Ecosystemic functions in shallow water environments

Marco Bartoli

Department of Environmental Sciences, Parma University, 43100 Parma, Italy

INTRODUCTION

In shallow water environments a number of processes and functions are regulated by macrophytes and vary according to primary producers typology

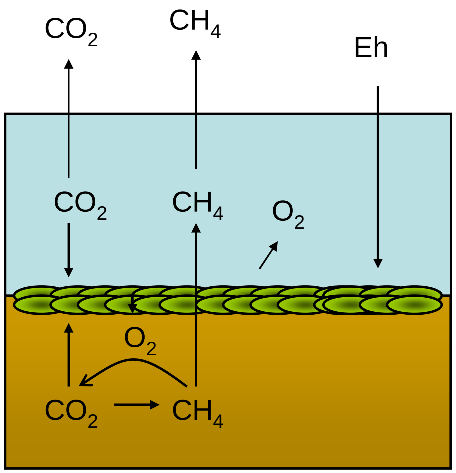
Many studies report on the recent evolution of primary producer communities (Malmer, 1986; Scheffer et al., 2003; Hauxwell & Valiela 2004; Viaroli et al., 2008).

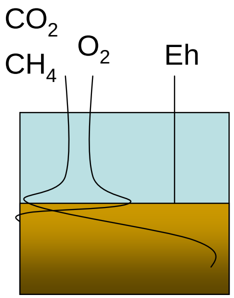
Basically, natural and anthropogenic eutrophication results in higher nutrients availability in the water column, higher production by phytoplankton and epiphyte communities, decreased water transparency and progressive disappearance of submersed rooted phanerogams.

In freshwater shallow environments pleustonic communities can develop (Scheffer et al., 2003).

Pleustophytes typically colonize the whole water surface, shade the water column and outcompete other primary producers.

Monospecific stands of pleustophytes trigger and maintain anoxic conditions over long time periods, alter the functioning of shallow water bodies and C, N and P dynamics.

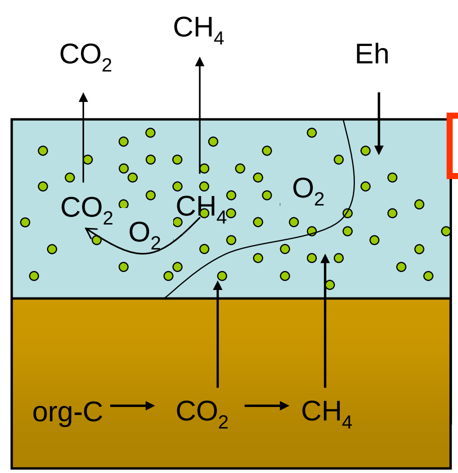


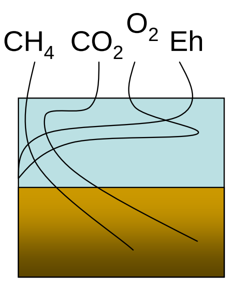


Microphytobenthos

- High light penetration
- High CH_4 reoxidation, low efflux to the atmosphere
- CO_2 net flux dependent on internal and allochtonous org-C load
- burial of org-C irrelevant

C fixed = C released ; C released mostly as CO_2

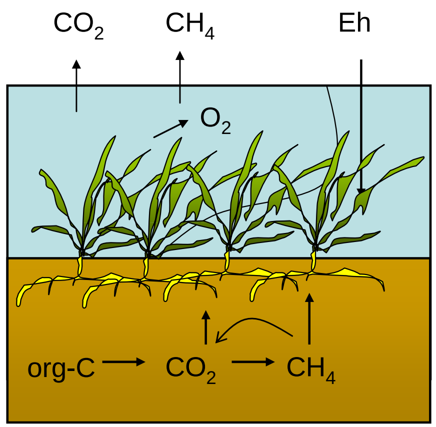




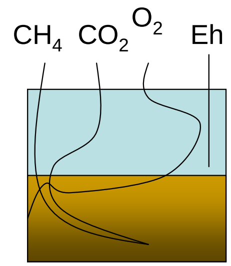
Phytoplancton

- Limited light penetration
- Surface O_2 supersaturation, bottom anoxia
- CH_4 reoxidation in the water column, night efflux to the atmosphere (?)
- CO_2 net flux dependent on internal and allochtonous org-C load and CO_2 uptake
- burial of labile org-C, fluffy sediment, reduced and anoxic

