Wetland hydrological dynamics and methane emissions

Shihao Cui[†], Pengfei Liu[‡], Haonan Guo[†], Claudia Kalla Nielsen[†], Johannes Wilhelmus Maria Pullens[†], Qing Chen[§], Lorenzo Pugliese[†], Shubiao Wu[†]*

[†] Department of Agroecology, Aarhus University, Blichers Allé 20, 8830 Tjele, Denmark
[‡] Center for The Pan-Third Pole Environment, Lanzhou University, Lanzhou 730000, China
[§] Beijing Key Laboratory of Farmland Soil Pollution Prevention and Remediation, College of Resources and Environmental Sciences, China Agricultural University, Beijing 100193, China
* Corresponding author (Email: wushubiao@agro.au.dk)

This Supplementary Information contains Supplementary Methods, 2 Supplementary Figures, and 2 Supplementary Tables (8 pages).

Supplementary Methods

Literature review

To gather information about the impact of hydrological fluctuations on methane cycle processes, this review utilized two fundamental literature databases, Web of Science and Google Scholar, to search for studies published from 1900-2023. The main database search terms used were “wetland”, “peatland”, “hydrological fluctuation”, “water table fluctuation”, “methane cycle”, “methane production”, “methane oxidation”, “methane transport”, “methane emission”, and “methane flux”. To ensure comprehensive coverage, we also searched using related terms such as “water level” and “change” to replace “water table” and “fluctuation”, respectively. Recognizing that wetlands were historically often drained for agricultural, grazing, and forestry purposes, resulting in hydrological fluctuations, we further integrated “water table/level drawdown” and “drainage” as search terms.

Data extraction

To representatively illustrate hydrological fluctuation phenomenon in wetlands, 31 wetland sites, including six bogs, seven fen sites, three swamp sites, seven marsh sites, three salt marsh sites, and five rice field sites, were selected from the database of “FLUXNET-CH_4 Community Product: CC-BY-4.0” (https://fluxnet.org/data/fluxnet-ch4-community-product/)[1-3]. FLUXNET data product is a publicly available database that uses eddy covariance for continuous monitoring of carbon, water, and energy cycling between the biosphere and atmosphere. These 31 wetland sites represent most of available data on the water table for these six typical wetland types within the FLUXNET database. Given that the use of water table data aims to provide readers with a visual understanding of water table fluctuations in wetlands, we consider these selected sites sufficient. Site information for 31 wetlands is shown in Table S1.

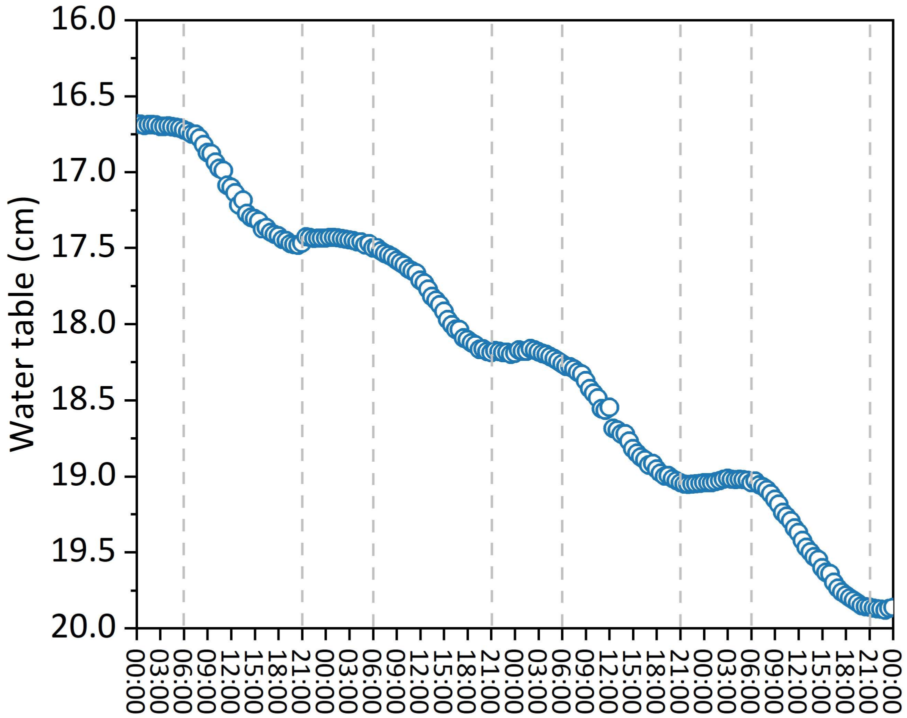
Figure and table captions

Supplementary Figure 1. Diurnal water table fluctuations from 3 June to 7 June 2016 in a bog (FLUXNET-ID: US-Uaf; Region: Alaska, USA). Note: positive values of the water table represent distance below the surface.

