rewet

RESILIENT WETLANDS
EXPLORING THE ROLE OF INLAND WETLANDS & PEATLANDS IN MITIGATING CLIMATE CHANGE

Water-atmosphere fluxes of greenhouse gas in wetlands: the role of aquatic vegetation

Marco Bartoli (marco.bartoli@unipr.it)
Department of Chemistry, Life Sciences and Environmental Sustainability

22 November 2023

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

Outline

- Growth forms of aquatic plants
- Aquatic plants regulate greenhouse gas fluxes in wetlands
- Fluxes exhibit large variability
- Oxygen links aquatic plants and greenhouse gas
- The aerenchyma, a conduit to contrast oxygen limitation
- Floating plants dominance as a stable state

Types of wetland plants

Wetland vascular plants are generally categorised based on their **growth form**. This scheme is independent of phylogenetic relationships; it is based solely on the way in which the plants grow in physical relationship to the water and the sediment. Wetland plants can be grouped in 4 categories:

1) Emergent plants

2) Submerged plants

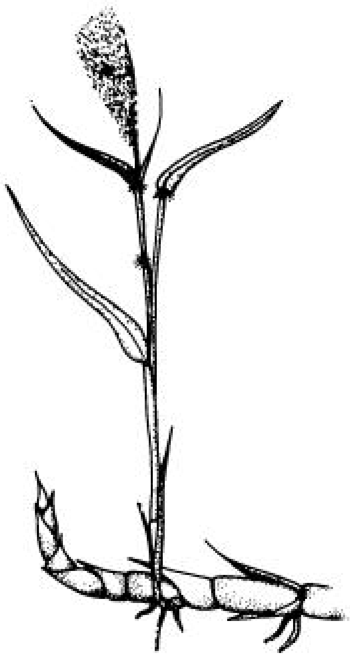
3) Floating-leaved plants

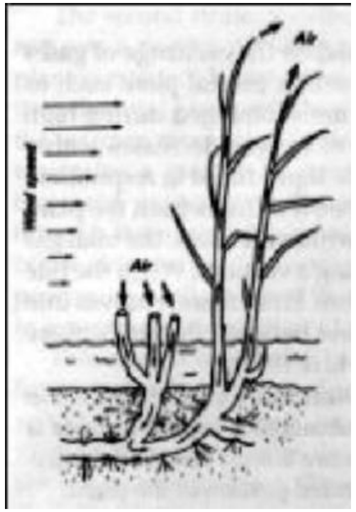
4) Floating plants

1) Emergent plants

Emergent plants are rooted in the sediment with basal portions that typically grow beneath the surface of the water, but whose leaves, stems (photosynthetic parts), and reproductive organs are aerial. Among the types of wetland plants they are the most similar to terrestrial species, relying on aerial reproduction and sediments as source of nutrients.

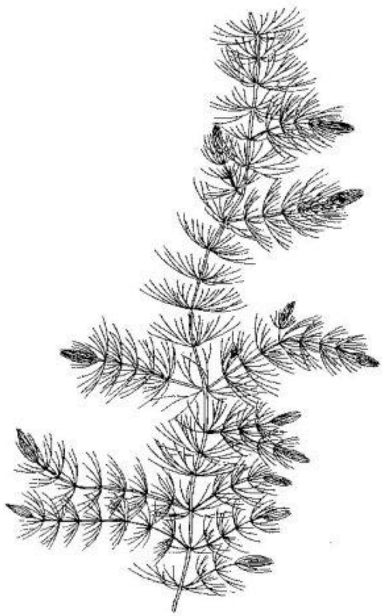
<u>They directly connect the sediments to the atmosphere, and vice-versa</u>





2) Submerged plants

With the possible exception of flowering, submerged plants typically spend their entire life cycle beneath the surface of water and are distributed in coastal, estuarine and freshwater habitats. Nearly all are rooted in the substrate, although there are several rootless species that float free in the water column. In submerged species, all photosynthetic tissues are normally underwater (Cook, 1996).

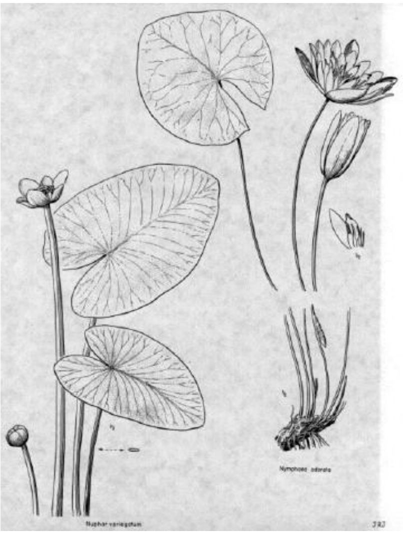


Submersed plants oxygenate bottom water and surface sediments

3) Floating-leaved plants

The leaves of floating-leaved species float on the water’s surface while their roots are anchored in the substrate. Petioles or a combination of petioles and stems connect the leaves to the bottom. Most floating-leaved species have circular, oval, or cordate leaves with entire margins that reduce tearing, and a though leathery texture that prevents both herbivory and wetting (Guntenspergen et al., 1989).

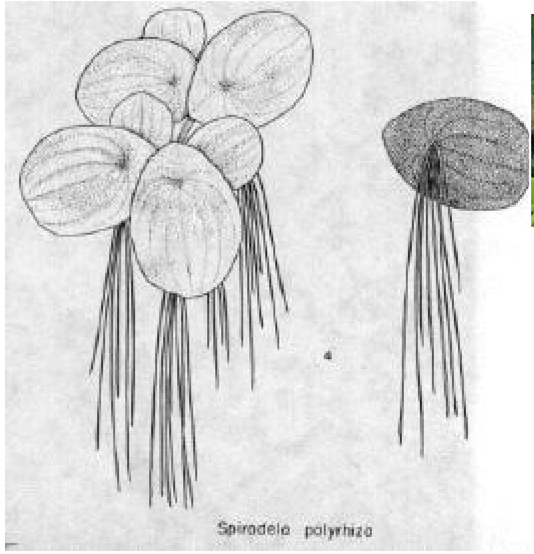
<u>They shade the water column, limit water reareation and connect the sediments to the atmosphere</u>



4) Floating plants

The leaves and stems of floating plants float on the water's surface. Roots hang free in the water and are not anchored in the sediments, Floating plants move on the water's surface with winds and water currents.
Besides the roots' role in absorbing nutrients, they also serve as a weigh that helps stabilise the plant on the water. Floating wetland plants commonly exhibit extensive vegetative growth.

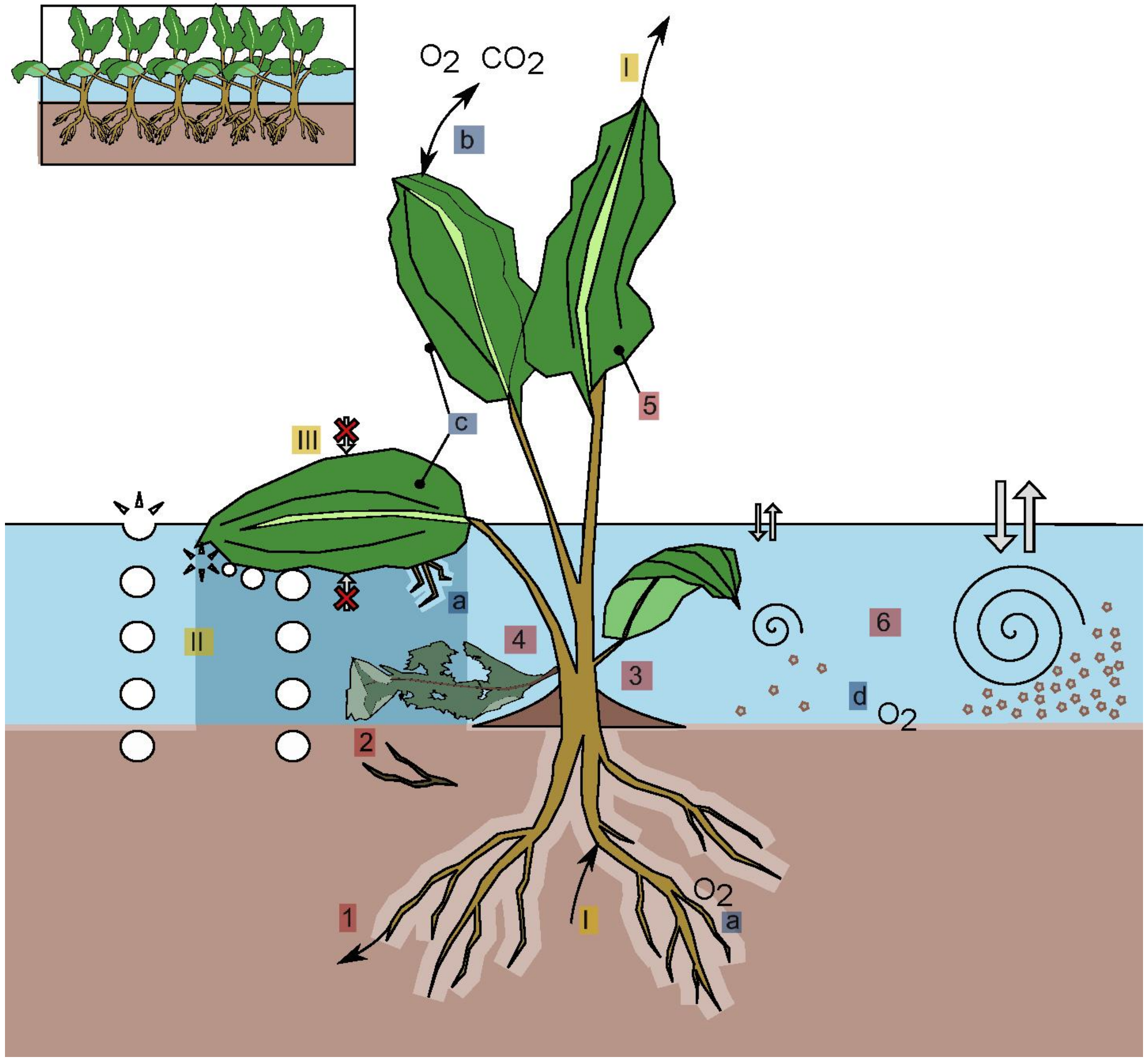
<u>They characterize eutrophic ecosystems and can turn the water anoxic</u>



Aquatic vegetation plays an important role as regulator of greenhouse gas flux in wetlands

-Emergent, floating, and submerged vegetation affects CO_2, CH_4 and N_2O dynamics, including production, consumption, oxidation, and transport.
-Plant-mediated effects on GHG production include the provision of organic carbon or oxygen through roots.
-Plant-mediated effects on GHG transport include direct connection between anoxic sediment and the atmosphere, retention of bubbles and alteration of diffusive water-atmosphere gas exchange.