C fixed >= C released ; C released as CO_2 and in minor portion as CH_4



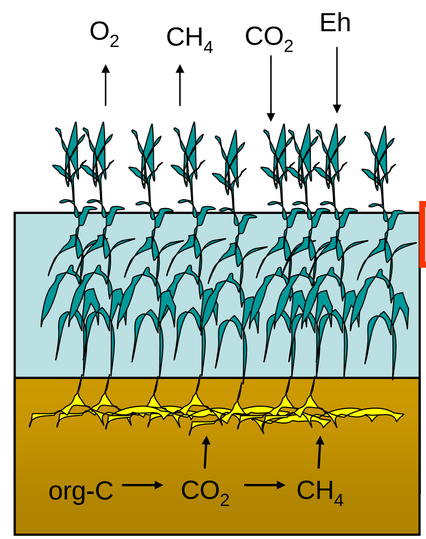
Phanerogams



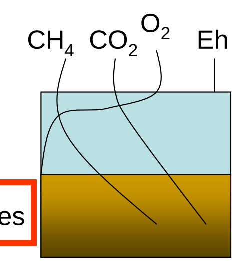
- Light penetration
- O_2 supersaturation (daylight), oxic micro-niches within sediments
- CH_4 reoxidation in the sediment (daylight), night efflux to the atmosphere (?)
- CO_2 net flux dependent on internal and allochtonous org-C load and CO_2 uptake
- burial of org-C dependent on litter C/N ratio
- highest rates of CH4 production but highest reoxidation (?)

C fixed >> C released ; C released as CO_2 and in minor portion as CH_4

Large body of literature, with detailed and exhaustive investigation on gas transport mechanisms

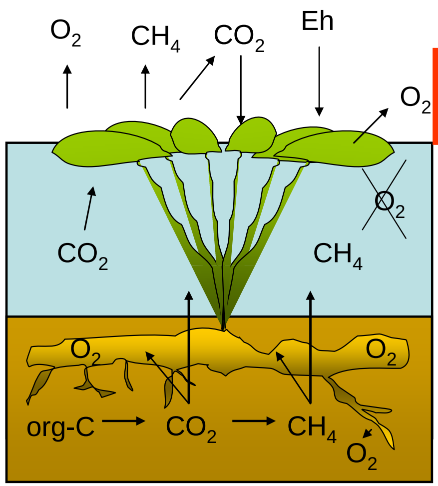


Emergent macrophytes

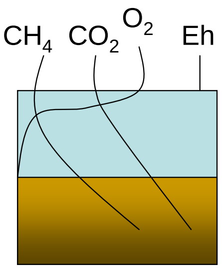


- Limited light penetration
- O_2 hypoxia (?)
- CH_4 and CO_2 diffusion in aerenchima
- burial of org-C due to high litter C/N ratio
- reoxidation of produced CH_4