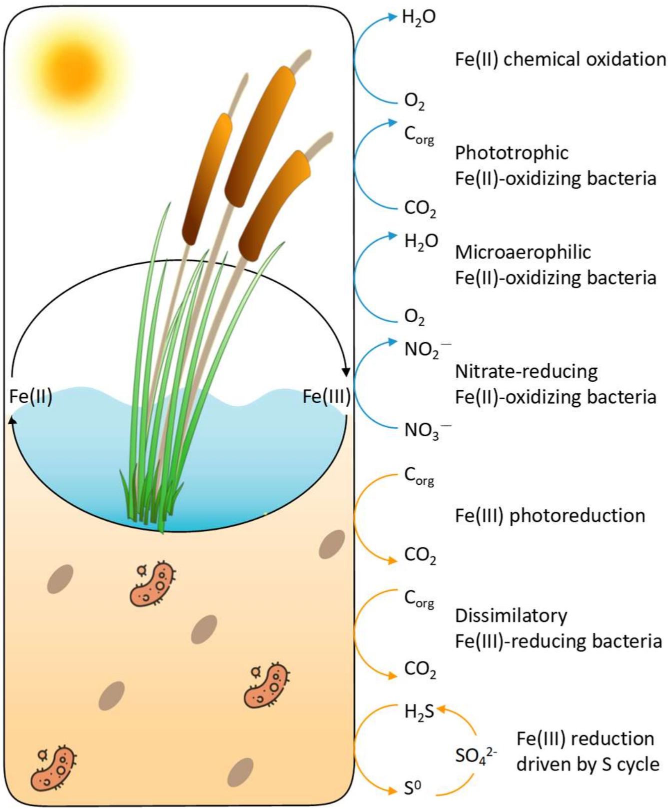
Supplementary Figure 2. Potential redox cycling pathways for iron in wetlands. Under anoxic conditions, Fe(III) can be reduced by dissimilatory Fe(III)-reducing bacteria or via abiotic processes such as the cryptic sulfur cycle or photoreduction. Under oxic conditions, Fe(II) can be chemically oxidized or biologically oxidized by aerobic bacteria, such as acidophilic or neutrophilic microaerophilic Fe(II)-oxidizing bacteria. Fe(II) can also be biologically oxidized by anaerobic bacteria, such as nitrate-reducing Fe(II)-oxidizing and photosynthetic Fe(II)-oxidizing bacteria.

Supplementary Table 1. Wetland site information (https://fluxnet.org/data/fluxnet-ch4-community-product/).

Supplementary Table 2. The redox potential (Eh) range for methane production in different soil samples [a].



Supplementary Figure 1. Diurnal water table fluctuations from 3 June to 7 June 2016 in a bog (FLUXNET-ID: US-Uaf; Region: Alaska, USA)[4]. Note: positive values of the water table represent distance below the ground surface.



Supplementary Figure 2. Potential redox cycling pathways for iron in wetlands. Under anoxic conditions, Fe(III) can be reduced by dissimilatory Fe(III)-reducing bacteria or via abiotic processes such as the cryptic sulfur cycle or photoreduction. Under oxic conditions, Fe(II) can be chemically oxidized or biologically oxidized by aerobic bacteria, such as acidophilic or neutrophilic microaerophilic Fe(II)-oxidizing bacteria. Fe(II) can also be biologically oxidized by anaerobic bacteria, such as nitrate-reducing Fe(II)-oxidizing and photosynthetic Fe(II)-oxidizing bacteria.

Supplementary Table 1. Wetland site information (https://fluxnet.org/data/fluxnet-ch4-community-product/).