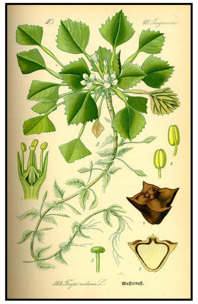
from Bodmer et al., 2021. Methane fluxes of vegetated areas in natural freshwater ecosystems: assessments and global significance. EarthArXiv (2021), 10.31223/X5ND0F

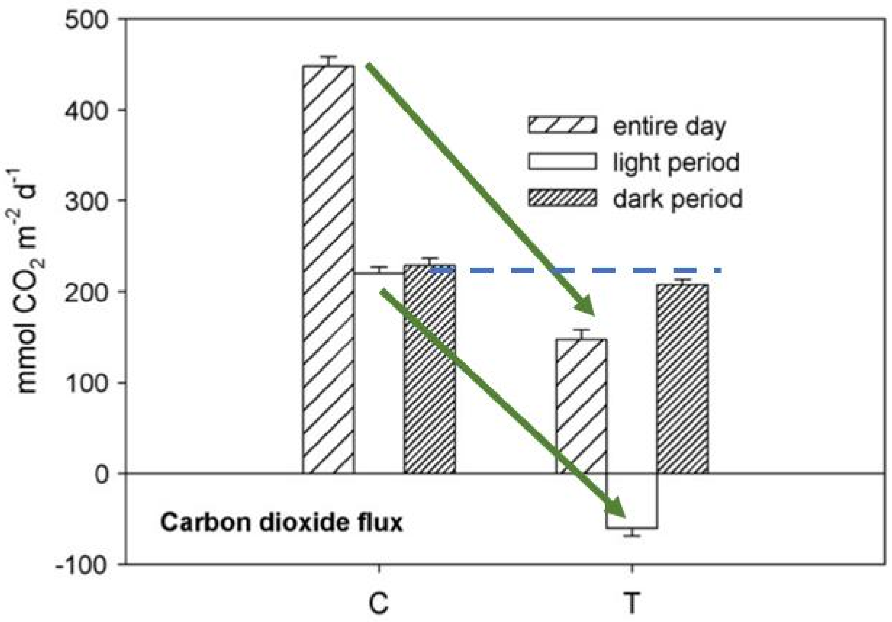


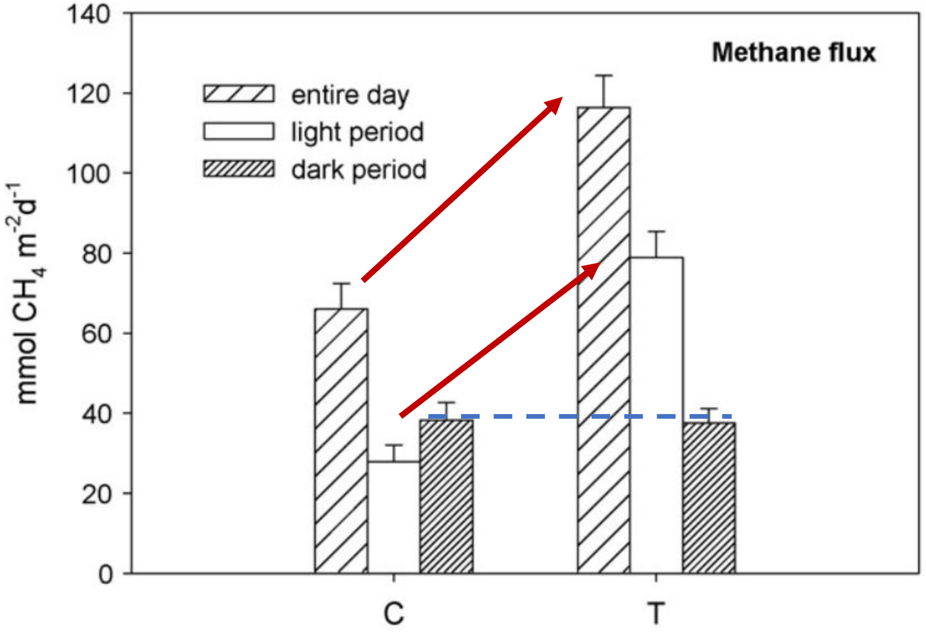
Trapa natans affects CO_2 and CH_4 fluxes

Water-atmosphere fluxes of carbon dioxide and methane in spots with free water surface (C) and in the presence of the common water chestnut (T) are significantly different.

The macrophytes reduces the daily emission of CO_2 and increases the emission of CH_4.

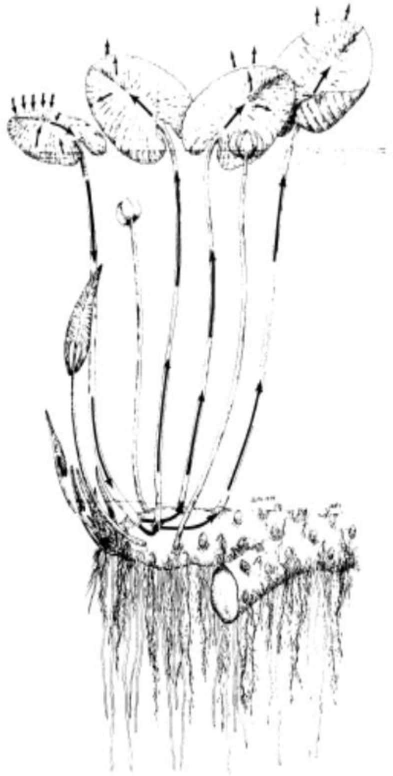






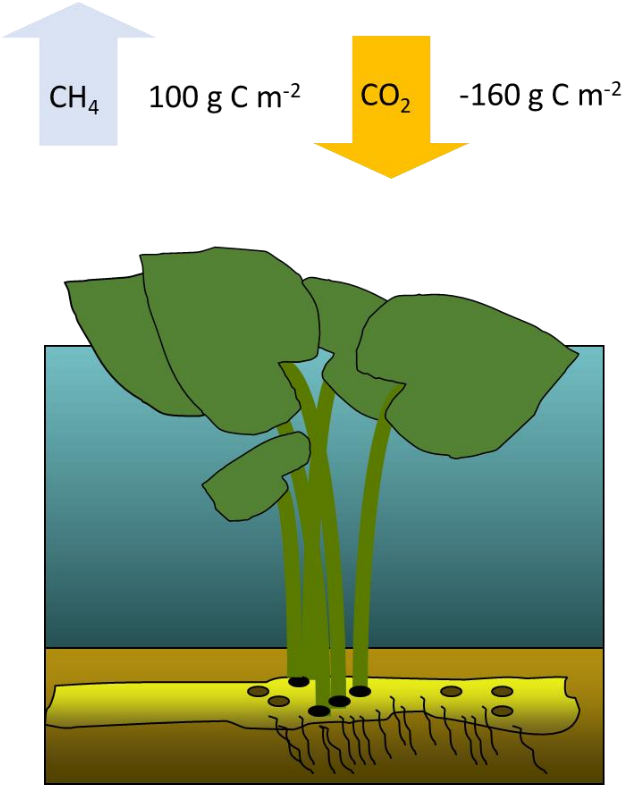
*From Bolpagni et al., 2007. Diurnal exchanges of CO_2 and CH_2 across the water–atmosphere interface in a water chestnut meadow (*Trapa natans *L.). Aquatic botany, 87(1), pp.43-48.*

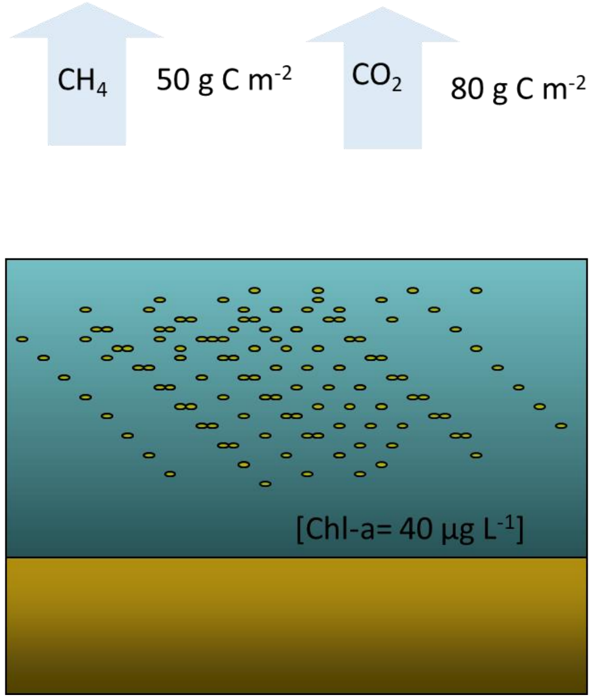
Nuphar lutea (L.) reverses CO_2 fluxes and enhances CH_4 emissions



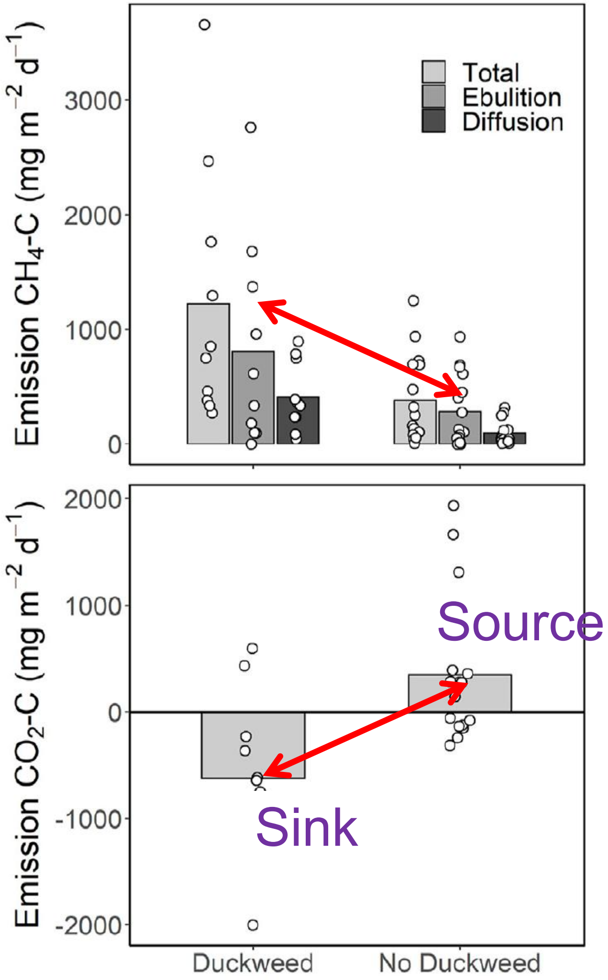
from Ribaudo et al., 2012. CO_2 and CH_2 fluxes across a Nuphar lutea (L.) Sm. stand. Journal of Limnology, 71(1).

from Dacey, 1980. Internal Winds in Water Lilies: An Adaptation for Life in Anaerobic Sediments. Science (1980)

