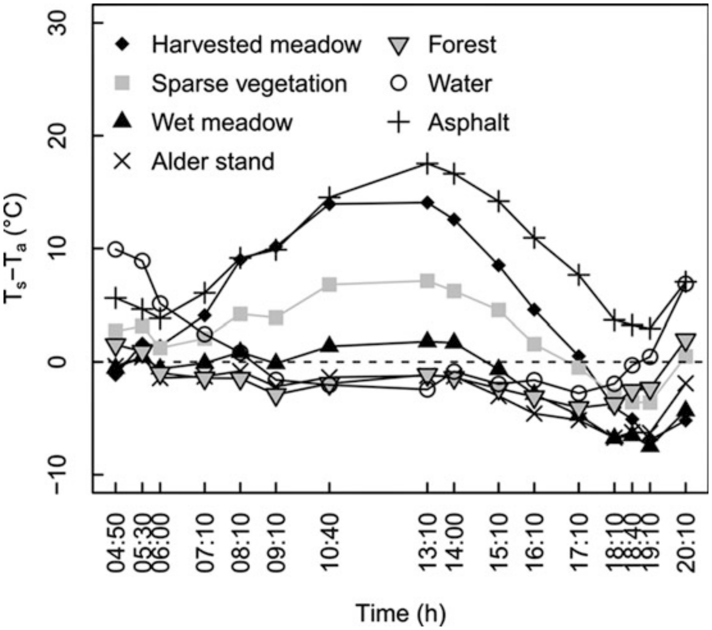

Fig. 3 Temperature differences $T_s - T_a$ between surface T_s and air temperature T_a (at 2 m above ground under white screen) at all the studied localities (With permission from Hesslerová et al. 2013)

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