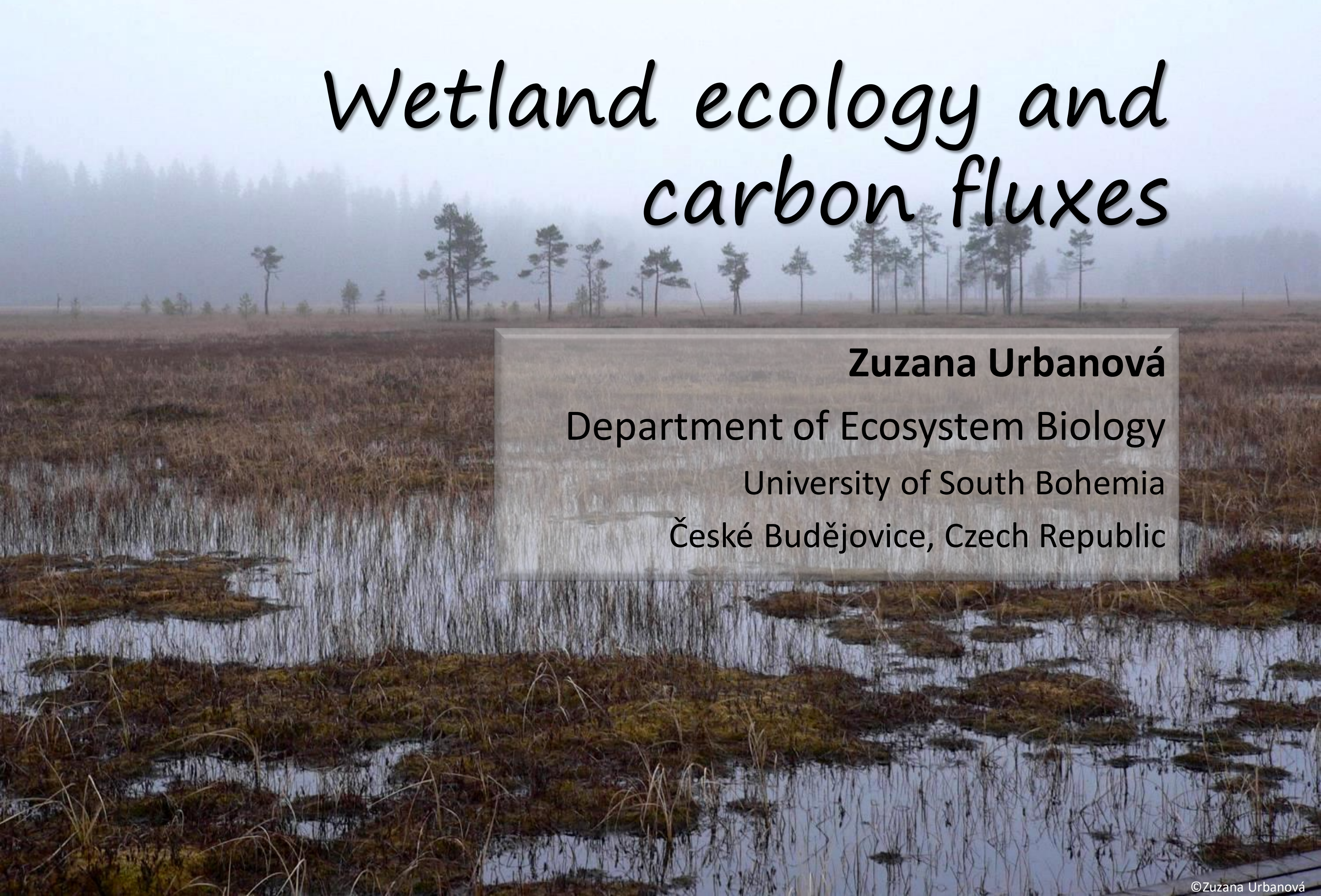
Přírodovědecká fakulta
Faculty of Science

Jihočeská univerzita v Českých Budějovicích
University of South Bohemia in České Budějovice

Wetland ecology and carbon fluxes



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Outline

1. Introduction to wetland ecology
2. Carbon cycling in wetlands
3. Wetlands as a source of methane
4. Wetlands and climate

Attributes of wetlands:

Photo: Zuzana Urbanová

Peatlands

Photo: Zuzana Urbanová

Salt marsh

https://www.britannica.com/science/wetla

Rice fields

Photo by Nigel Goodman, https://blogs.reading.ac.uk/cwac/2015/01/16/phd-research-abroad-birds-in-rice-fields-of-the-philippines

Wet meadows

Photo: Jan Vymazal

River deltas and floodplains

home_new / GREECE / ALEXANDROUPOLIS / EVROS RIVER DELTA

Swamp

http://www.cyklo-jizni-morava.cz/mokrad-zumpy-u-drnovic

Constructed wetlands

http://www.korenova-cisticka.cz/o-korenovkach/financovani/Korenova-cisticka%E2%80%93korenova-cistirna%E2%80%93naklady.html

Mangroves

http://followgreenliving.com/mangroves-mans-best-friend-rtr/

Attributes of wetlands:

1. permanently or seasonally waterlogged or flooded
2. hydrotropic vegetation
3. substrate saturated with water

Ramsar Convention definition:

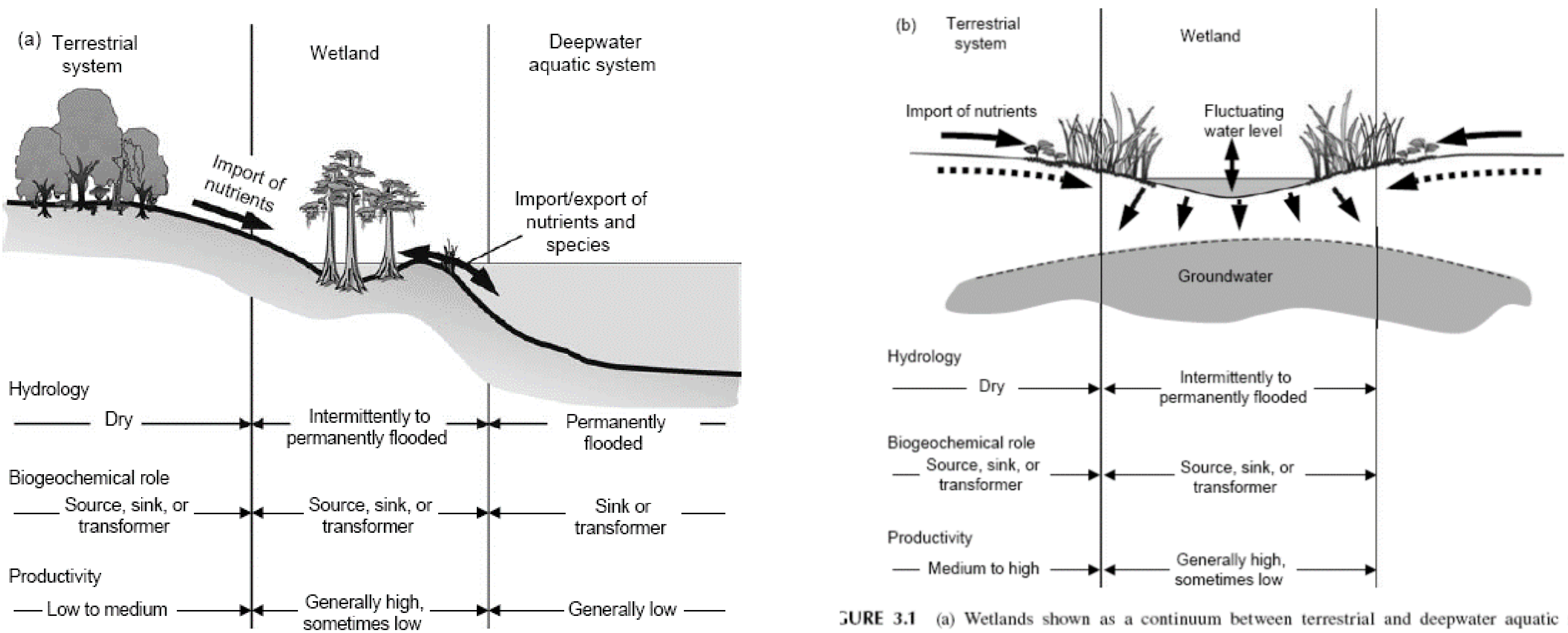
"...wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres."

Photo: Zuzana Urbanová

Hydrology

the most important driver of wetland functioning

- source of water (salt, freshwater; oligotrophic – eutrophic)
- water regime (period of flooding)
- water quality, oxygen concentration….