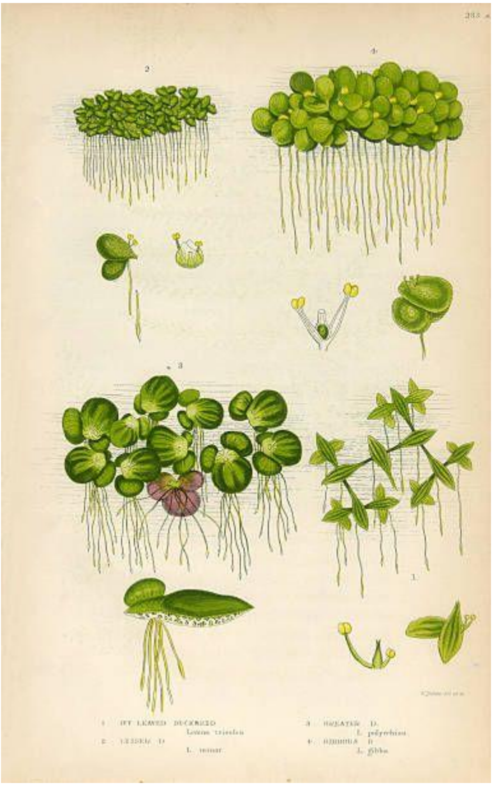




Duckweeds also reverse CO_2 efflux and stimulate CH_4 emission

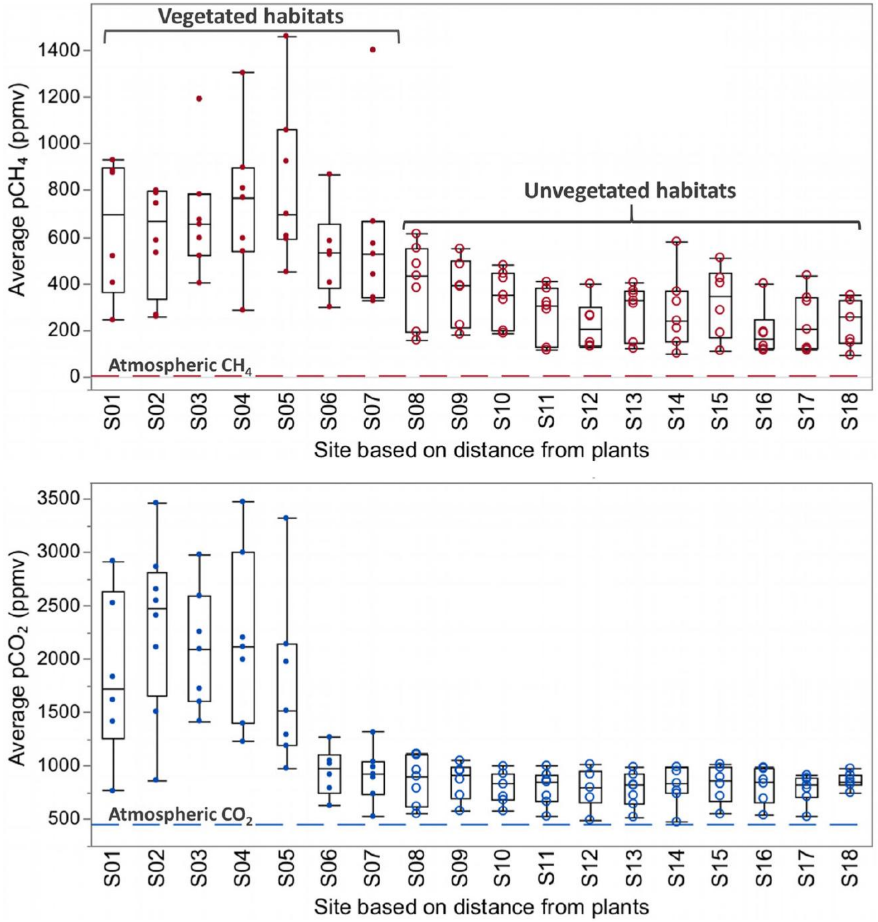


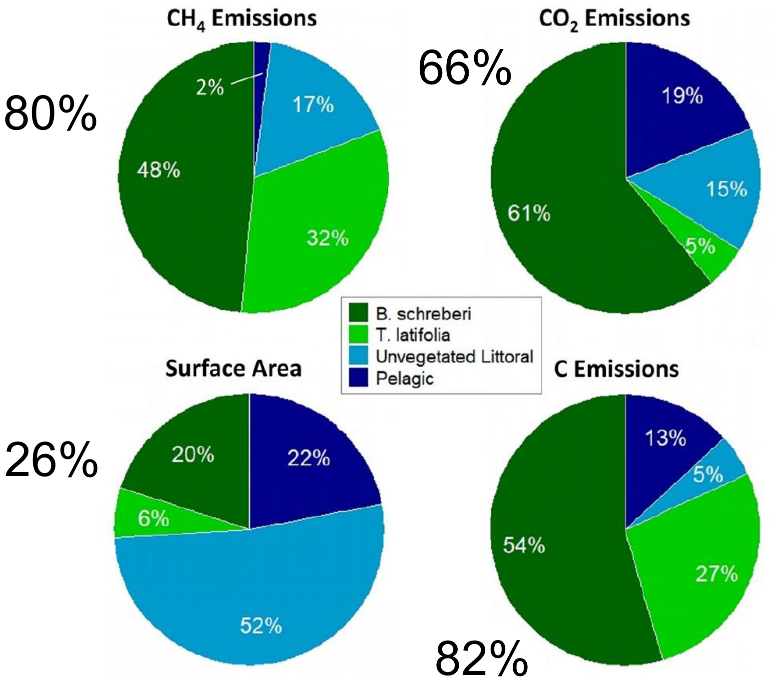
Ponds have disproportionate greenhouse gas emissions relative to their size.
A study on 26 ponds in Minnesota (USA) revealed that they are all CH_4 sources and CO_2 sinks, depending on duckweed coverage.
Duckweed ponds had a mean emission rate in CO_2 equivalents of 31 g C m^{-2} d^{-1} compared to 11.0 g Cm $^{-2}$ d^{-2} in non-duckweed ponds.



from Rabaey and Cotner, 2022. Pond greenhouse gas emissions controlled by duckweed coverage. Frontiers in Environmental Science 10 (2022): 889289.

Lakes vegetated areas contribute major fractions of C emission



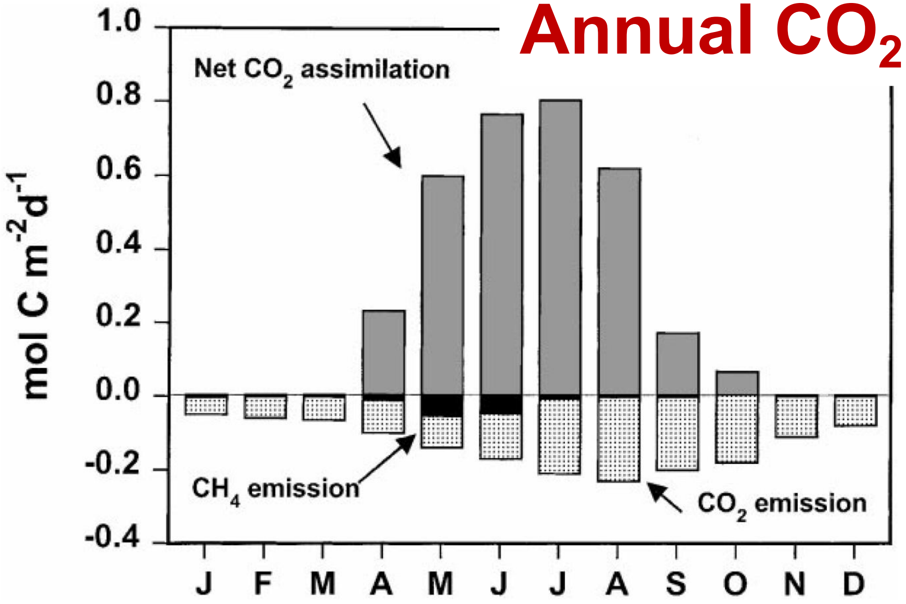


Typha latifolia

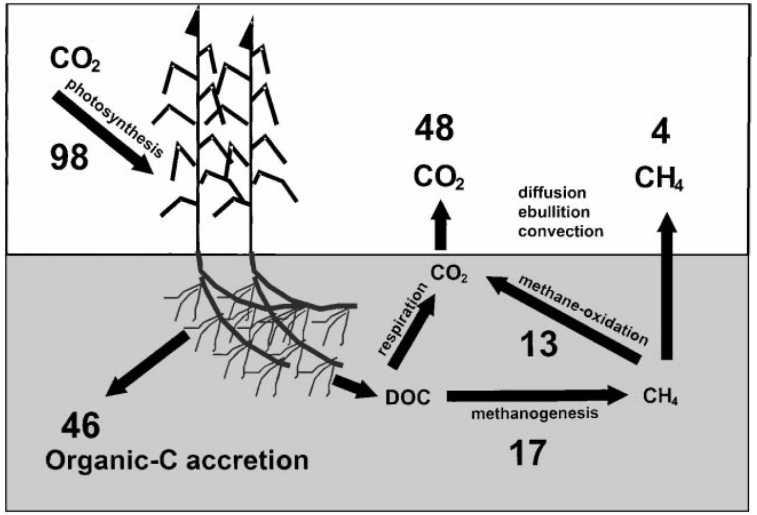
Brasenia schreberi

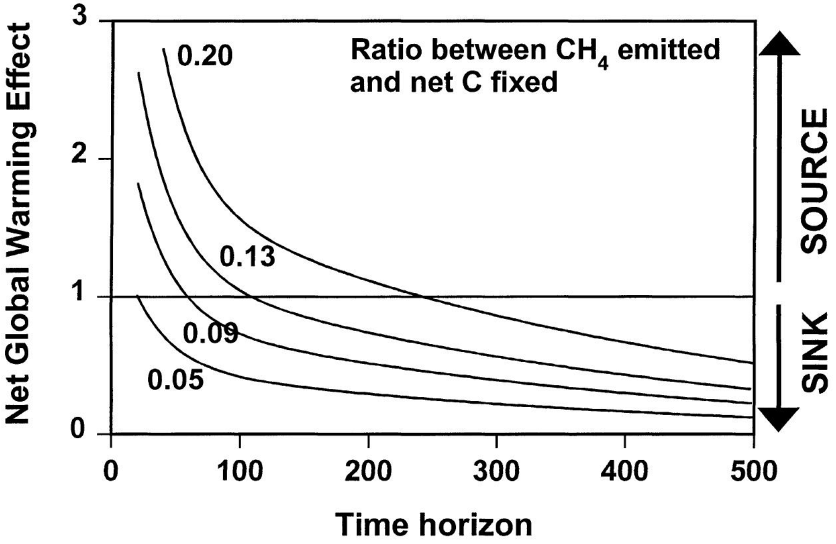
from Desrosiers et al., 2022. Disproportionate contribution of vegetated habitats to the CH_4 and CO_2 budgets of a boreal lake. Ecosystems (2022): 1-20.

Annual CO_2 and CH_4 budget in *Phragmites australis*



Approximately 50% of the net primary production by *P. australis* is respired to CO_2 and CH_4 and released via convective gas flow within plants. CH_4 release is about 4% of photosynthetic CO_2 fixation and 9% of the net C fixation in the wetland.
On the basis of current GWP values for CH_4 relative to CO_2 and the molar ratios, *P. australis* wetland can be viewed as net sources of greenhouse gas over timescales <60 years, but net sinks over longer time scales.