C fixed >> C released ; C released as CO_2 and in minor portion as CH_4



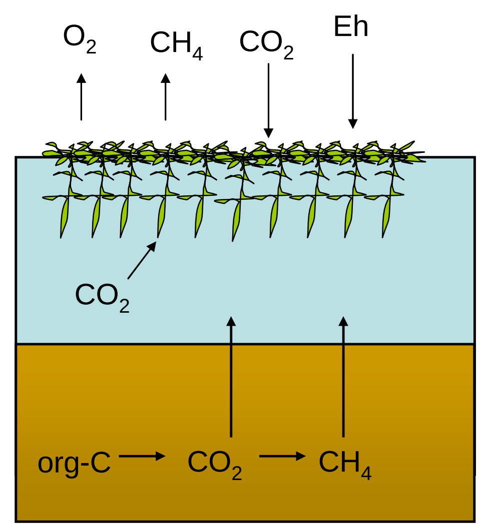
Floating leaved, sediment rooted



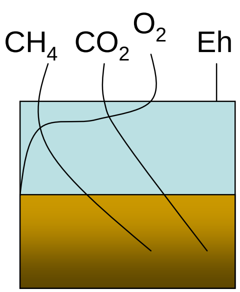
No light penetration
-Hypoxia/anoxia
-CH_4 and CO_2 supersaturation
-CH4 and CO2 diffusion in aerenchima
-CO_2 net flux dependent on internal and allochtonous org-C load, CO_2 uptake and degree of coverage (barrier)
-burial of org-C dependent on litter C/N ratio
-reoxidation of produced CH_4
-rhizome as C reserve
-direct contact between porewater and atmosphere via aerenchimous tissue

Large body of literature, with detailed and exhaustive investigation on gas transport mechanisms

C fixed >= C released ; C released as CO_2 and as CH_4



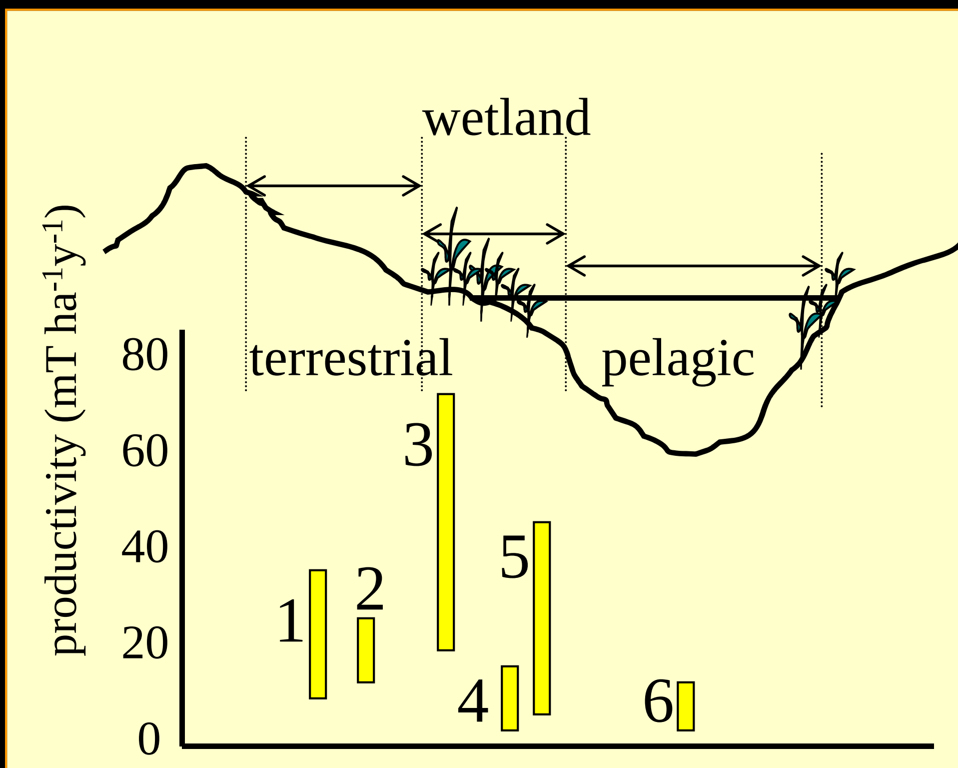
Pleustophytes



-No light penetration
-anoxia
-CH_4 and CO_2 supersaturation
-CH4 and CO2 diffusion in aerenchima
-CO_2 net flux dependent on internal and allochtonous org-C load, CO_2 uptake and degree of coverage (barrier)
-burial of org-C dependent on litter C/N ratio
-limited reoxidation of produced CH_4 (?)