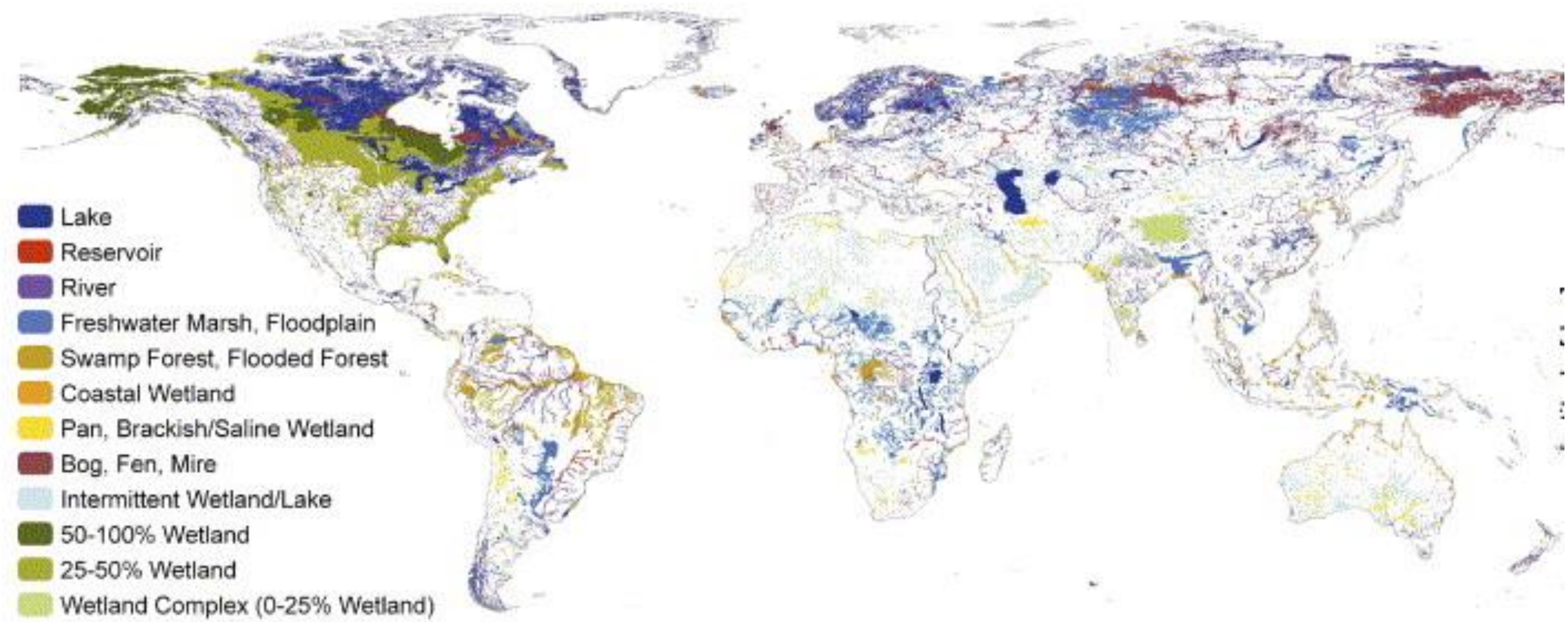


GURE 3.1 (a) Wetlands shown as a continuum between terrestrial and deepwater aquatic systems. Wetlands can exist as isolated from other water bodies. (From Mitsch and Gosselink, 2000. With mission.)

Wetlands as a continuum between terrestrial and aquatic systems – fluxes of energy and materials

Mitch and Gosselink . Wetlands. 2000. DOI: 10.1002/rrr.637

Distribution of wetlands



6% of the Earth surface

Lehner and Doll, 2004. doi: http://dx.doi.org/10.1016/j.jhydrol.2004.03.028

What is the use of wetlands?

http://img.radio.cz/KhNJtRoaIOyyLll3kDQlg5roLvE=/fitin/1200x1200/1216279773__pictures/r/grafik/blato_louze.jpg

Ecological functions of wetlands

- the most biologically productive and biologically diverse ecosystem

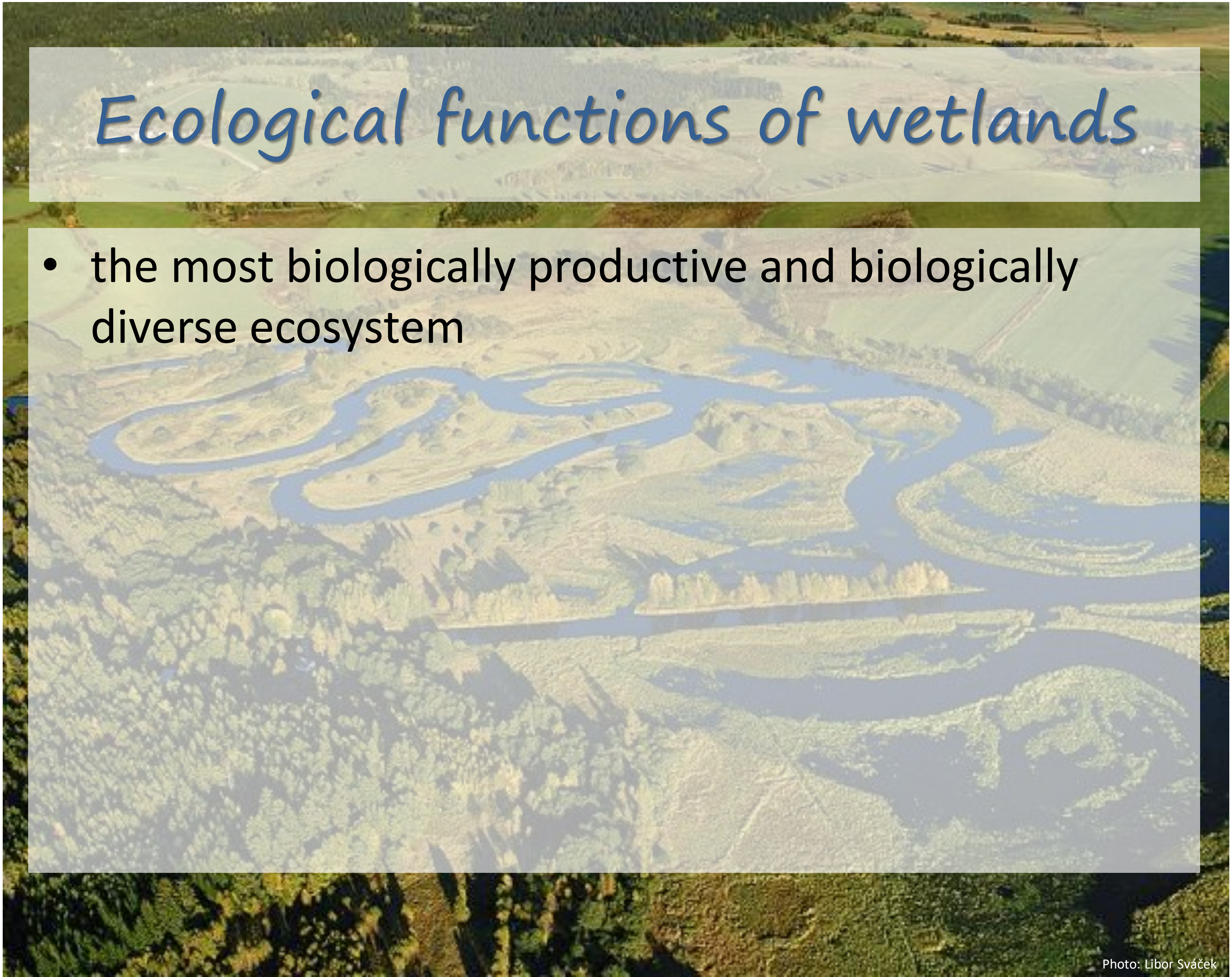


Photo: Libor Sváček

Table 1.7 Net primary production of vegetation in different ecosystems (Compiled from Houghton & Skole, 1990; Schlesinger, 1997; Larcher, 2003)

Ecosystems	NPP (Mg ha^{-1} year^{-1}) (range)	NPP (Mg ha^{-1} year^{-1}) (mean)	Phytomass (Mg C ha^{-1}) (mean)	Carbon in vegetation (Pg C)	Area (million square kilometres)
Rock and ice	0–0.1	0.03	–	–	15.2
Tundra (mean of different types)	0.1–4	1.4	8	9.0	11.0
Boreal forests	2.0–15	8	95	143.0	15.0
Temperate forests	4–25	12	80	73.3	9.2
Temperate grassland (mean of different types)	2–15	6	30	43.8	15.1
Tropical rain forests	10–35	22	150	156.0	10.4
Tropical dry forests	16–25	18	65	49.7	7.7
(Sub)tropical wood-land and savanna	2–25	9	20	48.8	24.6
Deserts and semideserts	0.1–3	0.9	3	5.9	18.2
Cropland	1–40	6.5	14	21.5	15.9
Wetlands	10–60	30	27	7.8	2.9
Inland waters	1–15	4			2.0
Total				558.8	147.2

R. Nieder and D.K. Benbi Carbon and Nitrogen in the Terrestrial Environment. DOI 10.1007/978-1-4020-8433-1

Ecological functions of wetlands

- the most biologically productive and biologically diverse ecosystem
- effect on water quality (living filters)
- element cycling (accumulation, transformation and transport)
- effect on climate (local and global)
- flood control
- shoreline stability
- host many species of plants and animals

Photo: Libor Sváček

Wetland use by human

- agriculture (rice paddies, floodplains)
- fishing
- hunting (waterfowls)
- water use for drinking or irrigation
- source of peat (burning, horticulture)
- wood (timber) and biomass production
- water purification (constructed wetlands)
- recreation

Wetland soils

©M. Dworschak, Gd NRW, https://www.dbges.de/en/working-groups/soil-systematics

http://wwwuser.gwdg.de/~kuzyakov/soils/WRB-2006_Keys.htm

Wetland soils

Mineral wetland soils

- part or the whole soil profile is saturated for a sufficient period of time to create distinctive gley horizons
- sandy, loamy, or clay
- Increase in organic matter accumulation in surface horizon
- Mottled zone (gley horizon) where iron and manganese accumulate
- Permanently reduced zone (gray color or bluish-green color)

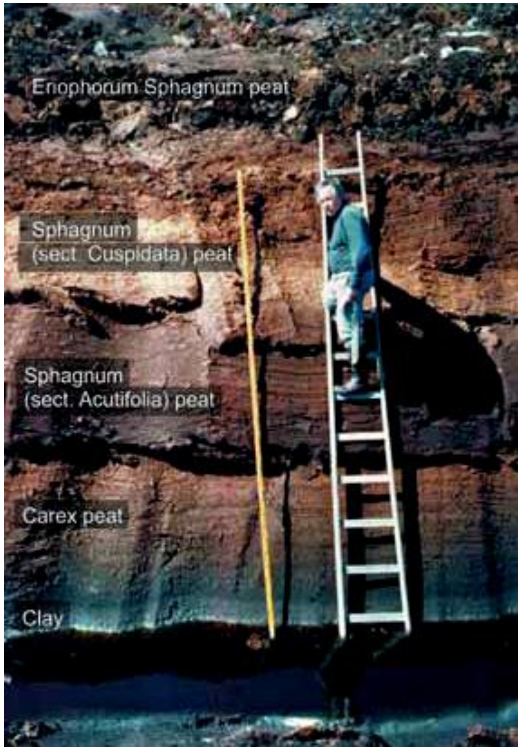
Wetland soils

http://broome.soil.ncsu.edu/student_projects_2014/fall_2003/whiteoakcreek/gley.html