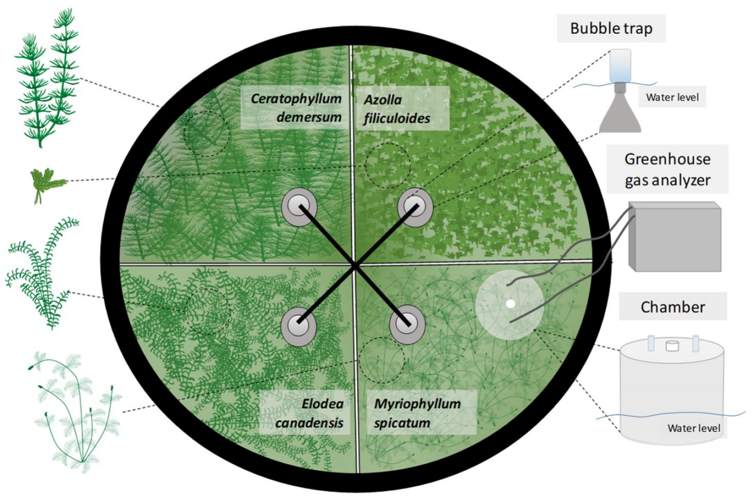


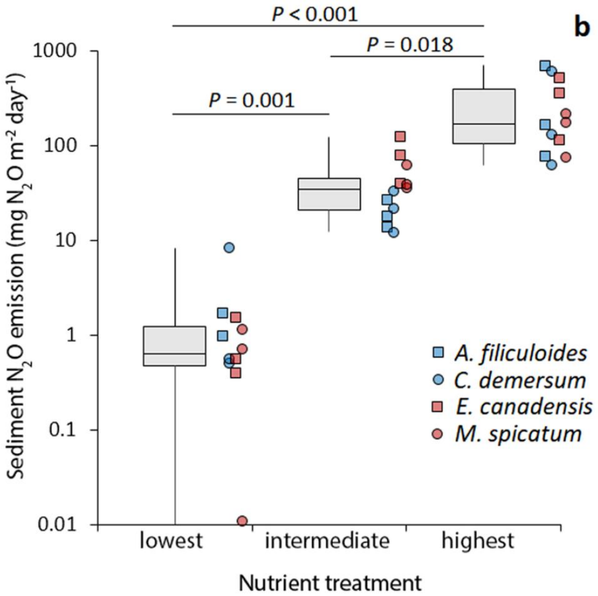


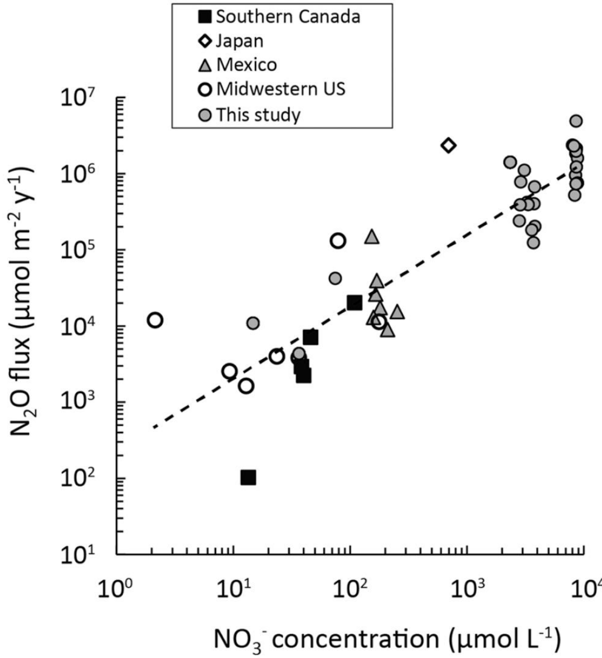
from Brix et al., 2001. Are Phragmites-dominated wetlands a net source or net sink of greenhouse gases? Aquatic botany 69, no. 2-4 (2001): 313-324.

The regulation of N_2O fluxes by aquatic plants is comparatively understudied

Nutrient loads (specifically nitrate loads) regulate N_2O fluxes more than macrophytes in laboratory experiments

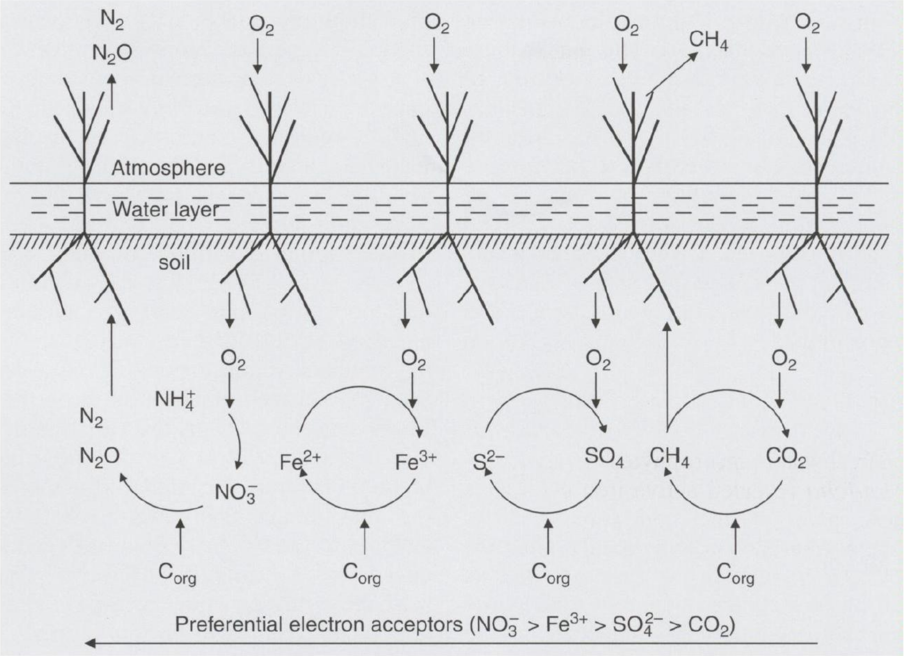






from Aben et al., 2022. Impact of plant species and intense nutrient loading on CH4 and N2O fluxes from small inland waters: an experimental approach. Aquatic Botany, 180, p.103527.

Large heterogeneity among different plants



from Laanbroek, 2010. Methane emission from natural wetlands: interplay between emergent macrophytes and soil microbial processes. A mini-review. Annals of botany, 105(1), pp.141-153.

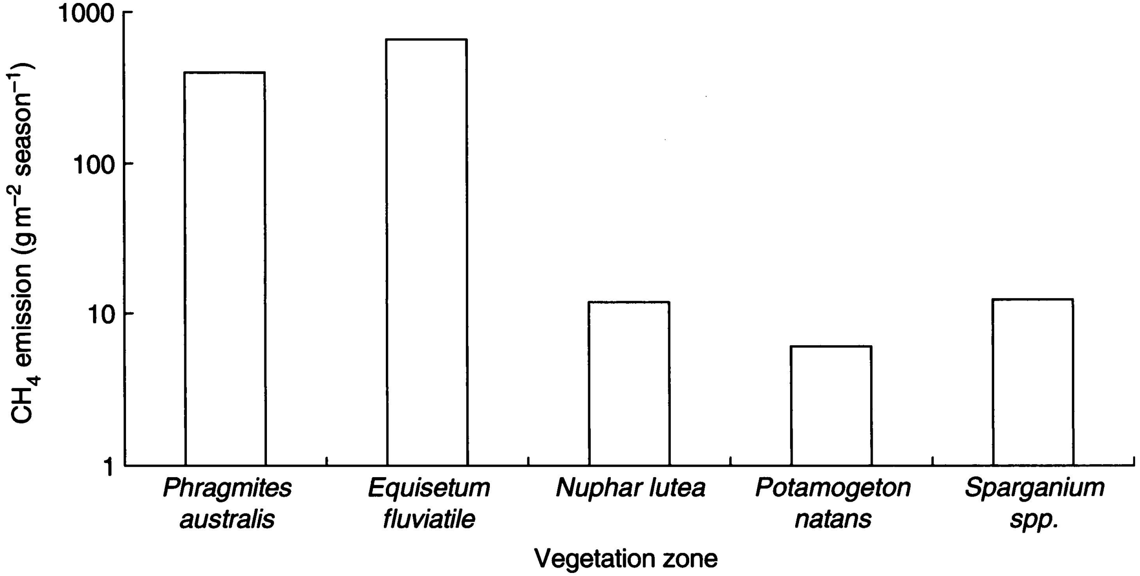


TABLE 1. *Percentages of methane oxidized in the wetland vegetation before entering the atmosphere*

Vegetation	Percentage oxidized	Method	Reference
Carex rostrata	20–40*	^{14}C-labelled acetate in monoliths	Ström *et al.* (2005)
Equisetum fluviatile	40	Darkened/nitrogen atmosphere	Kankaala and Bergström (2004)
Eriophorum vaginatum	0†	Changes in methane concentration in bottles containing different plant parts	Frenzel and Rudolf (1998)
Eriophorum vaginatum	>90*	^{14}C-labelled acetate in monoliths	Ström *et al.* (2005)
Juncus effusus	>90*	^{14}C-labelled acetate in monoliths	Ström *et al.* (2005)
Phragmites australis	16	Methylfluoride/nitrogen atmosphere	Van der Nat and Middelburg (1998*b*)
Pontederia cordata	63	Soil-free, split chambers	Calhoun and King (1997)
Scirpus lacustris	35	Methylfluoride/nitrogen atmosphere	Van der Nat and Middelburg (1998*b*)
Sparganium eurycarpum	88	Soil-free, split chambers	Calhoun and King (1997)
Mixed freshwater vegetation	43‡	Nitrogen atmosphere	Roslev and King (1996)
Mixed weeds	95	Acetylene inhibition/nitrogen atmosphere	Holzapfel-Pschorn *et al.* (1986)

* In the root zone.
† In the presence of isolated below-ground plant parts.
‡ Annual average; range 15–76 %.

Importance of local conditions (e.g. trophic level)

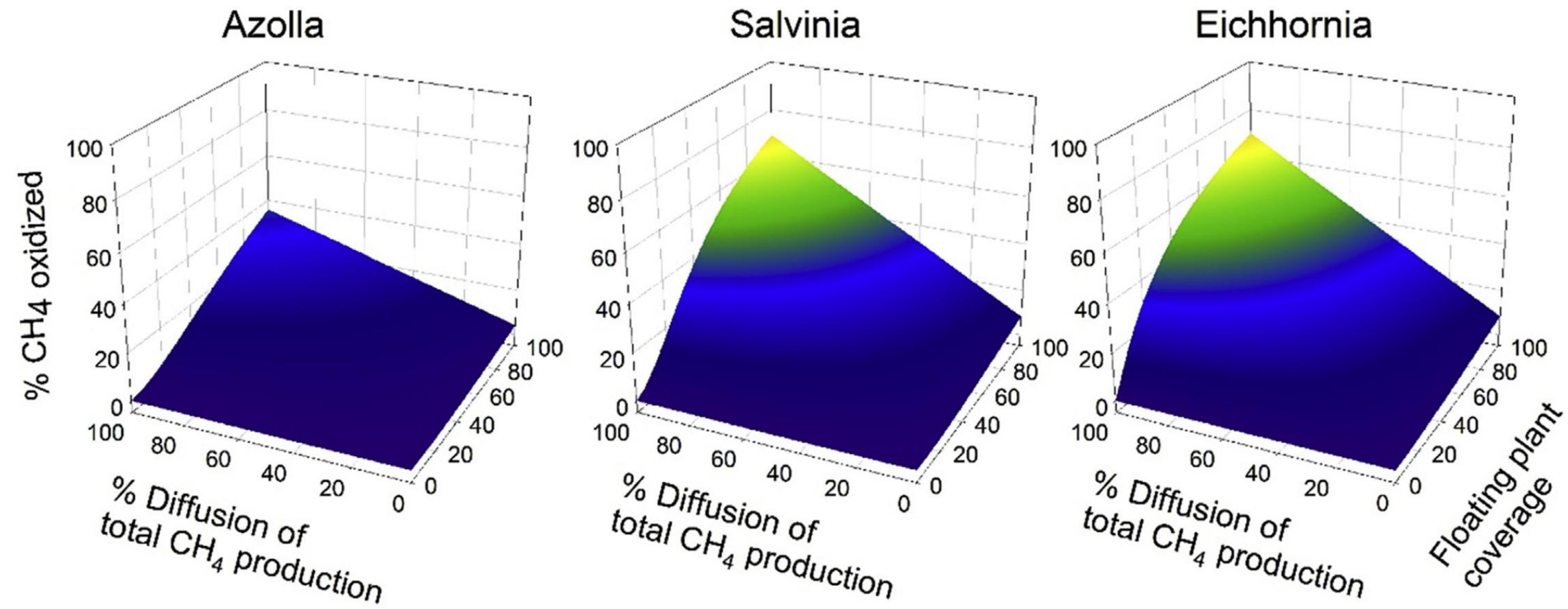
Table 2
Effect of floating plants on CH_4 emissions as compared to open water.

