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Wetlands and carbon revisited

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ABSTRACT

This paper summarizes 19 papers published in a special issue of *Ecological Engineering* under the general banner of wetlands and carbon. Many of the papers were presented at a special session at *EcoSummit 2016* in Montpellier, France in August-September 2016. The papers are in four general categories: estimating greenhouse gas fluxes with eddy covariance; methane and other greenhouse gas emissions from wetlands; carbon sequestration by wetlands; and organic carbon decomposition in wetlands. Overall, we found that further development and wider use of eddy covariance measuring stations could help clarify long-term annual budgets of CO_2 and CH_4 in wetlands and, while CH_4 fluxes in some coastal wetlands such as mangroves can be negligible, some inland wetlands can be significant sources of CH_4 where hydroperiods are the major determinants of the emission rates. The papers here demonstrated a variety of parameters determining dynamics of methane fluxes and carbon sequestration in different wetlands and lead us to suggest that more attention should be paid to detailed analysis of the impact of environmental and management factors on carbon budgets in wetlands. Carbon sequestration is almost always estimated by soil dating methods such as with ^{137}Cs and 210Pb isotopes and results continue to show order of magnitude differences among systems but sometimes among laboratories. This is due to the inexact nature of estimating soil dates over relatively short (~50 year) time horizons. The idea of capping landfills, which are enormous methane sources, with wetlands which could then turn them into carbon sinks is worth investigating further but the design of these systems is still in its infancy. Organic carbon decomposition in wetlands has been investigated extensively for decades and more recently on the biogeochemical processes. 'Enzymic latches" such as phenol oxidase, which can break down phenolics and therefore speed up decomposition, may be key controllers of organic matter decomposition in waterlogged and submerged soils in wetlands. The best approach for balancing greenhouse gases and carbon sequestration remains an enigma, but the papers in this special issue take us one step closer to providing clarity.

1. Introduction

Wetland ecosystems provide an optimum natural environment for the sequestration and long-term storage of carbon dioxide from the atmosphere, yet are natural sources of greenhouse gases emissions, especially methane. Methane is now described on a molecular basis as 34 times more potent as a greenhouse gas than carbon dioxide in a 100-year horizon (IPCC, 2013). Therefore, to many landscape managers and non-specialists, most wetlands are regarded as sources of climate warming or net radiative forcing and nothing else. For example, Mitsch et al. (2013) found that methane emissions in terms of carbon were about 14% of the carbon sequestered in 21 wetlands around the world (Mitsch et al., 2013). This 7.1:1 (sequestration/methane) carbon ratio is equivalent to 19.5:1 as CO_2/CH_4. Comparing this ratio to the global warming potential (GWP_M) ratio of 34 for methane relative to carbon dioxide listed above, it could be concluded that the world's wetlands are net sources of radiative forcing on climate. We argue that many landscape managers would also conclude from that simple comparison that wetlands should not be created or restored.

Publications that emphasize this comparison of the two major carbon fluxes in wetlands are relatively few. Mitsch et al. (2013) and Mitsch and Gosselink (2015) illustrated by dynamic modeling of carbon flux that methane emissions become unimportant within 300 years compared to carbon sequestration in wetlands. Within that time frame, most of the wetlands became both net carbon and radiative sinks. The only wetlands that remained net radiative sources in these comparisons were peatlands that were already sources of CO_2 caused by drainage. Furthermore, Mitsch et al. (2013) and Mitsch (2016) illustrated that the world's wetlands, despite being only about 5–8% of the terrestrial landscape, may currently be net carbon sinks of about 0.83 Pg yr-1 of carbon with an average of 118 g-C m^{-2} yr^{-1} of net carbon retention.

We brought experts who have studied carbon balancing of wetlands

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around the world together to EcoSummit 2016 in Montpellier France to discuss carbon fluxes in wetlands and their controlling factors. The international forum and subsequent papers published in this special issue were also partially organized to continue the discussion that our paper created five years earlier and to revise calculations that may now be needed because of many more wetland data sets since then.

2. EcoSummit 2016

Several of the papers in this special issue are the result of presentations at a special session (symposium) held at the 5th International EcoSummit held in Montpellier, France, on August 29–September 1, 2016. EcoSummit 2016 provided a forum for more than 1300 delegates from 75 countries to focus on finding solutions for today's massive environmental and ecological problems. Sessions were held on ecological engineering, ecological restoration, green infrastructure, adaptation to climate change, earth stewardship, ecohydrology, eco-informatics, ecological modeling, sustainable agriculture, protection of biodiversity, carbon sequestration, human ecology and enhancement of ecosystem services.

EcoSummit 2016 also hosted 11 plenary presentations by some of the world's premier ecologists and environmental scientists including Giovanni Bidoglio, Italy; Sandra Díaz, Argentina; John Philip Grime, UK; Connie Hedegaard, Denmark; Stephen P. Hubbell, USA; Blanca E. Jiménez, Cisneros, France; Sandra Lavorel, France; Bai-Lian (Larry) Li, USA; William J. Mitsch, USA; Mihir Shah, India; and Peter Vitousek, USA. Over 750 presentations were given in 93 scientific sessions. There were also 15 side events in the form of workshops, round tables and world cafés. More than 600 posters were also displayed during EcoSummit 2016.