Wetland soils

Organic wetland soils (Histosols)

- contain more than 12 % of total C in the upper 1 m layer
- peat (peatlands)



http://geo.msu.edu/extra/soilprofiles/histosols.htm

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Carbon in wetlands

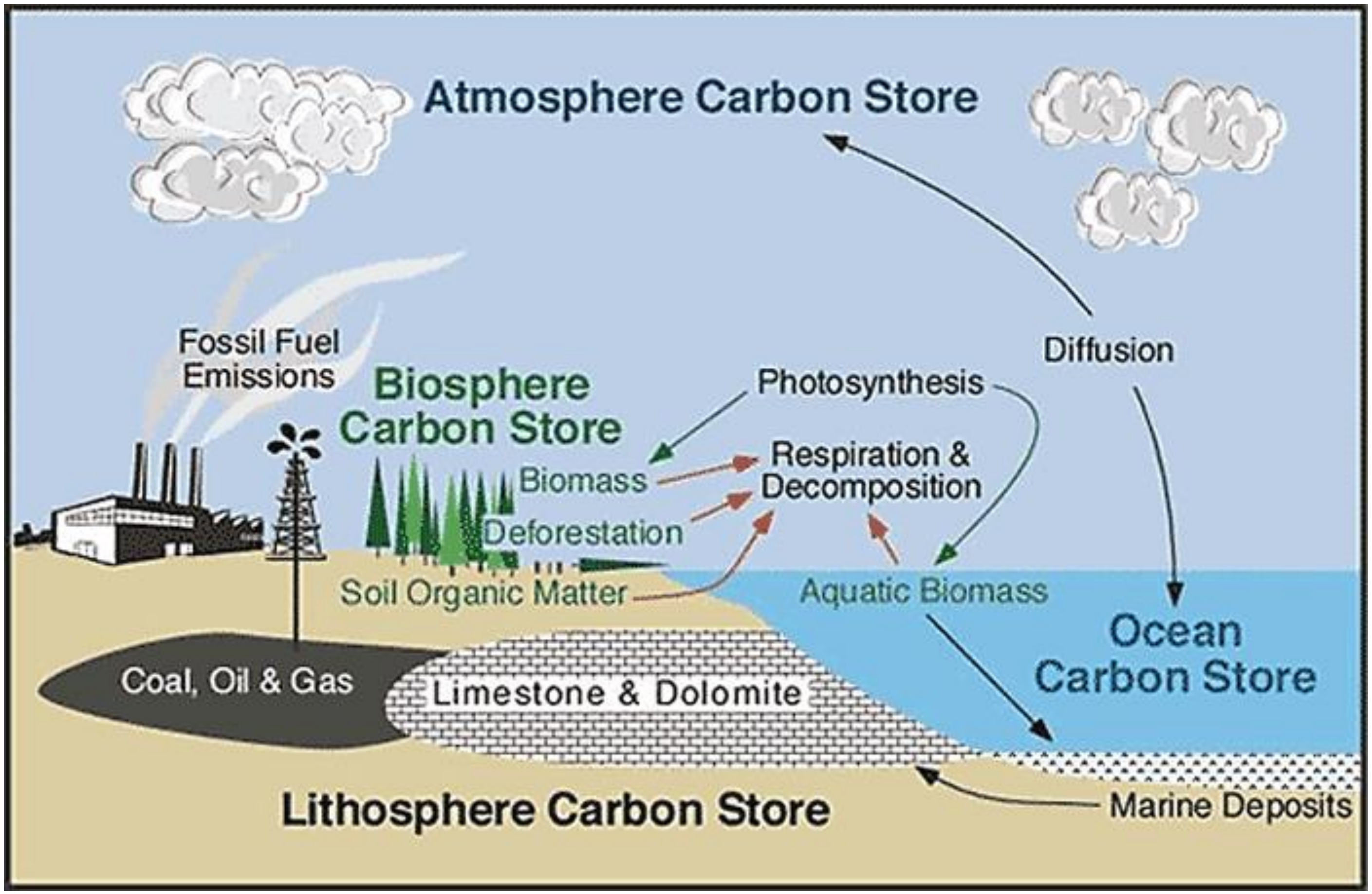
- C – basic element of life forms
- Organic x inorganic reservoirs of C

  continuous interactions and exchange ⇨ feedbacks

- Photosynthesis x respiration
- $6CO_2 + 6H_2O = C_6H_{12}O_6 + 6O_2$ (Photosynthesis)
- $C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O$ (Respiration [Aerobic])

http://www.nottingham.ac.uk/etc/guide-carboncycle.php

Carbon in wetlands



Major reservoirs of C

Reservoir of C		Total C amount (Pg)
Atmosphere	CO_2 - 732	735
	CH_4 - 3	
	CO - 0,2	
Hydrosphere		38 000
Sediments		>10 000 000
Fossil fuels		5000 / 10 000
Biosphere		600
Soils	**Wetland soils 450-700**	2100-2500

Peatlands **250 – 400 Pg**

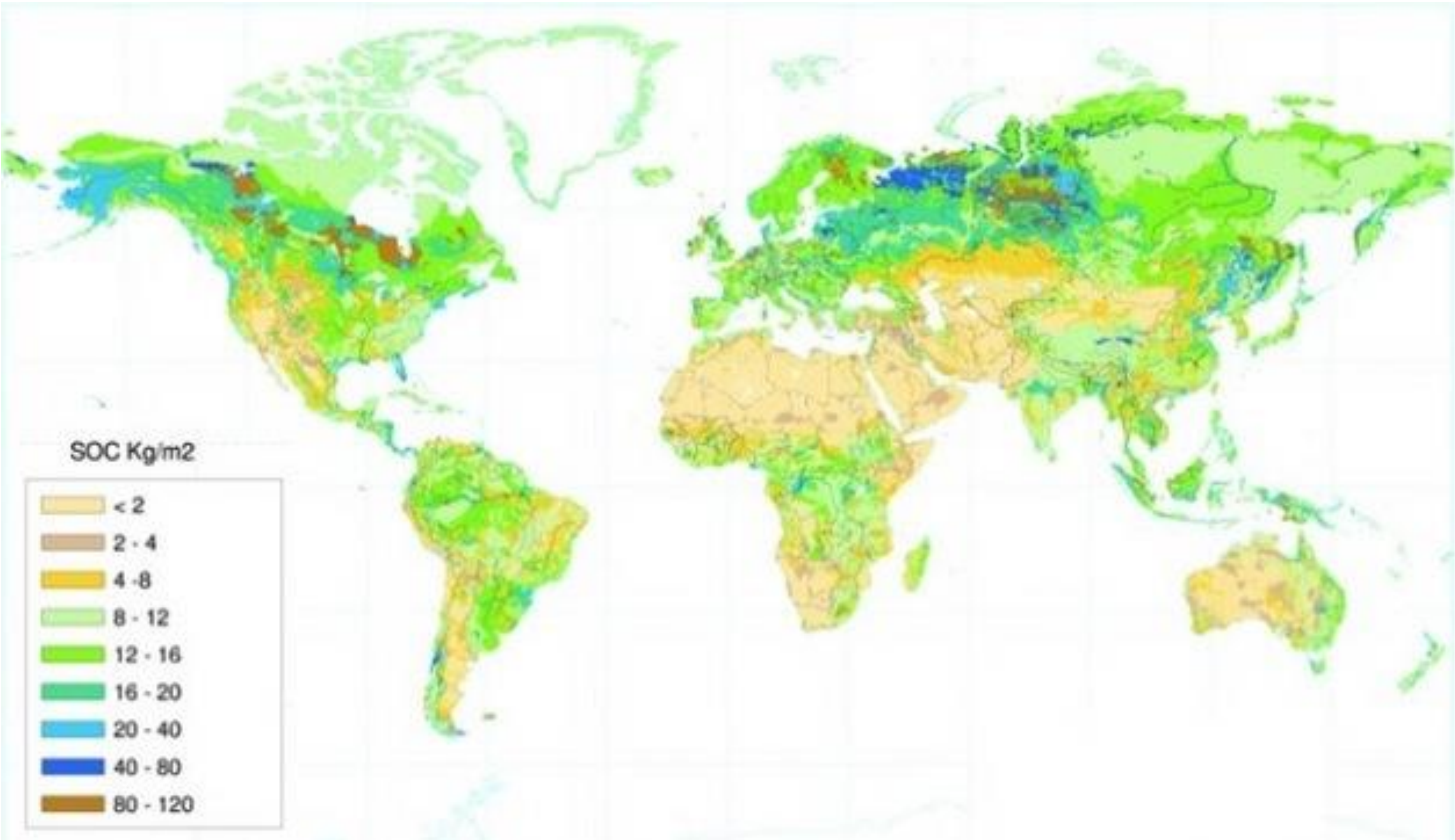
It is equals 30-50% of C in the atmosphere