Species	Type of system and location	CH_4 fluxes measured	Plant effect on CH_4 flux	Reference
Azolla sp.	Rice paddies (India)	Total emission	Reduction	(Bharati et al., 2000)
Lemna sp.	Rice paddies (China)	Total emission	Reduction	(Wang et al., 2015)
Lemna sp.	Wastewater stabilization ponds (the Netherlands)	Total emission	Reduction	(Van der Steen et al. 2003a)
Lemna sp.	Wastewater stabilization pond reactors (the Netherlands)	Total emission	Reduction	(van der Steen et al., 2003b)
Eichhornia crassipes	Shallow lake (India)	Diffusion	Reduction	(Attermeyer et al., 2016)
Floating plant beds[a]	Orinoco floodplain (Venezuela)	Total emission Diffusion	No effect Reduction	(Smith et al., 2000)
Nuphar lutea	Shallow pond (Italy)	Diffusion	No effect	(Ribaudo et al., 2012)
Nuphar lutea	5 lakes (Colorado, USA)	Total emission	Increase	(Smith and Lewis, 1992)
Nuphar lutea	Shallow eutrophic lake (Michigan, USA)	Ebullition	Increase	(Dacey and Klug, 1979)
Eichhornia crassipes	Pantanal river (Brazil)	Total emission	Increase	(Bastviken et al., 2010)
Trapa natans	Shallow eutrophic lake (Italy)	Diffusion	Increase	(Pierobon et al., 2010)
Different submerged and floating species[b]	10 natural and man-made shallow ponds (India)	Total emission	Increase	(Singh et al., 2000)
Floating beds of different Poaceae species[c]	Amazon river floodplain (Brazil)	Diffusion	Increase	(Devol et al., 1990)
Floating plant beds[d]	Central Amazonian Amazon river floodplain and lakes (during high and low water) (Brazil)	Total emission	Increase	(Bartlett et al., 1988) (Bartlett et al., 1990)

[a] Dominant plants are *Paspalum* sp. and *Eichhornia* sp.
[b] *Azolla pinnata, Bacopa monnieri, Ceratophyllum demersum, Eichhornia crassipes, Hydrilla verticillata, Ipomoea aquatica, Jussieua repens, Lemna minor, Limnanthemum cristatum, Marselia minuta, Nelumbo nucifera, Nymphaea alba, Pistia stratiotes, Potamogeton pectinatus, Schoenoplectus subalatus, Spirodela polyrrhiza, Typha latifolia, Trapa natans, Vallisneria spiralis, Zannichellia palustris, and floating algal mats.*
[c] *Paspalum repens, Paspalum fasiculatum, Echinochloa polystachya.*
[d] *Paspalum repens, Echinochloa polystachya, Orzya arandialumis, Salvinia auriculata, Azolla microphylla, Eichhornia crassipes, Pistia stratioides, Ludwigia spp., Alchorneas chomburakiana, Phyllanthus fluitans, Utricularia spp.*

from Kosten et al., 2016. Fate of methane in aquatic systems dominated by free-floating plants. Water Research 104 (2016): 200-207.

Invasive floating plants reduce CH_4 emission?



from Kosten et al., 2016. Fate of methane in aquatic systems dominated by free-floating plants. Water Research 104 (2016): 200-207.

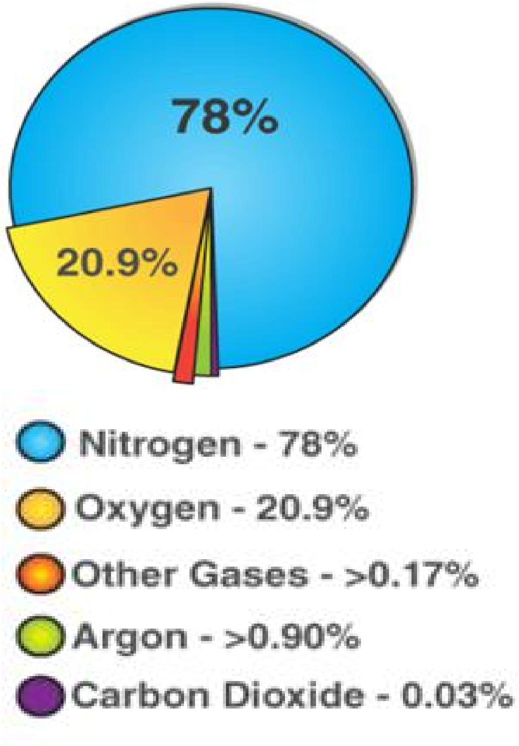
Terrestrial and aquatic access to oxygen (O_2)

-The earth atmosphere contains an incredible amount of oxygen (21%). At sea level such amount corresponds to nearly **300** mg O_2 per litre of air

-Atmospheric oxygen concentration does not vary across seasons or between night and day hours and in the last decades it did not undergo measurable changes

-Terrestrial organisms are never oxygen limited. In unsaturated soil air (and oxygen!) can penetrate by meters

-*What about aquatic ecosystems?*



Oxygen solubility in freshwater

1236 NATURE June 26, 1954 VOL. 173

Prof. C. Boswell, Dr. G. E. Francis, Miss M. Blundell and Miss M. Jeremy for help in various ways.

DENNIS LACY
Department of Zoology and Comparative Anatomy,
St. Bartholomew's Medical College,
London, E.C.1. March 16.

[1] Lacy, D., *J. Roy. Micro. Soc.* (in the press).
[2] Baker, J. R., *Quart. J. Micr. Sci.*, **85**, 1 (1944).
[3] Baker, J. R., *Quart. J. Micr. Sci.*, **87**, 441 (1946).
[4] Palade, G. E., and Claude, A., *J. Morph.*, **85**, 71 (1949).
[5] Weigl, quoted from Bowen, R. H., *Anat. Rec.*, **40**, 103 (1928).
[6] Gatenby, J. B., and Beams, H. W., "Microtomists' Vade Mecum" (edit. 11, Churchill, London, 1950).
[7] Pearse, A. G. E., "Histochemistry, Theoretical and Applied" (Churchill, London, 1953).
[8] Lacy, D., *J. Roy. Micro. Soc.* (in the press).
[9] Bourne, H. B., "Cytology and Cell Physiology" (Clarendon Press, Oxford, 1951).

Solubility of Oxygen in Water

THE rate at which self-purification can occur in waters polluted by oxidizable organic matter may depend largely on the rate at which oxygen from the air is dissolved by the water. In natural water the rate of solution is influenced by many variable factors; but Adeney and Becker[1] have stated that for constant conditions, and for a uniformly mixed body of water, it is proportional to the difference between the concentration of oxygen in solution and the saturation or equilibrium concentration. Unfortunately, the absolute saturation values are not known with great precision; indeed, some of the values published by several independent investigators differ by as much as 0·4 part of oxygen per million at temperatures in

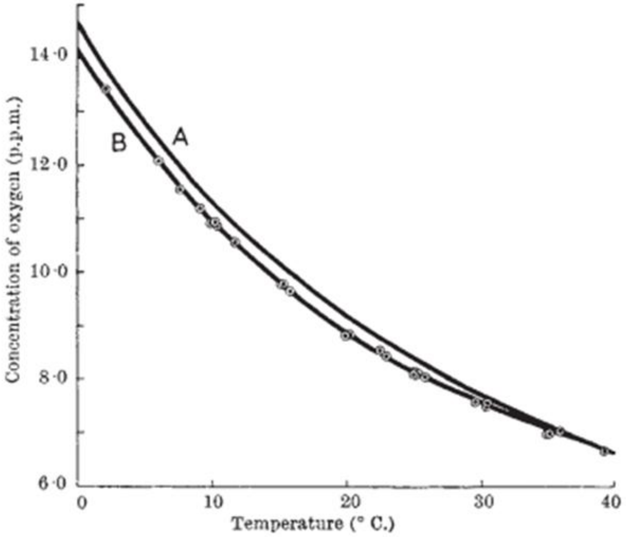
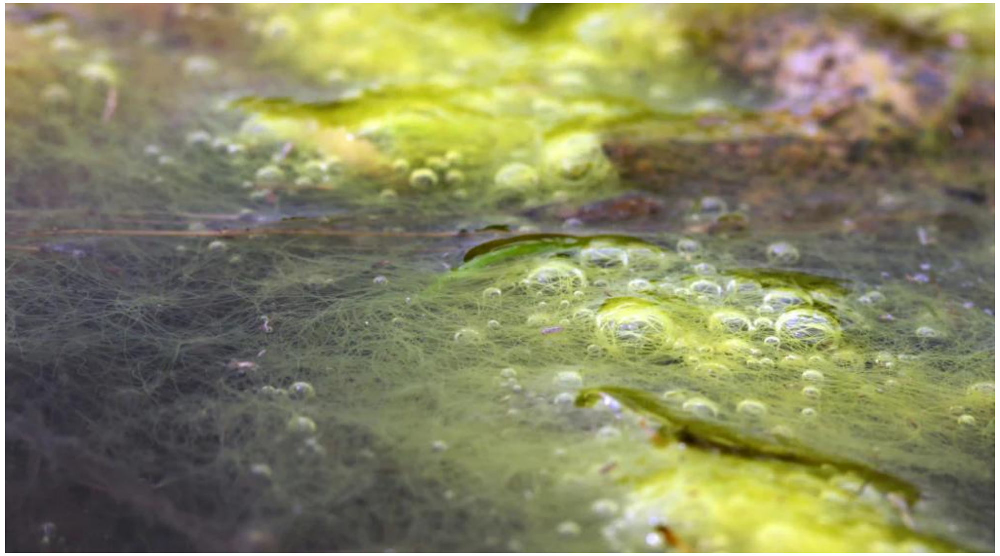


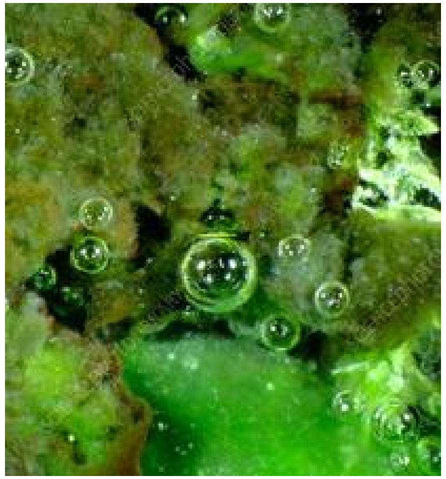
Fig. 1. Curve *A*, saturation values taken from "Standard Methods" calculated by Whipple and Whipple on measurements made by C. J. J. Fox (atmosphere assumed to contain 20·9 per cent oxygen); curve *B*, saturation values determined by the Winkler method

pressure. This value was assumed to be the saturation concentration at the temperature of the experiment. The results obtained by this procedure are related by the empirical equation $C_s = 14{\cdot}16 - 0{\cdot}3943T + 0{\cdot}007714T^2 - 0{\cdot}0000646T^3$, where C_s equals saturation concentration in parts of oxygen per million and T equals temperature in degrees C.