Site ID	Site name	Country	Latitude	Longitude	Wetland type	Monitoring time	Dominant vegetation
CA-SCB	Scotty Creek Bog	Canada	61.3089	-121.2984	Bog	2014 – 2017	Moss_sphagnum
DE-Sfn	Schechenfilz Nord	Germany	47.80639	11.3275	Bog	2012 – 2014	Tree
FI-Si2	Siikaneva-2 Bog	Finland	61.8372	24.1967	Bog	2012 – 2016	Moss_sphagnum
JP-BBY	Bibai bog	Japan	43.32300556	141.8106972	Bog	2016 – 2018	Aerenchymatous
NZ-Kop	Kopuatai	New Zealand	-37.3879	175.5539	Bog	2012 – 2015	Aerenchymatous
US-Uaf	University of Alaska, Fairbanks	USA	64.86627	-147.85553	Bog	2011 – 2018	Moss_sphagnum
DE-Hte	Hütelmoor	Germany	54.210278	12.176111	Fen	2014 – 2018	Aerenchymatous
DE-Zrk	Zarnekow	Germany	53.87594	12.88901	Fen	2016 – 2018	Aerenchymatous
FI-Lom	Lompolojankka	Finland	67.99724	24.20918	Fen	2006 – 2010	Aerenchymatous
FI-Sii	Siikaneva	Finland	61.83265	24.19285	Fen	2016 – 2018	Moss_sphagnum
FR-LGt	La Guette	France	47.322917	2.284102	Fen	2017 – 2018	Aerenchymatous
SE-Deg	Degerö	Sweden	64.182029	19.556539	Fen	2014 – 2016	Moss_sphagnum
US-Los	Lost Creek	USA	46.0827	-89.9792	Fen	2014 – 2018	Eri_shrub
BR-Npw	Northern Pantanal Wetland	Brazil	-16.498	-56.412	Swamp	2013 – 2016	Tree
ID-Pag	Palangkaraya undrained forest	Indonesia	-2.32	113.9	Swamp	2016 – 2017	Tree

MY-MLM	Maludam National Park	Malaysia	1.453575	111.149492`	Swamp	2014 – 2015	Tree
US-Myb	Mayberry Wetland	USA	38.049861	-121.76498	Marsh	2010 – 2018	Aerenchymatous
US-OWC	Old Woman Creek	USA	41.37951667	-82.5124667	Marsh	2015 – 2016	Aerenchymatous
US-Sne	Sherman Island Restored Wetland	USA	38.0369	-121.7547	Marsh	2016 – 2018	Aerenchymatous
US-Tw1	Twitchell Wetland West Pond	USA	38.1074	-121.6469	Marsh	2011 – 2018	Aerenchymatous
US-Tw4	Twitchell East End Wetland	USA	38.10274361	-121.6413286	Marsh	2013 – 2018	Aerenchymatous
US-Tw5	East Pond Wetland	USA	38.107192	-121.642576	Marsh	2018 – 2018	Aerenchymatous
US-WPT	Winous Point North Marsh	USA	41.464639	-82.996157	Marsh	2011 – 2013	Aerenchymatous
US-EDN	Eden Landing Ecological Reserve	USA	37.61562	-122.114	Salt marsh	2018 – 2018	Aerenchymatous
US-Srr	Suisun marsh - Rush Ranch	USA	38.200556	-122.026358	Salt marsh	2014 – 2017	Aerenchymatous
US-StJ	St Jones Reserve	USA	39.08821106	-75.43722534	Salt marsh	2016 – 2016	Aerenchymatous
JP-Mse	Mase rice paddy field	Japan	36.05393	140.02693	Rice	2012 – 2012	Aerenchymatous
KR-CRK	Cheorwon Rice paddy	Korea	38.2013	127.2506	Rice	2015 – 2018	Aerenchymatous
US-HRA	Humnoke Farm Rice Field – Field A	USA	34.585208	-91.751735	Rice	2017 – 2017	Aerenchymatous
US-HRC	Humnoke Farm Rice Field – Field C	USA	34.58883	-91.751658	Rice	2017 – 2017	Aerenchymatous
US-Twt	Twitchell Island	USA	38.1087204	-121.6531	Rice	2009 – 2017	Aerenchymatous

Supplementary Table 2. The redox potential (Eh) range for methane production in different soil samples [a].