They cover only 3% of the Earth surface

Pg – 10^{15}g

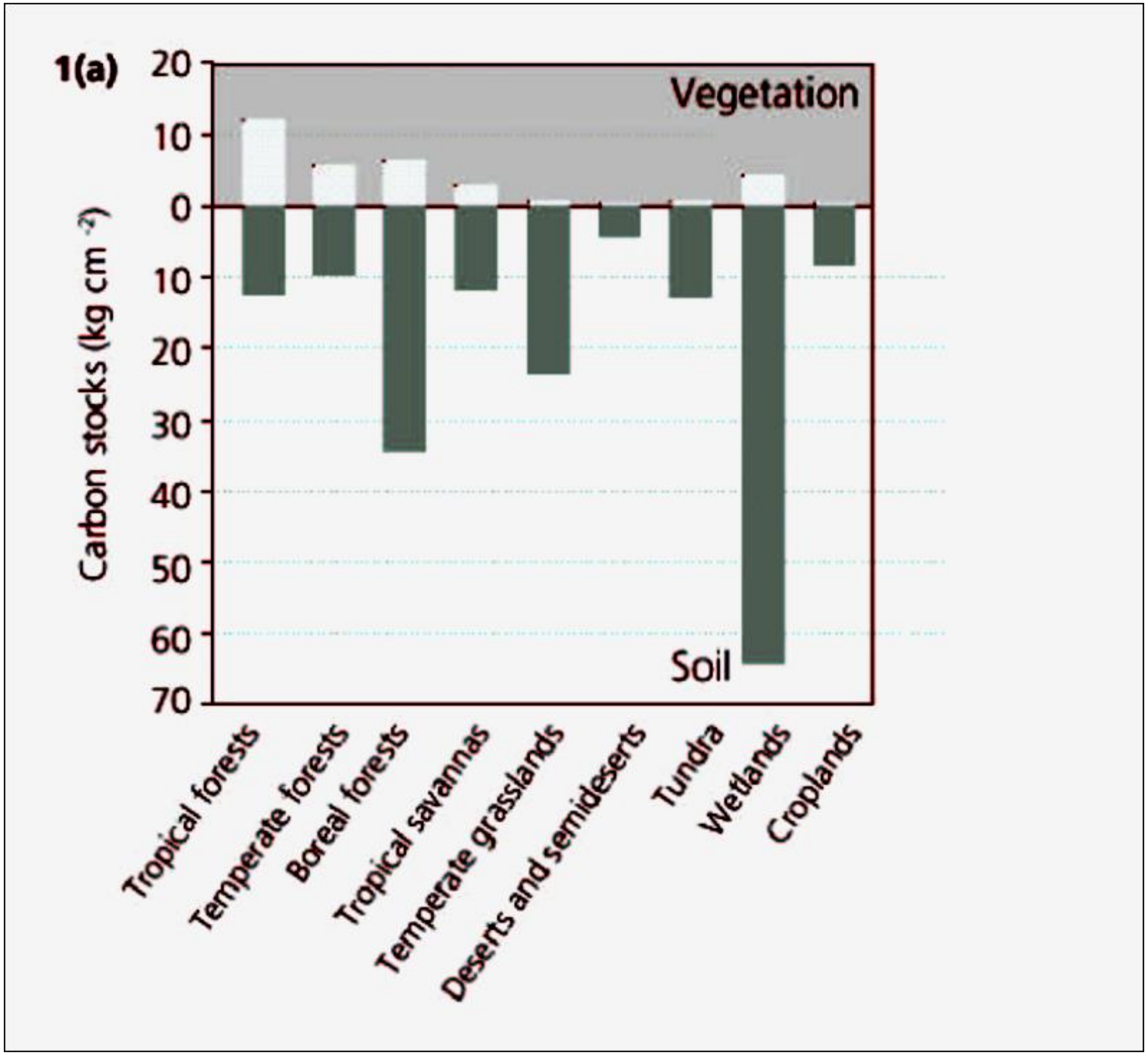
Mitsch a Gosselnik 2000, Brady 2002, Bolin et al. 1979, Gorham 1991

World map showing the quantity of soil organic carbon (SOC) to 1 m depth.

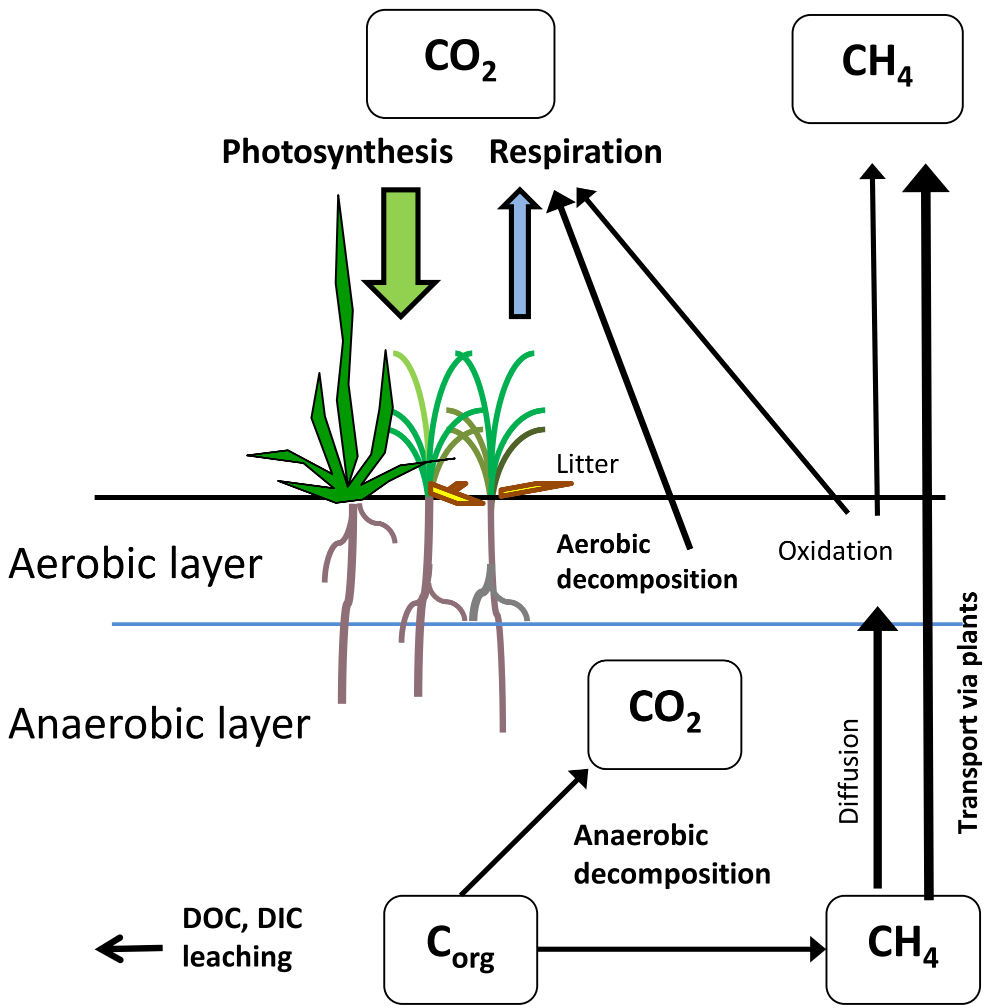


http://www.nature.com/scitable/knowledge/library/soil-carbon-storage-84223790

Wetland carbon storage potential compared to other ecosystems



Carbon cycling in wetlands

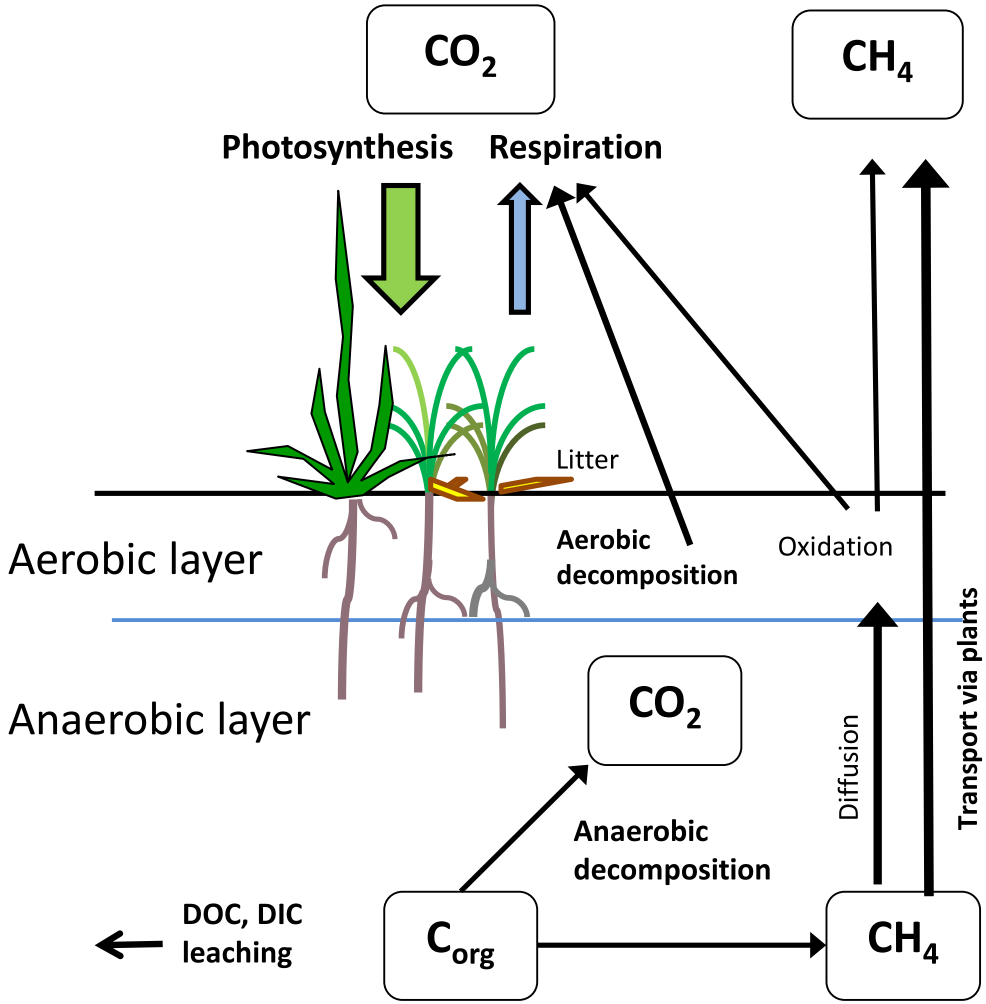


Carbon income
- photosynthesis

Carbon losses
- autotrophic respiration
- heterotrophic respiration
- leaching

Carbon accumulates when income exceeds carbon losses

Carbon cycling in wetlands



NET PRIMARY PRODUCTION

NPP = GPP – R_{plant} [g m^{-2} $year^{-1}$]