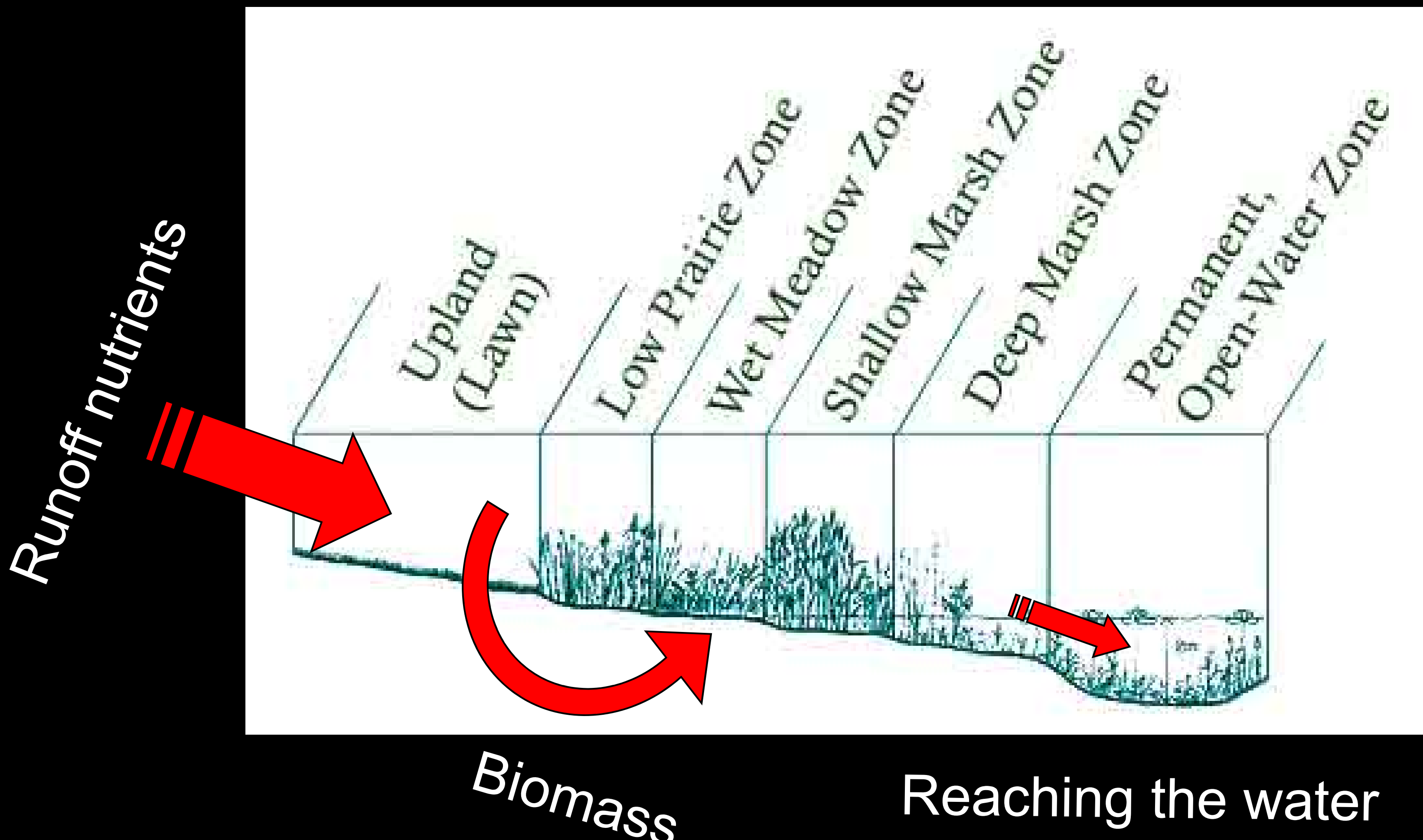
C fixed >= C released ; C released as CO_2 and as CH_4

· **Wetlands macrophytes colonize saturated sediments; these plants are characterised by extremely high productivity, up to 80 ton $ha^{-1}y^{-1}$ (Wetzel, 1990)-**



1 Forests
2 Grass
3 Emergent macrophytes
4 Submerged macrophytes
5 Epiphytes
6 Phytoplancton

· **Wetlands plants do act as a "physical sponge": transition areas with <u>elevated retention potentials</u> for nutrients**