At 20°C, the theoretical oxygen concentration in a freshwater wetland is nearly **9 mg O_2 per litre**, around **30 times less** than the atmospheric concentration (!)

Solubility increases at lower temperatures but decrease at higher temperatures, coinciding with high metabolic activity and the vegetative phase

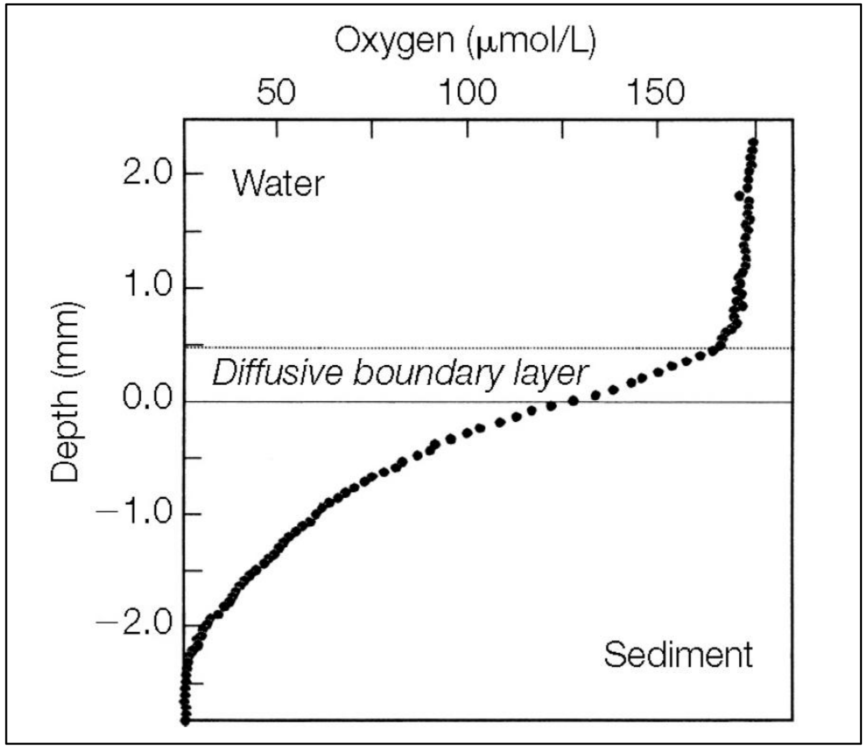


What about oxygen availability in sediments?

Oxygen microsensors allow to explore the penetration of oxygen in sediments.

In most organic sediments that characterize wetlands oxygen penetration is limited to the **upper 1-3 mm,** due to high heterotrophic microbial activity and slow diffusion.

Sediments are mostly anaerobic environments

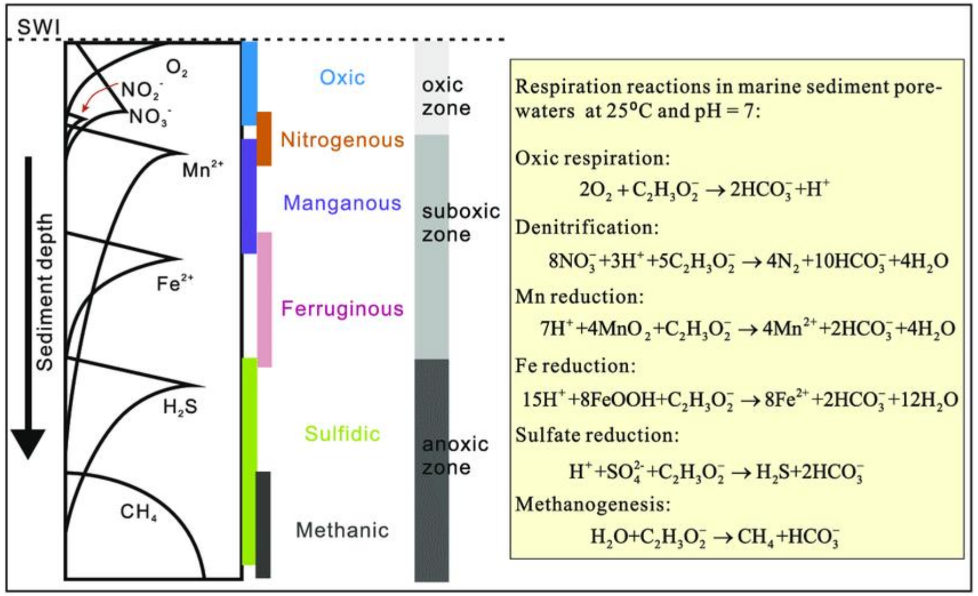


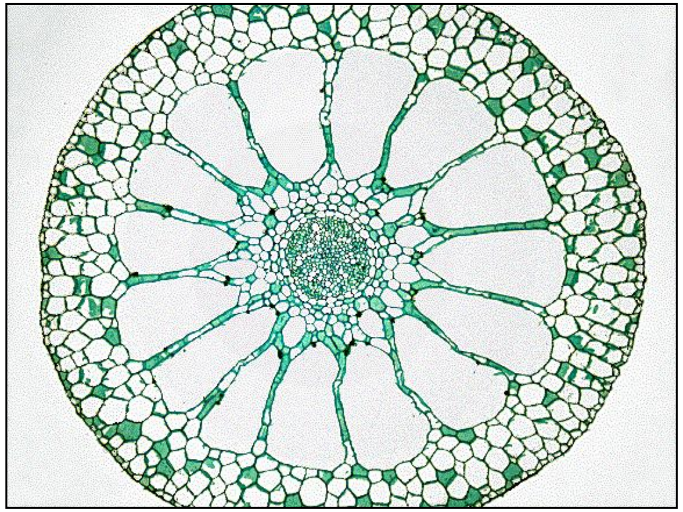
Hard life for rooted aquatic plants

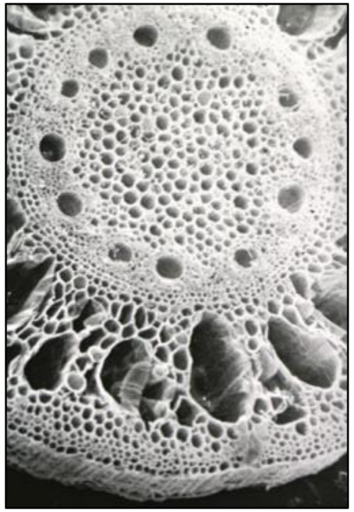
-Aquatic plants are aerobic organisms with roots made of cells that need oxygen to respire

-Such roots are growing in a medium (the sediment) which is anoxic and sometimes rich of toxic compounds

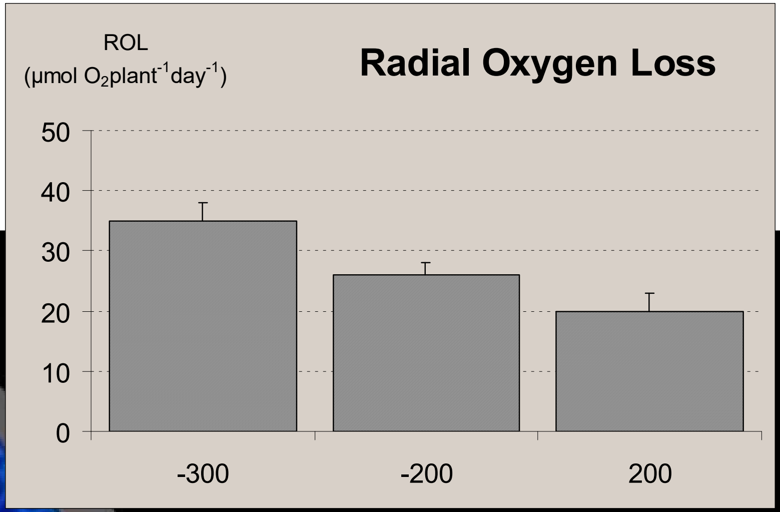
-To survive in sediments aquatic plants have developed the **aerenchyma**, an airy tissue which allows exchange of gas between the shoots and the roots







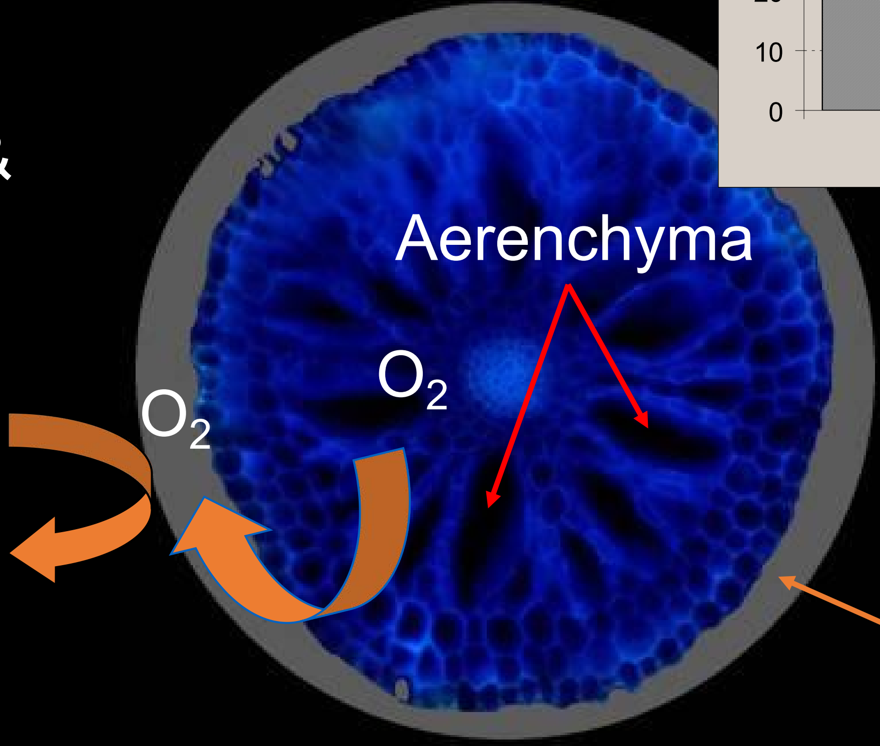
Biogeochemical processes at the sediment/rhyzosphere interface