EcoSummit was founded in the mid-1990s as a forum to meet the demands of scientists working in several new ecological disciplines, and who required a better understanding of the concepts and methods for a holistic use of ecology in environmental management. EcoSummit 2016 was the fifth EcoSummit held around the world since the first one was held twenty years ago in 1996 in Copenhagen, Denmark. Other EcoSummits were then held in Halifax, Nova Scotia, Canada (EcoSummit 2000), Beijing, China (EcoSummit 2007), and Columbus, Ohio, USA (EcoSummit 2012; see http://ecosummit2016.org/ecosummit-2012.asphttp://ecosummit2016.org/ecosummit-2012.asp for a listing of journal special issues from that conference). See the history of previous ecosummits at http://ecosummit2016.org/ecosummit-history.asp

2.1. *EcoSummit 2016 special session on wetland restoration and biogeochemistry—engineering carbon balanced landscapes*

The papers in this special issue are partially based on 14 oral presentations in a special session at EcoSummit 2016 entitled "Wetland Restoration and Biogeochemistry—Engineering Carbon Balanced Landscapes" held on August 30, 2017 (Table 1). A photo of the speakers and participants in that special session is shown in Fig. 1. Other authors of papers not presented in that session or presented as posters in EcoSummit 2016 were also invited to submit to this special issue.

3. This special issue on wetlands and carbon

The 19 papers in this special issue are divided into the following categories: 1. estimating greenhouse gas fluxes with eddy covariance (3 papers); 2. methane and other greenhouse gas emissions from wetlands (8 papers); 3. carbon sequestration by wetlands (5 papers); and 4. organic carbon decomposition in wetlands (3 papers).

3.1. *Estimating greenhouse gas fluxes with eddy covariance*

Three papers of this thematic block are analyzing carbon balance of various wetland ecosystems using the EC technique which has been rapidly developed since 1990s (Baldocchi, 2014), Using combined EC and chamber techniques Rey-Sanchez et al. (2018) detected high rates of methane emission in Old Woman Creek, a coastal marsh of freshwater Lake Erie, Ohio, USA. CH_4 flux was mainly determined by water temperature and wind speed but was also related to respiration and photosynthesis. Different parts of wetlands showed different CH_4 flux rates, whereas mud flats had the highest and open water the lowest rates. Accounting for this heterogeneity improves the accuracy of CH_4 flux estimates.

Duman and Schäfer (2018) compared net ecosystem carbon exchange of native and invasive plant communities in an urban tidal wetland in the New Jersey Meadowlands (USA) in the New York City metropolitan area. Vegetation-based partitioning of fluxes was done using footprint model and light response curves. During restoration, the invasive wetland species *Phragmites australis* was replaced by the native *Spartina alterniflora*. The area with native species had an increased CO_2 uptake during summer days, but also higher CO_2 emissions during nights and winters. Higher emissions can be explained by the input of river water with high organic material content. At the restored site allochthonous carbon input from the river to the wetland was found to be higher. Conclusively, the *S. alterniflora* marsh was serving as a carbon source, releasing CO_2 to the atmosphere.

Morin et al. (2018) measured CO_2 emissions from an oligotrophic temperate lake in Northern Michigan (USA) by the EC method. They found that during two full growing seasons the lake was an overall net carbon source, but emitting significantly less CO_2 than nearby terrestrial ecosystems. The net carbon flux from the lake is primarily correlated with wind speed, indicating the key role of mixing in the upper water layer whereas respiration is more strongly depending on microbial indicators than on gross primary production (GPP). Horizontal advection between the lake and the observation point far from shore was significantly lower than EC-observed vertical turbulent fluxes.

Development and wider use of EC technique in measurement carbon balances in freshwater lakes (see Vesala et al., 2012) will possibly clarify freshwater ecosystem's role in global carbon cycle because most of publications present freshwater lakes like significant net sources of carbon (Bastviken et al., 2011; Kortelainen et al., 2011). The carbon balance in freshwater inland wetlands is even less known. Contributions in our special issue demonstrate elevated CO_2 and CH_4 emissions in freshwater wetlands (Duman and Schäfer, 2018; Rey-Sanchez et al., 2018). Similarly, a meta-analysis provided by Lu et al. (2017) on CO_2 balance of inland and coastal wetlands measured using EC method showed that inland wetlands were small CO_2 sinks or nearly CO_2 neutral, while coastal wetlands provided large CO_2 sinks.

3.2. *Methane and other greenhouse gas emissions from wetlands*

Eight papers in this special issue provide information on soil/sediment respiration and CH_4 emissions in peatlands of the Americas (Veber et al., 2018), cypress swamps (Pereyra and Mitsch, 2018) and coastal mangroves (Cabezas et al., 2018) in subtropical Florida, fens (Duval and Radu, 2018; Radu and Duval, 2018), treatment wetlands (Hernandez et al., 2018), wetland mesocosms (Schultz and Pett, 2018), and tidal freshwater marshes (RoyChowdhury et al., 2018).

Veber et al. (2018) analyzed relations among CO_2, CH_4 and nitrous oxide (N_2O) emissions and the physical and chemical conditions of the peat in following peatland ecosystems in a natural and managed transitional bog in Quebec, Canada, a natural páramo and grazed peatland in the Colombian Andes, and a bog and a fen in Tierra del Fuego, Argentina. The dark static chamber-based analyses of GHG emissions showed that (1) intensive peatland management increases emissions of all GHGs with the highest impact on N_2O-N emissions and ecosystem respiration; (2) nitrous oxide emissions were mostly controlled by Total Inorganic Nitrogen (TIN), C/N ratio, and soil temperature. Proposed mitigation measures include the regulation of grazing intensity and replacement of arable fields with grasslands.