GPP ... Gross primary production (Photosynthesis)

R_{plant} ... Plant respiration

NET ECOSYSTEM EXCHANGE

NEE = GPP – Re [g m^{-2} $year^{-1}$]

GPP ... gross primary productivity (photosynthesis)

Re ... ecosystem respiration (respiration of plants, animals,and soil microbes)

NET ECOSYSTEM PRODUCTIVITY

NEP = GPP – Re +/- $F_{lateral}$ [g m^{-2} $year^{-1}$]

$F_{lateral}$ .... lateral fluxes of carbon into and out of ecosystem

⇨ **ECOSYSTEM CARBON BALANCE**

Wetlands as a C sinks

- **C accumulates in wetlands because of slower decomposition** (NPP > Re)
- decomposition rate controlled by:

hydrological regime

content of O_2

temperature

quality and quantity of org. material (plant species)

microbial activity

pH, nutrient content, water quality, …

➡ **Carbon accumulation varies between wetland types and in time**

Wetland organic soil - peat

Upland soil - cambisol

http://www.wikiwand.com/nl/Cambisol

Carbon accumulation rate

Long-Term Accumulation of Organic Matter in Selected Wetlands

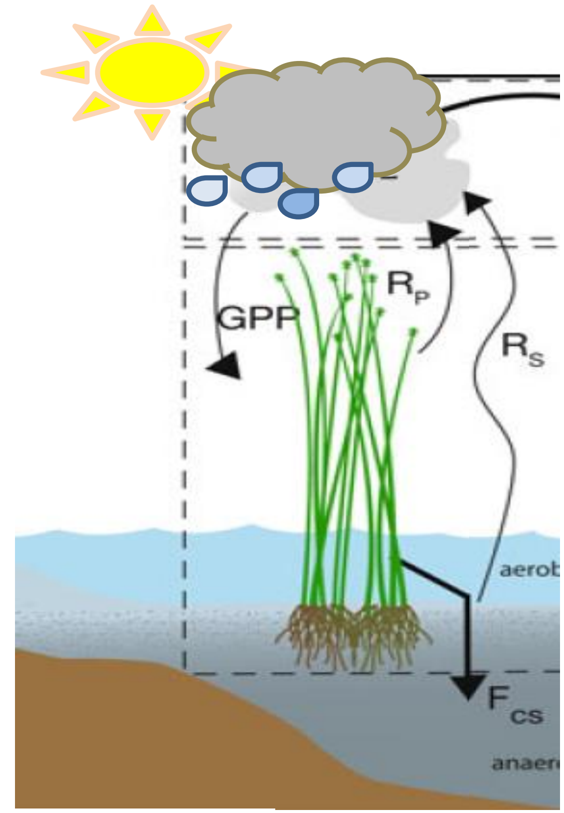
Wetland	Locations	Carbon Accumulation ($g\,m^{-2}\,year^{-1}$)	Reference
Peatland	Alaska	22–122	Billings (1987)
Everglades	Florida		
Typha sp.		163–387	Reddy et al. (1993)
Cladium sp.		86–140	
Salt marsh	Louisiana	200–300	Hatton et al. (1983)
Coastal marsh		50–500	Rabenhorst (1995)
Sphagnum	Wisconsin	34–75	Krazt and Dewitt (1986)
Taxodium	Georgia	45	Cohen (1974)
Bogs	Sweden	20–30	Armentano and Menges (1986)
Mangroves	Mexico	100	Twilley (1992)

Mitch and Gosselink . Wetlands. 2000. DOI: 10.1002/rrr.637

Variability of Carbon fluxes

Both photosynthesis (GPP)and ecosystem respiration (Re) are controlled by many factors, which are changing in time:

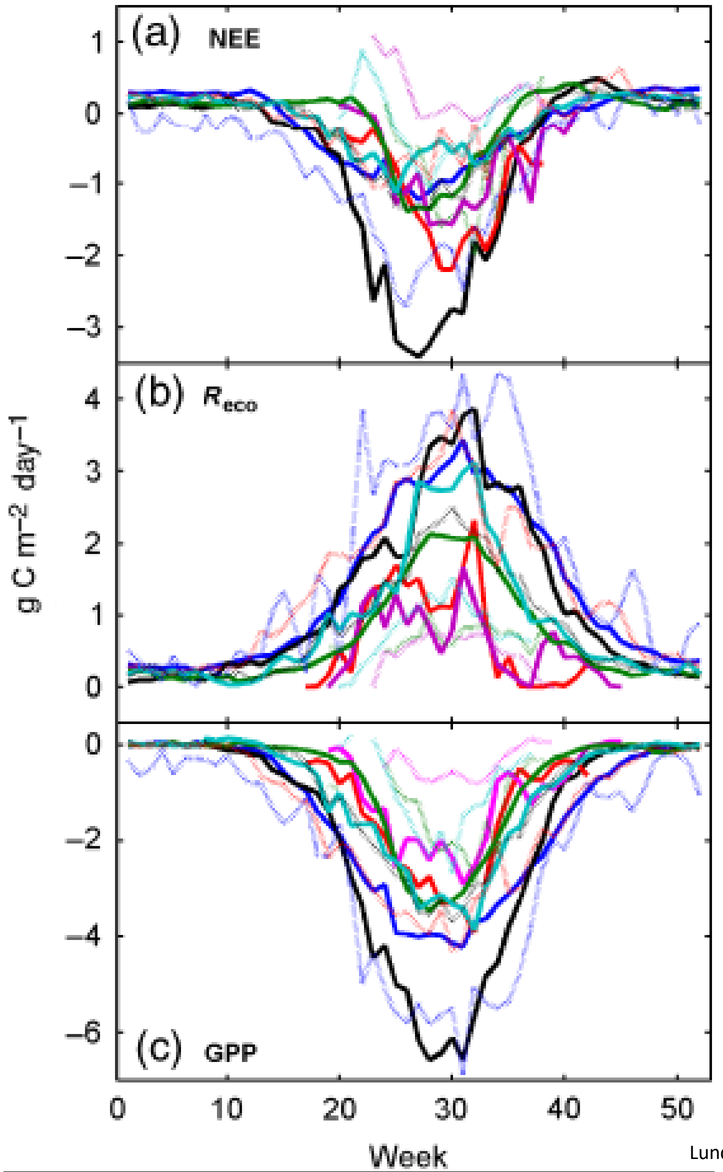
- **Climate** (radiation, temperature, precipitation)
- **Plant species composition** (quality and quantity of org. matter, VGA, root exudates, …)
- **Hydrology**