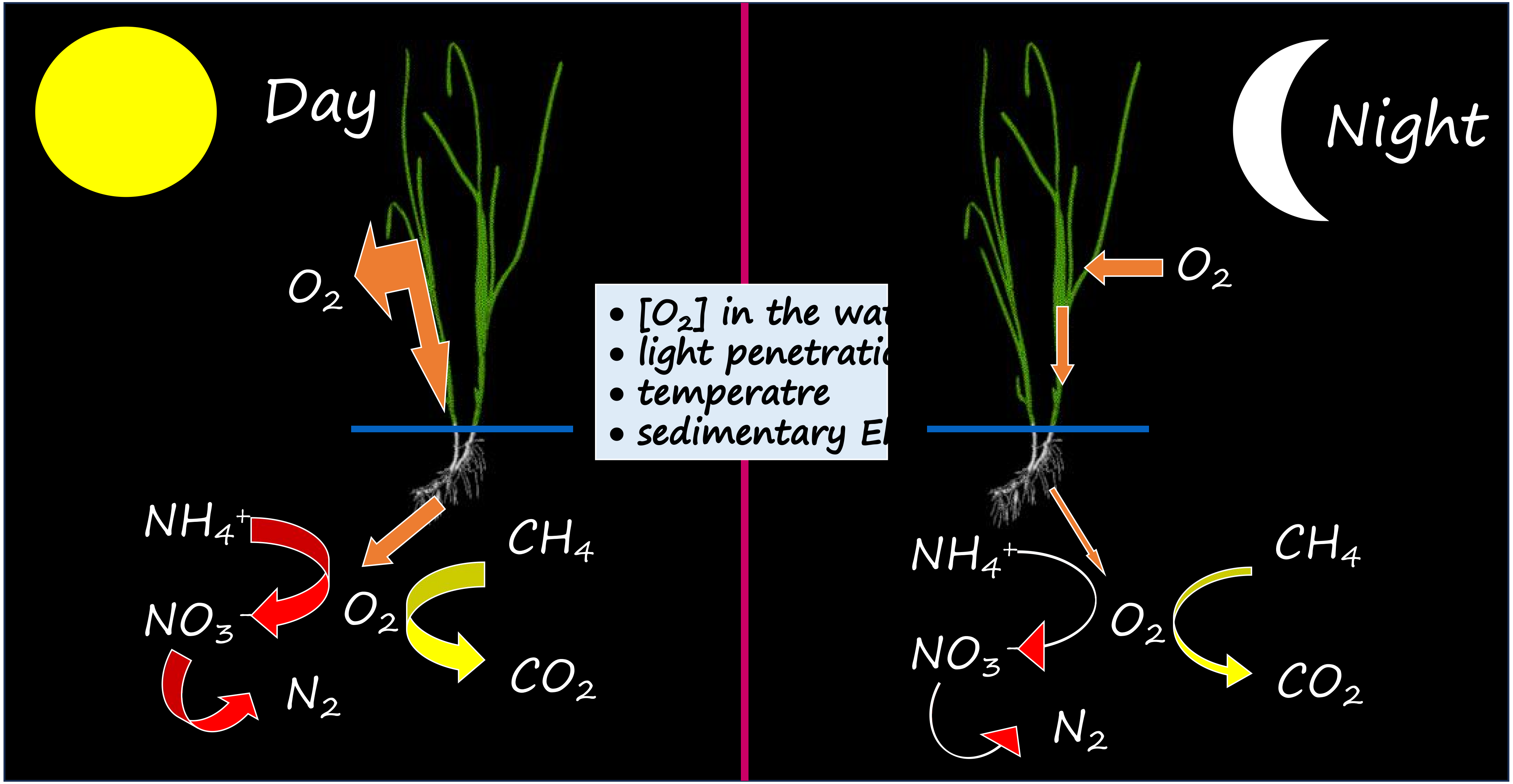
Sediment redox (Eh, mV)

Coupled reductions & oxidations

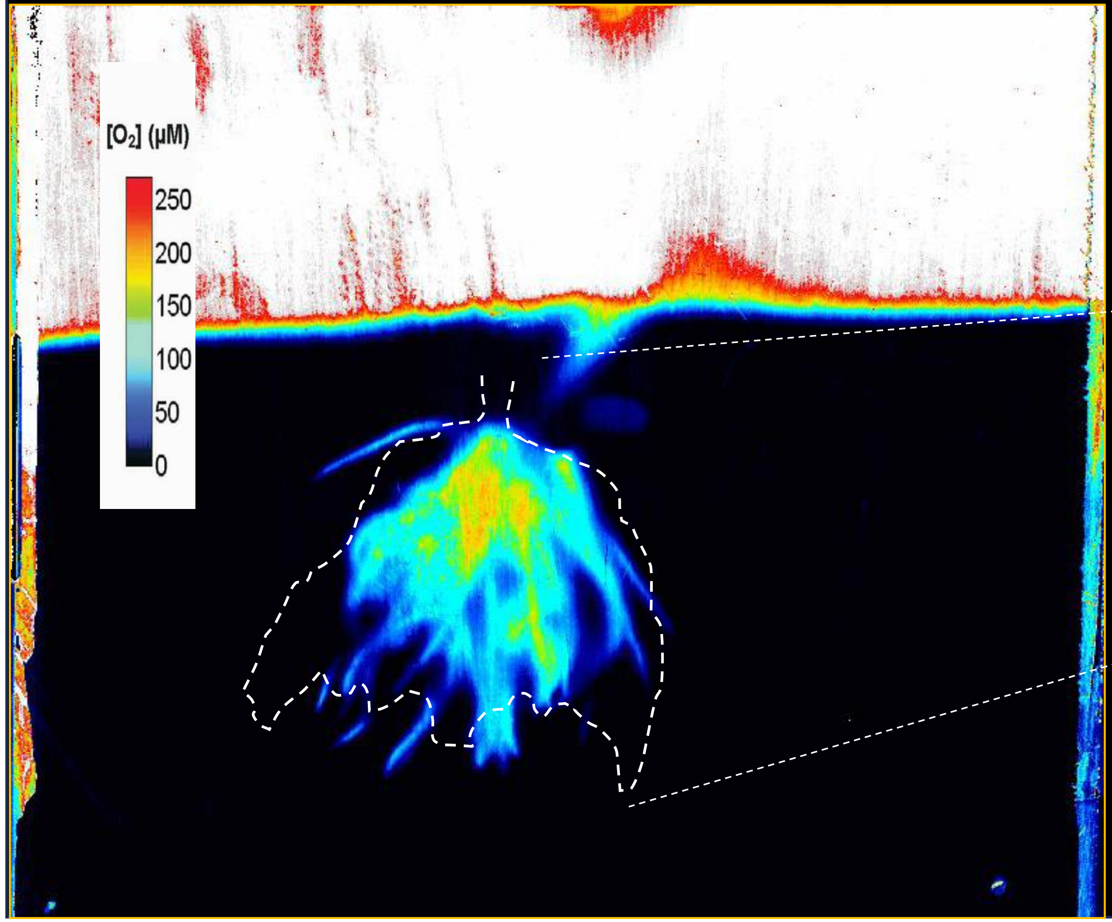
- aerobic respiration
- nitrification
- sulfide oxidation
- iron (+2) oxidation
- **CH_4 oxidation**

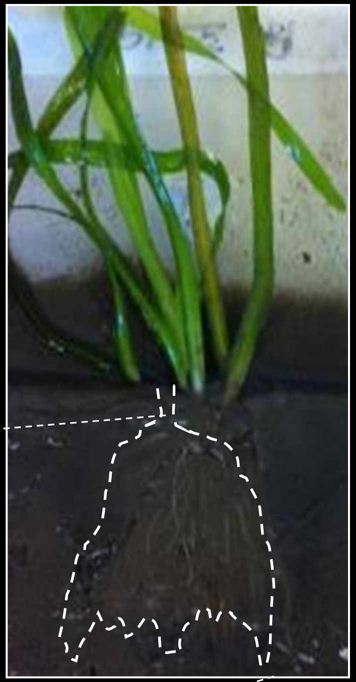


R.O.L.=radial oxygen loss creates an oxic microlayer often <<1mm


Day
Night
O_2
O_2
• $[O_2]$ in the wat
• light penetrati
• temperatre
• sedimentary E
NH_4^+
NO_3^-
N_2
O_2
CH_4
CO_2
NH_4^+
NO_3^-
N_2
O_2
CH_4
CO_2