Soils	Regions	Eh (mV)	References
Fen soil	Poland	+240 ~ +112	(Szafranek-Nakonieczna & Stępniewska, 2015)[5]
Black ash wetland soil	USA	< 100	(Toczydlowski et al., 2020)[6]
Forested wetland soil	USA	–100 ~ +100	(Minick et al., 2019)[7]
Wetland soil	Costa Rica	–147	(Nahlik & Mitsch, 2011)[8]
Wetland soil	Germany	–75	(Fiedler & Sommer, 2000)[9]
Wetland soil	Taiwan	+190	(Chang & Yang, 2003)[10]
Wetland soil	Denmark	–90	(Grünfeld & Brix, 1999)[11]
Mangrove soil	Tanzania	–150 ~ –300	(Lyimo et al., 2002)[12]
Rice soil	USA	+300	(Yu & Patrick, 2003)[13]
Rice soil	Japan	–150	(Minamikawa & Sakai, 2005)[14]
Rice soil	USA; China; Indonesia	+400	(Yu et al., 2007)[15]

[a] This table was modified from Szafranek-Nakonieczna & Stępniewska, (2015)[5].

Supplementary References

1 Knox, S. H. *et al.* FLUXNET-CH 4 synthesis activity: Objectives, observations, and future directions. *Bulletin of the American Meteorological Society* **100**, 2607-2632 (2019).

2 Delwiche, K. B. *et al.* FLUXNET-CH 4: a global, multi-ecosystem dataset and analysis of methane seasonality from freshwater wetlands. *Earth System Science Data* **13**, 3607-3689 (2021).

3 Pastorello, G. *et al.* The FLUXNET2015 dataset and the ONEFlux processing pipeline for eddy covariance data. *Scientific Data* **7**, 1-27 (2020).

4 Shihao, C. Wetland hydrological dynamics and methane emissions. Dataset. https://doi.org/10.6084/m9.figshare.26359939.v3 (2024).

5 Szafranek-Nakonieczna, A. & Stępniewska, Z. The influence of the aeration status (ODR, Eh) of peat soils on their ability to produce methane. *Wetlands Ecology and Management* **23**, 665-676 (2015).

6 Toczydlowski, A. J. Z., Slesak, R. A., Kolka, R. K. & Venterea, R. T. Temperature and water-level effects on greenhouse gas fluxes from black ash (Fraxinus nigra) wetland soils in the Upper Great Lakes region, USA. *Applied Soil Ecology* **153**, 103565 (2020).

7 Minick, K. J., Mitra, B., Noormets, A. & King, J. S. Saltwater reduces potential CO2 and CH4 production in peat soils from a coastal freshwater forested wetland. *Biogeosciences* **16**, 4671-4686 (2019).

8 Nahlik, A. M. & Mitsch, W. J. Methane emissions from tropical freshwater wetlands located in different climatic zones of Costa Rica. *Global Change Biology* **17**, 1321-1334 (2011).

9 Fiedler, S. & Sommer, M. Methane emissions, groundwater levels and redox potentials of common wetland soils in a temperate‐humid climate. *Global Biogeochemical Cycles* **14**, 1081-1093 (2000).

10 Chang, T.-C. & Yang, S.-S. Methane emission from wetlands in Taiwan. *Atmospheric Environment* **37**, 4551-4558 (2003).

11 Grünfeld, S. & Brix, H. Methanogenesis and methane emissions: effects of water table, substrate type and presence of Phragmites australis. *Aquatic Botany* **64**, 63-75 (1999).

12 Lyimo, T. J., Pol, A. & Op den Camp, H. J. M. Methane emission, sulphide concentration and redox potential profiles in Mtoni mangrove sediment, Tanzania. *Western Indian Ocean J. Marine Science*, 1 (1), p. 71-80 (2002).

13 Yu, K. & Patrick, W. H. Redox range with minimum nitrous oxide and methane production in a rice soil under different pH. *Soil Science Society of America Journal* **67**, 1952-1958 (2003).

14 Minamikawa, K. & Sakai, N. The effect of water management based on soil redox potential on methane emission from two kinds of paddy soils in Japan. *Agriculture, Ecosystems & Environment* **107**, 397-407 (2005).

15 Yu, K., Böhme, F., Rinklebe, J., Neue, H.-U. & DeLaune, R. D. Major Biogeochemical Processes in Soils‐A Microcosm Incubation from Reducing to Oxidizing Conditions. *Soil Science Society of America Journal* **71**, 1406-1417 (2007).