Interactions

Variability of Carbon fluxes

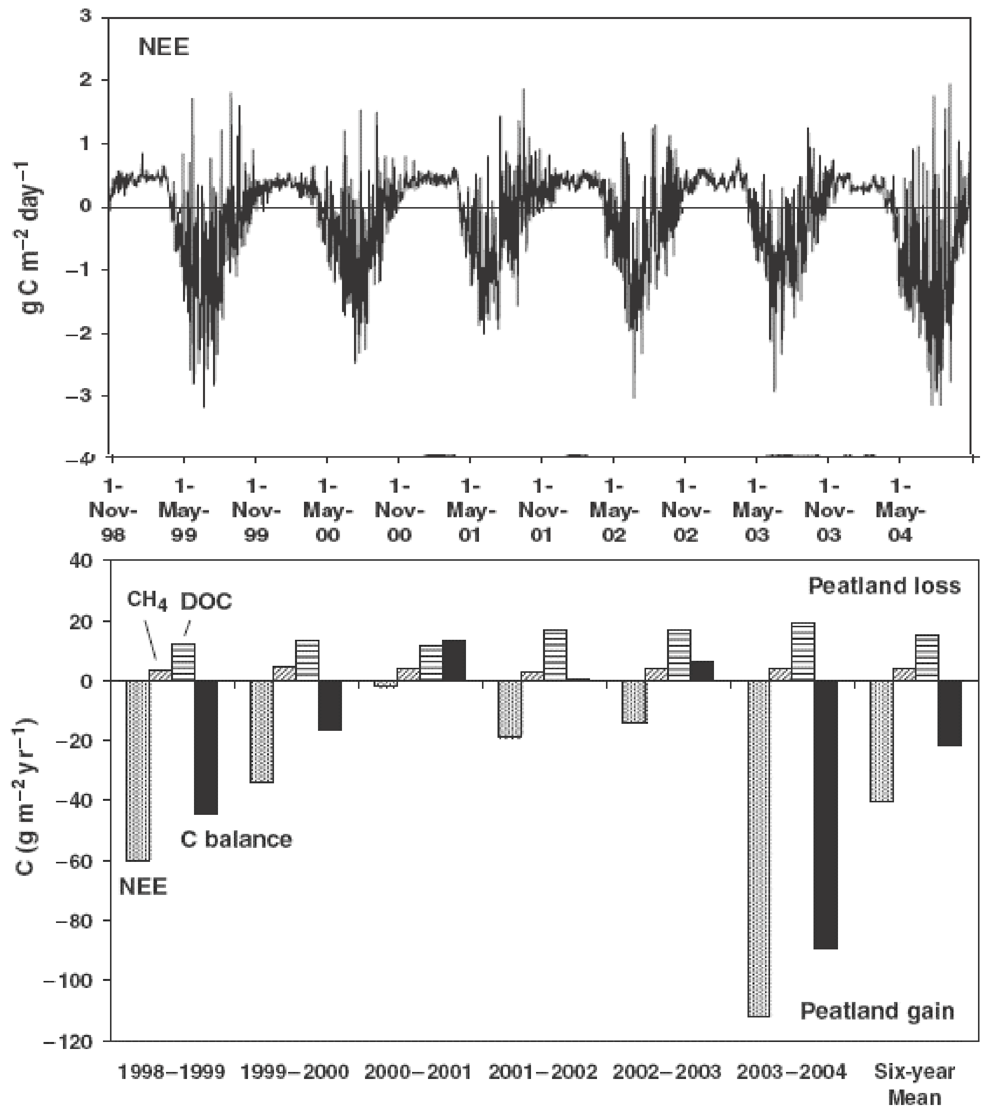
- Carbon fluxes during year



Lund et al. 2010 doi:10.1111/j.1365-2486.2009.02104.x

Variability of Carbon fluxes

- Carbon fluxes vary between years



Roulet et al. 2007 DOI: 10.1111/j.1365-2486.2006.01292.x

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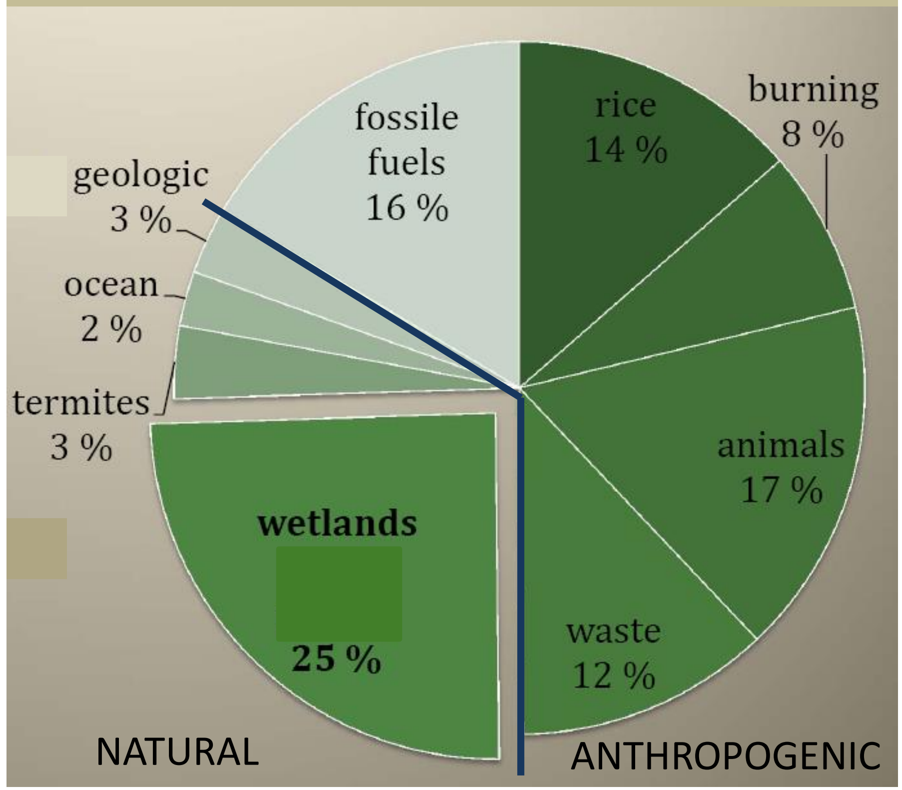
Wetlands as a CH_4 source

- Wetlands are one of the largest natural source of CH_4 to the atmosphere
- CH_4 – 25 times stronger global warming potential than CO_2

- Wetlands have dual impact on climate:

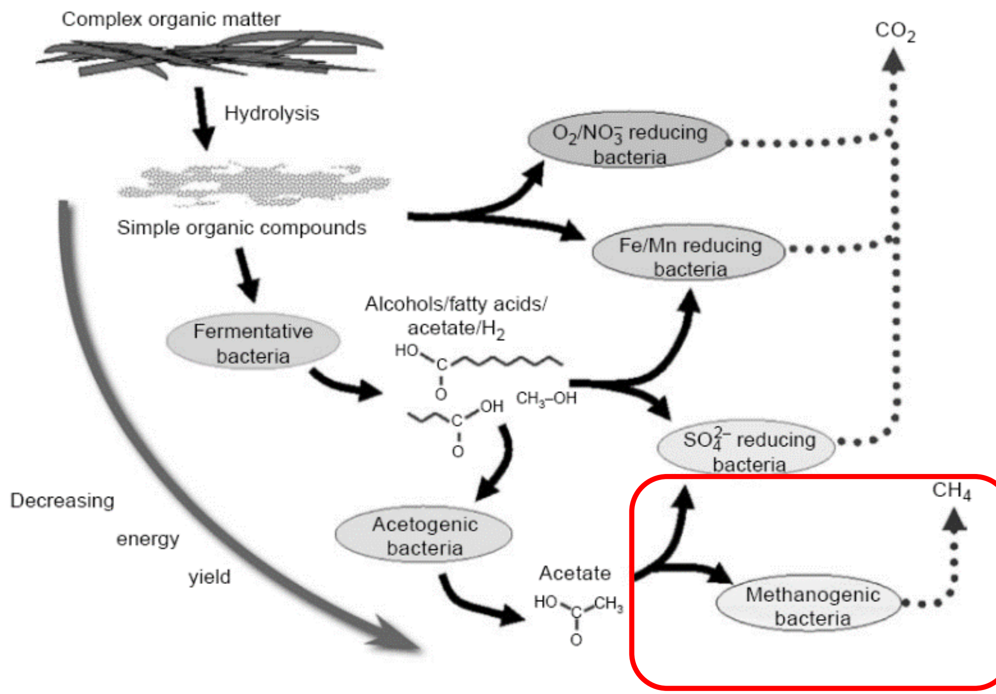
sink of CO_2 x source of CH_4

Natural and anthropogenic sources of CH_4 in the Atmosphere



Wetlands as a CH_4 source

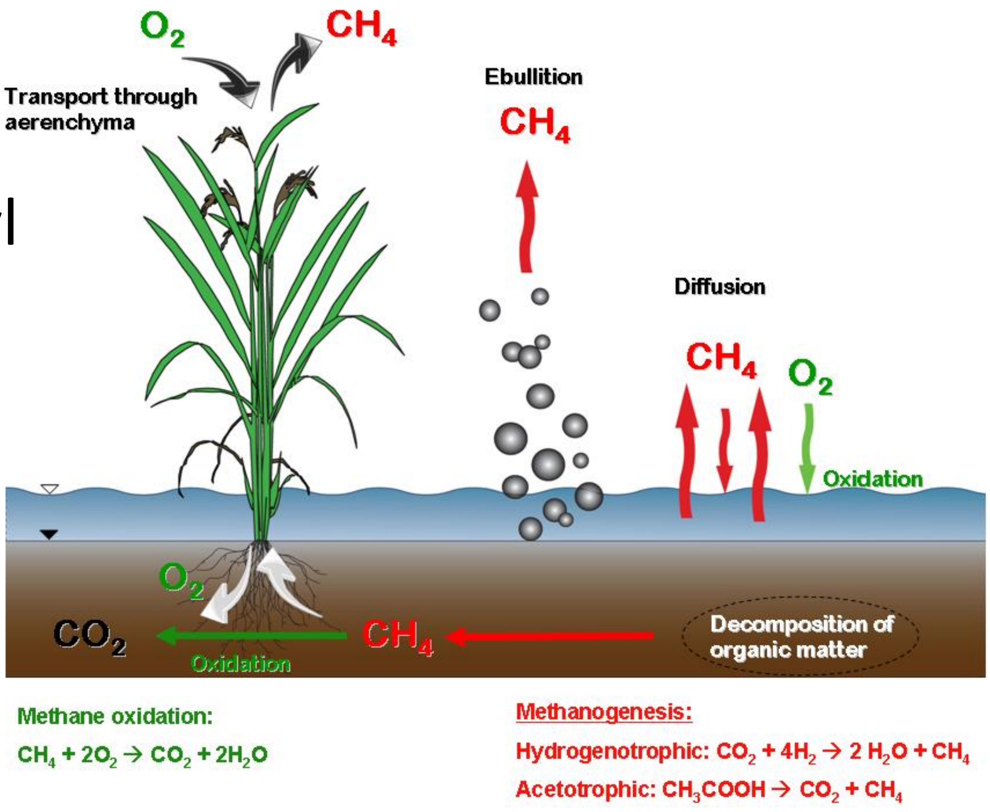
Methane – end product of anaerobic decomposition under the most reduced condition, when other electron acceptors are depleted (O_2, NO_3^-, Fe, Mn, SO_4^{2-})



Mitch and Gosselink . Wetlands. 2000. DOI: 10.1002/rrr.637

Wetlands as a CH_4 source

- CH_4 produced by methanogenic Archaea
- Substrate utilization: acetate, $CO_2 + H_2$, methyl compounds
- Transport to the atmopshere: via plants (aerenchym), diffusion, ebullition
- Methane oxidation – aerobic methanotrophic bacteria

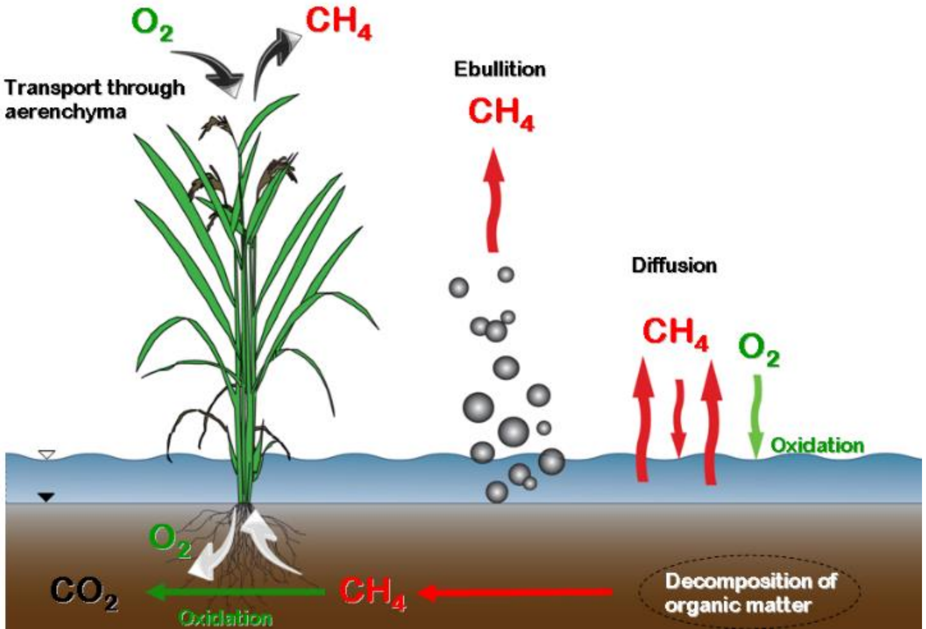


https://dl.sciencesocieties.org/publications/sh/articles/53/4/12

Wetlands as a CH_4 source

Factors influencing CH_4 production and emissions:

- Hydrology (aerobic/anaerobic conditions)
- Trophic status (nutrients, pH, substrate availability, ..)
- Plant species composition (aerenchym, quality of org. matter, exudates, ..)
- Temperature



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Wetlands as a CH_4 source

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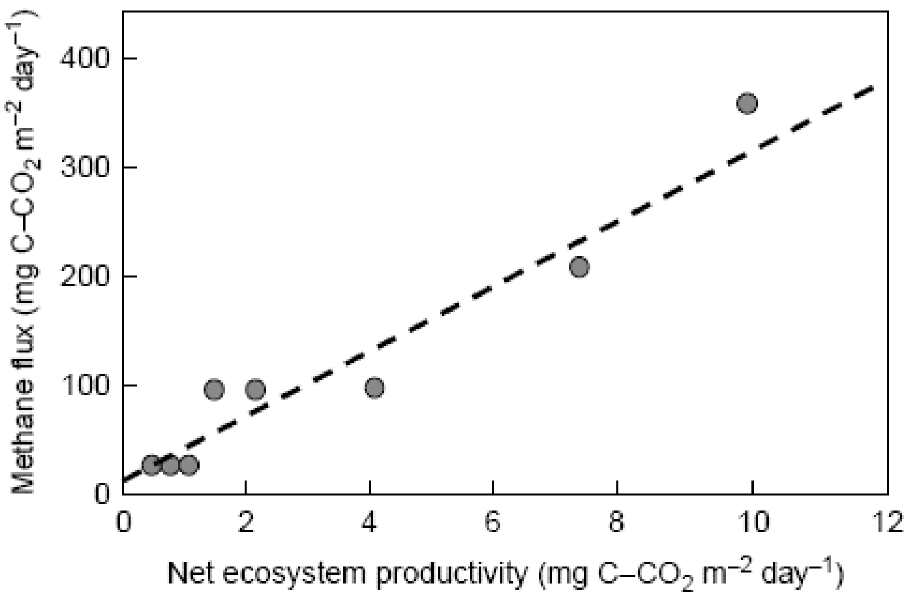
➡ **CH_4 production and emissions varies in time and between wetland types**

Wetlands as a CH_4 source

Factors influencing CH_4 production and emissions:

Relationship between net ecosystem productivity and net methane flux



3% of net ecosystem production (C fixation) released back to the atmosphere as CH_4

Whiting and Chanton, 1993. DOI: 10.1038/364794a0

Methane emissions

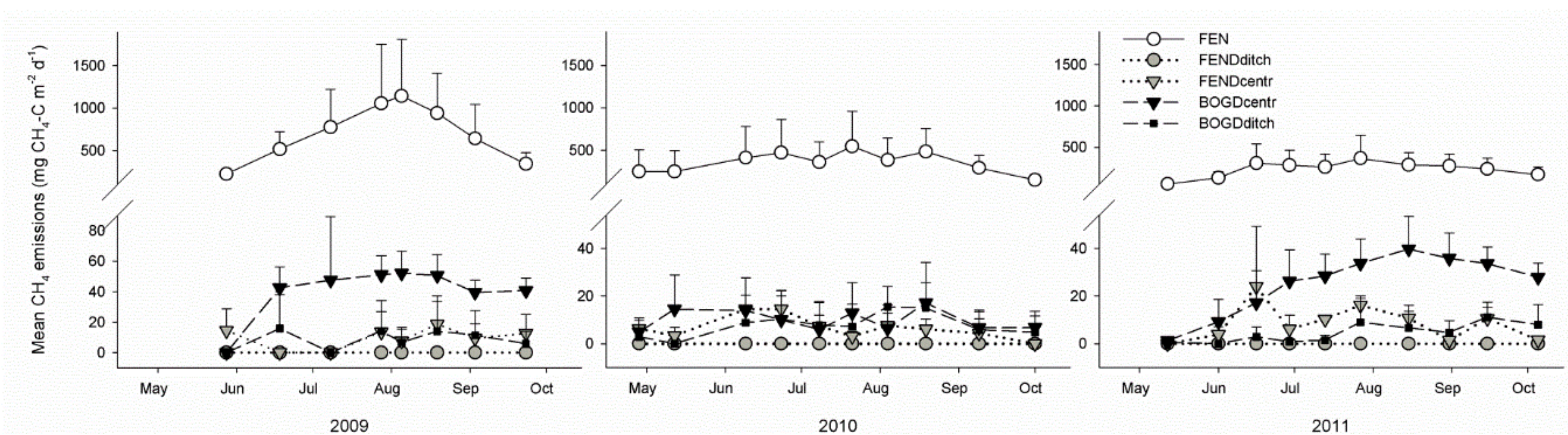
Methane emissions (as C) from different wetlands

Wetland type	g-C m^{-2} year^{-1}	Reference
Northern Peatlands		
Canadian peatlands	<7.5	Moore and Roulet (1995)
Temperate/Tropical Wetlands		
Amazon basin, Brazil	40–215	Devol et al. (1988)
Australian billabong	12–22	Sorrell and Boon (1992)
Louisiana freshwater marshes	3–225	Delaune and Pezeshki (2003)
Louisiana bottomland hardwood forest	10	Yu et al. (2008)
Amazon Basin	30	Melack et al. (2004)
Spring-fed wetlands, Mississippi	51	Koh et al. (2009)
Freshwater marsh, Virginia	62	Whiting and Chanton (2001)
Temperate forested wetlands	35	Bartlett and Harriss (1993)
Orinoco floodplain, Veneuzela	9	Smith et al. (2000)
This study		
Temperate flow-through wetlands, Ohio	57 ± 18	Nahlik and Mitsch (2010)
Created temperate marshes, Ohio	30 ± 14	Nahlik and Mitsch (2010)
Tropical flow-through wetland, Costa Rica	33 ± 5	Nahlik and Mitsch (2011)
Tropical floodplain wetland, Costa Rica	263 ± 64	Nahlik and Mitsch (2011)
Tropical rain forest isolated wetland, Costa Rica	220 ± 64	Nahlik and Mitsch (2011)
Tropical seasonally flooded wetland, Botswana	72 ± 8	This study

Mitsch et al. 2013 DOI 10.1007/s10980-012-9758-8

Methane emissions

- High seasonal and interseasonal variability of CH_4 emissions



Urbanová et al. 2013 DOI 10.1007/s10021-013-9637-4

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Wetlands and climate

Feedback mechanism

- Long term storage of CO_2 x source of CH_4
- CO_2 sequestration 830 Tg/year of C = **cooling effect**
- Methane emissions 400 Tg C $year^{-1}$ = **warming effect**

Wetlands and climate

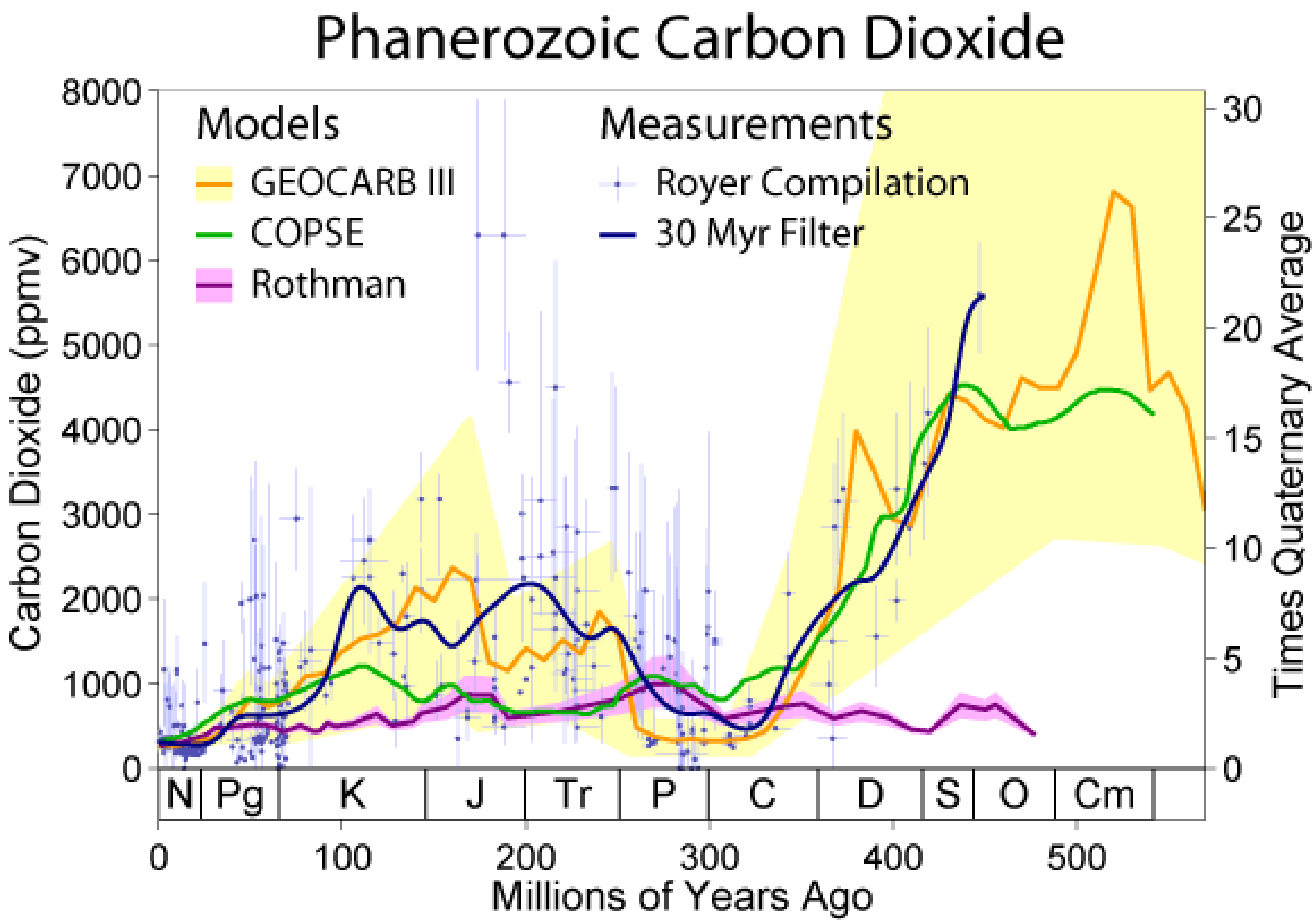
- Global warming potential (GWP) – a measure of the relative effect of a given substance compared to CO_2 for a chosen time horizon