Radial oxygen loss in the rhyzosphere of *V. spiralis*

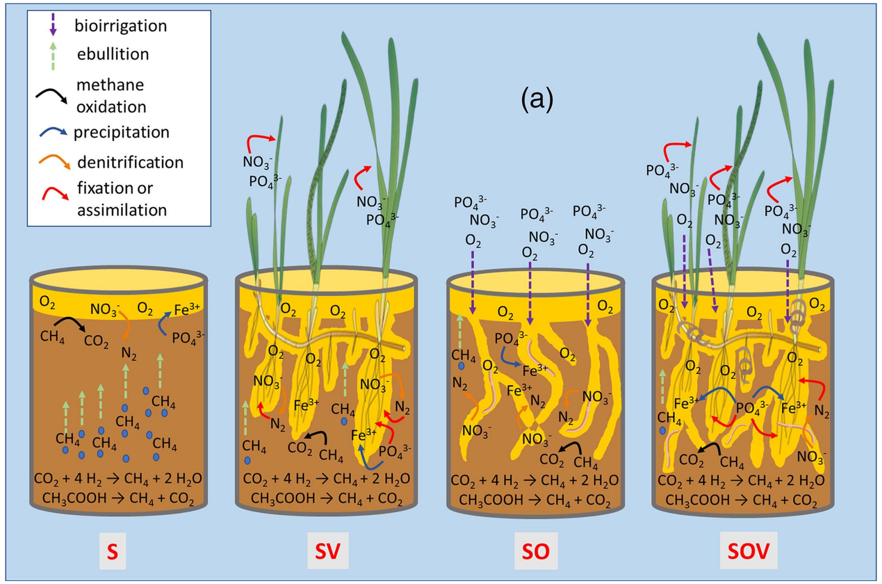




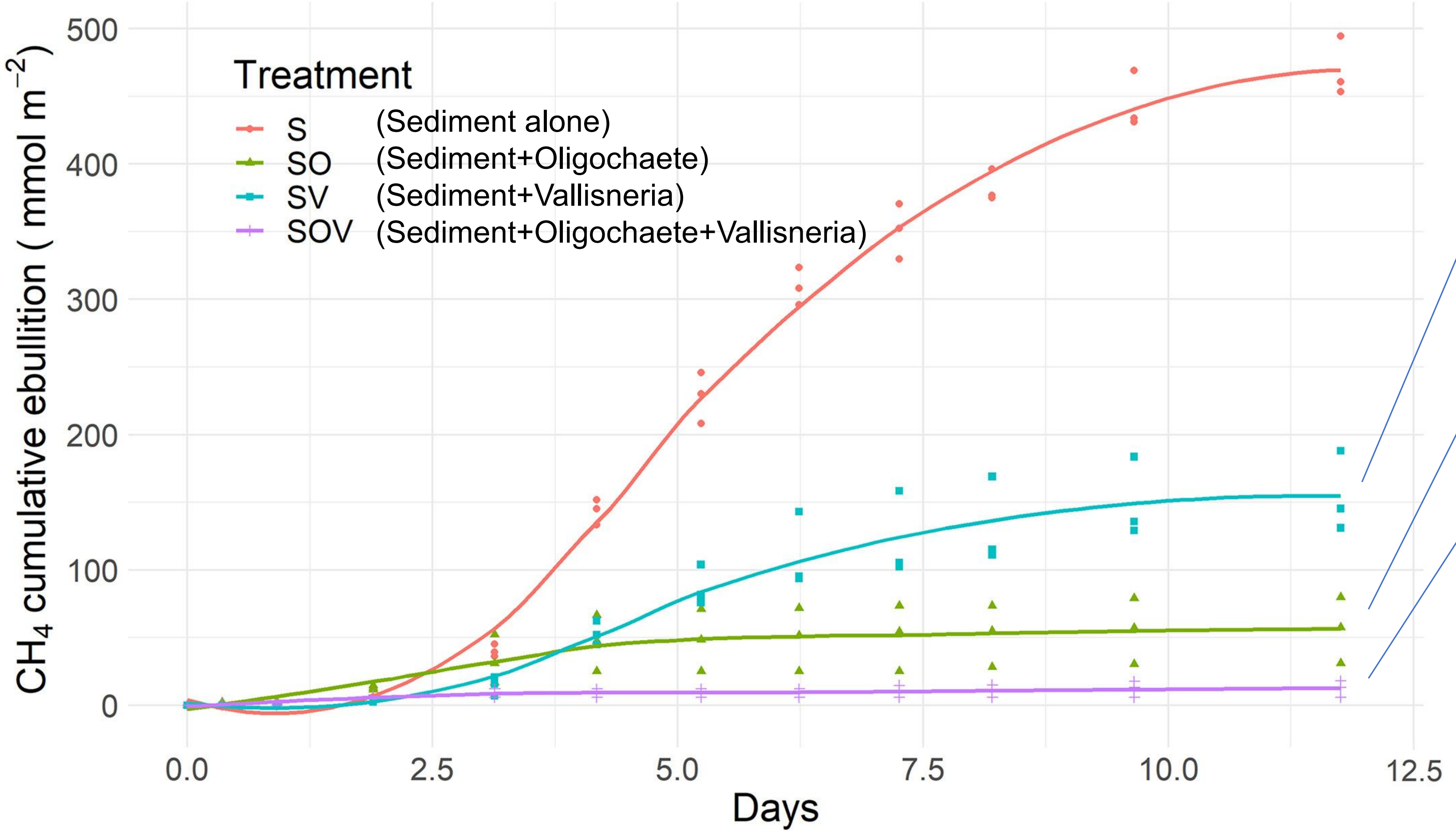
Daily oxygen variation measured with a *planar optode*.

Methane fluxes in *vegetated and bioturbated sediments*

Sparganophilus tamesis
loves roots



The plant and the worm reduce CH_4 ebullition by up to 95%



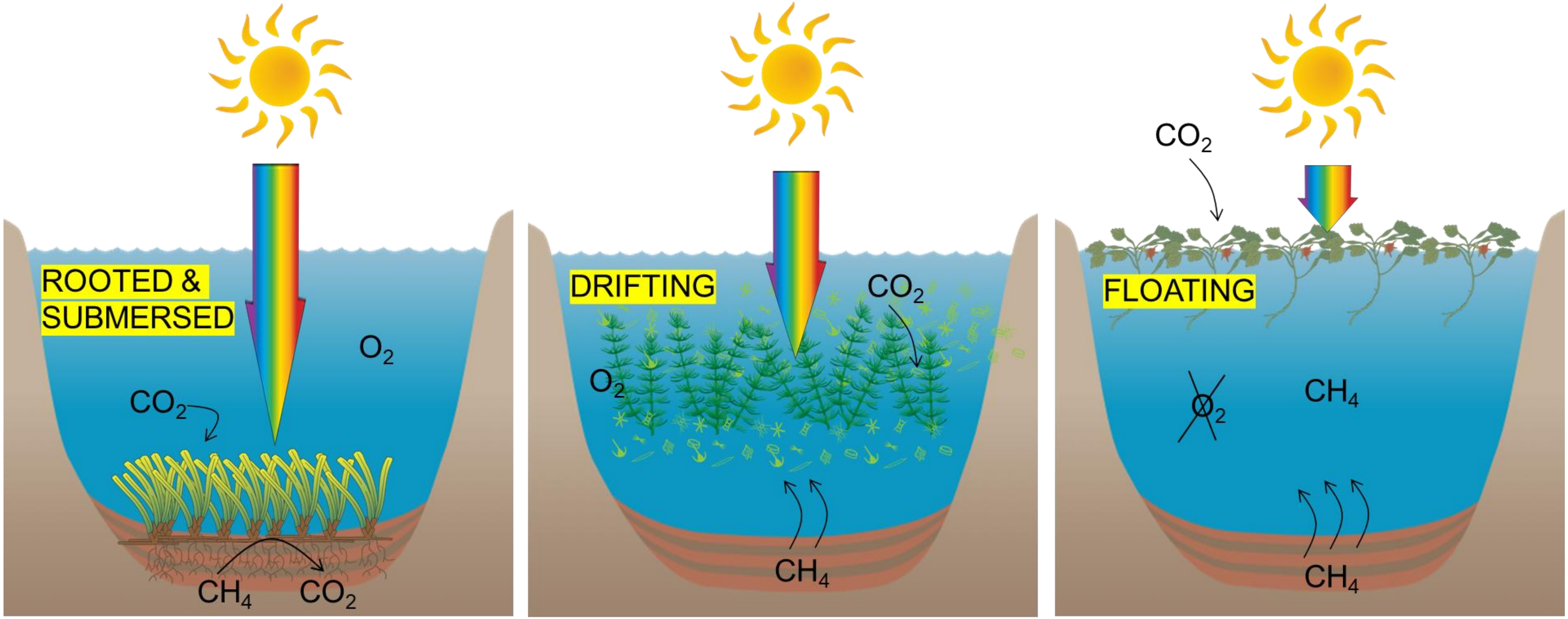
SV: -60%

SO: -90%

SOV: -95%

from Benelli and Bartoli, 2021. Worms and submersed macrophytes reduce methane release and increase nutrient removal in organic sediments. Limnology and Oceanography Letters, 6(6), pp.329-338.

Floating plants dominance as stable state due to interacting eutrophication, climate change and invasions?



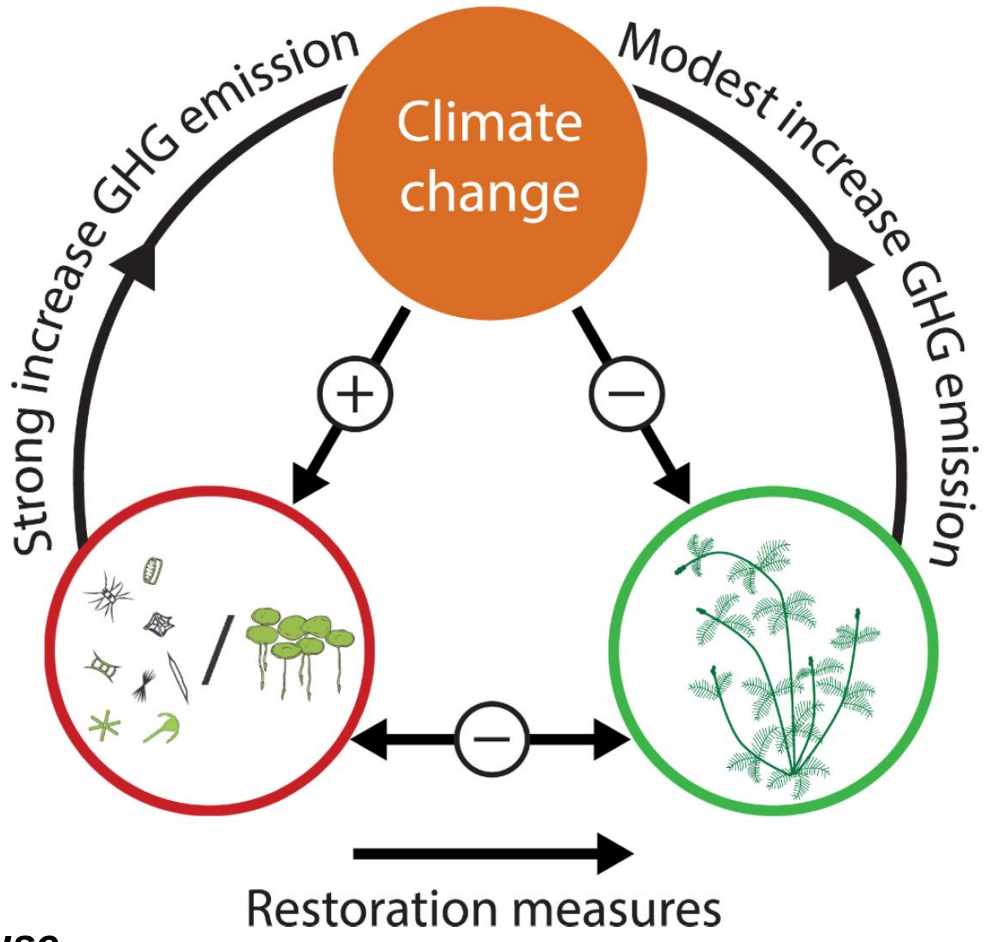
INTERACTING EUTROPHICATION, INVASIONS & CLIMATE CHANGE

Interacting climate and macrophyte changes increase GHG emissions?

Climate warming will favour the dominance of algae and free-floating plants over submerged plants, and the shift among these functional types will affect GHG emissions.

Aben et al. (2022) have tested the interacting effects of plant type and warming on GHG fluxes and demonstrated that the response to experimental warming (i.e., increased ebullition rates) was strongest for free-floating and lowest for submerged plant-dominated systems.

Management strategies should favour submerged plant dominance to mitigate GHG emissions.



From Aben et al., 2022. Temperature response of aquatic greenhouse gas emissions differs between dominant plant types. Water Research, 226, p.119251.

COORDINATOR

idener
SCIENTIFIC COMPUTING

PARTICIPANTS

Kneia

BOKU

fic
fundación para la investigación del clima

WAGENINGEN
UNIVERSITY & RESEARCH

Wetlands
INTERNATIONAL

stroming

UNIVERSITY OF
EASTERN FINLAND

MUNICÍPIO DE
ALPIARÇA

BAX
& COMPANY
VALUE FROM SCIENCE AND TECHNOLOGY

IUCN
National Committee
of The Netherlands

KU LEUVEN

UNIVERSITY OF TARTU
UNIVERSITAS TARTUENSIS
1632

Autorità di Bacino
Distrettuale del Fiume Po

UNIVERSITÀ
DI PARMA

rss
remote sensing
SOLUTIONS

UNIVERSIDADE
DE ÉVORA

UNIVERSITY
OF OULU

RESILIENT WETLANDS

EXPLORING THE ROLE OF INLAND WETLANDS & PEATLANDS IN MITIGATING CLIMATE CHANGE

Contacts:

Vanessa Ferreira de Almeida - coordinator
vanessa.ferreira@idener.ai

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

Discover more about REWET

Funded by the
European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.