Time horizon	20	100	500
CO_2	1	1	1
CH_4	72	25	7
N_2O	289	298	156

- CH_4 - more effective thermal absorption

  - 200% increase of CH_4 concentration over the last 200 years (0,7 – 1,8 ppm)

Wetlands and climate

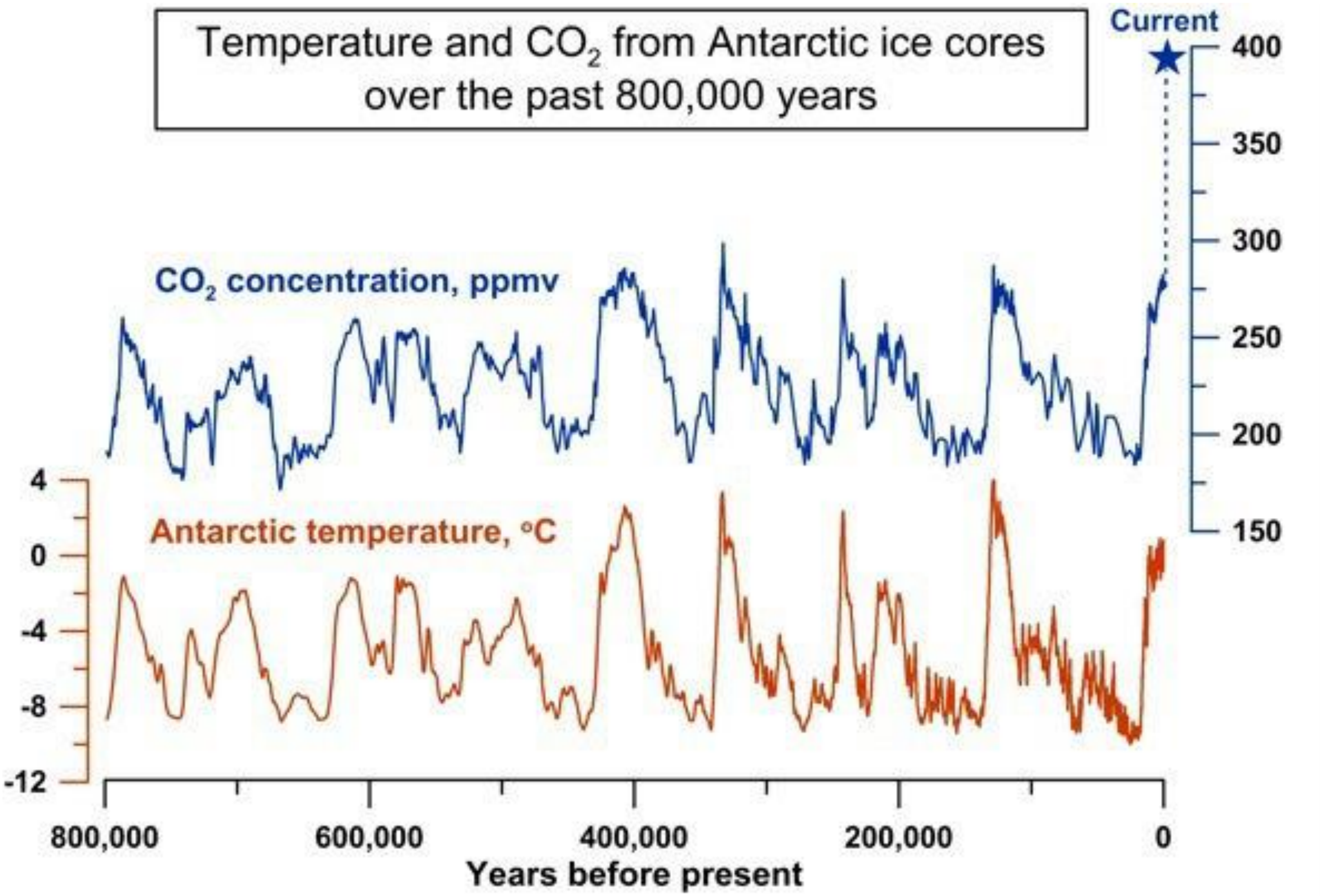


- ases

https://en.wikipedia.org/wiki/Carbon_dioxide_in_Earth%27s_atmosphere

https://www.ipcc.ch/publications_and_data/ar4/wg1/en/faq-2-1.html

Wetlands and climate



The 800,000-year record of atmospheric CO_2 from the EPICA Dome C and Vostok ice cores, and a reconstruction of local Antarctic temperature based on deuterium/hydrogen ratios in the ice. The current CO_2 concentration of 392 ppmv is shown by the blue star. (data from Lüthi et al., 2008, Nature, 453, 379-382, and Jouzel et al., 2007, Science, 317, 793-797).

Wetlands and climate

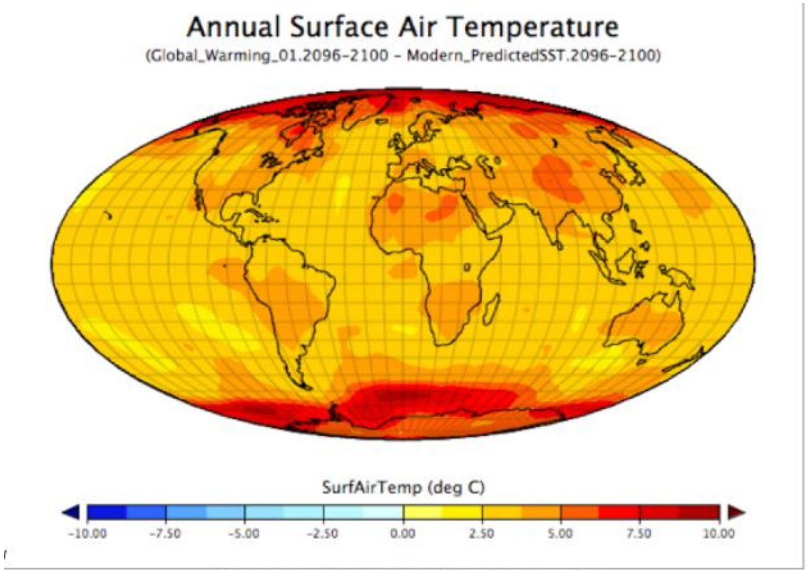
What will be the impact of climate change to wetlands?

Sea level rise - coastal wetlands

Higher temperatures - increase in photosynthesis, respiration, biomass production, decomposition, methane emissions, changes in plant species composition,..

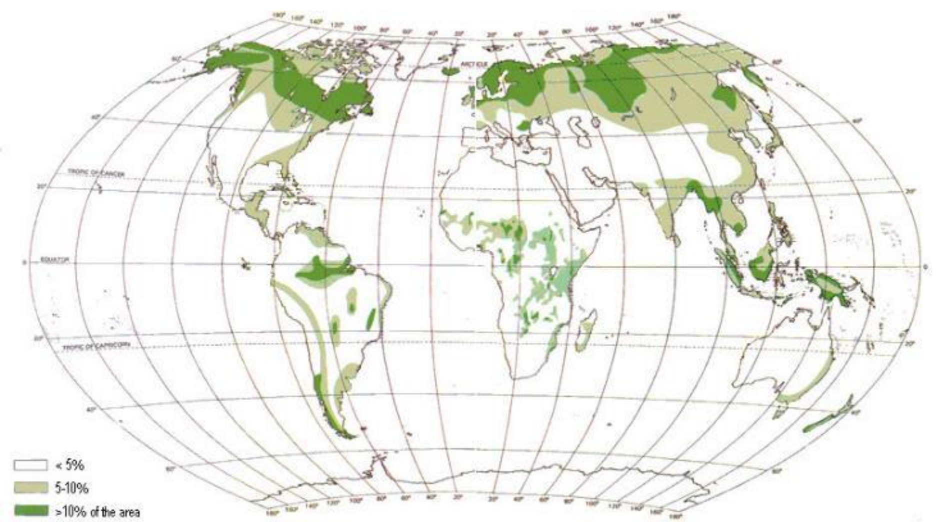
Changes in precipitation – hydrology, plant species composition, biogeochemical processes,..

Wetlands and climate



Map 1: Annual Surface Air Temperature Anomaly

Mire distribution around the world



- Climate change is projected to be the most severe at the high latitudes where most peatlands are situated
- Permafrost melting in tundra

http://serc.carleton.edu/usingdata/datasheets/EnvisioningClimateChange.html
http://wetlife.gpf.lt/en/kodel-svarbu-issaugoti-pelkes