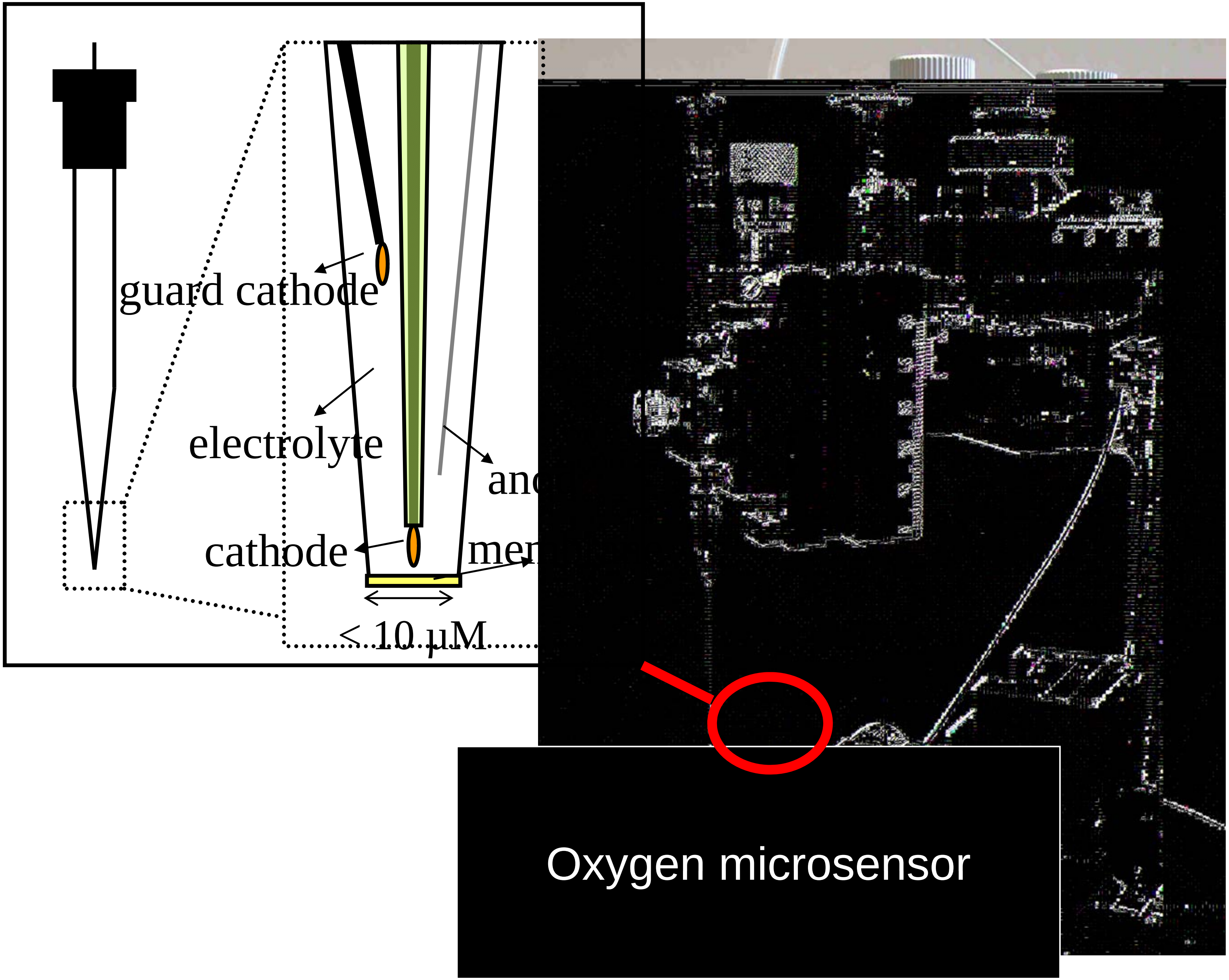


Rooted macrophytes colonize an hostile environment…

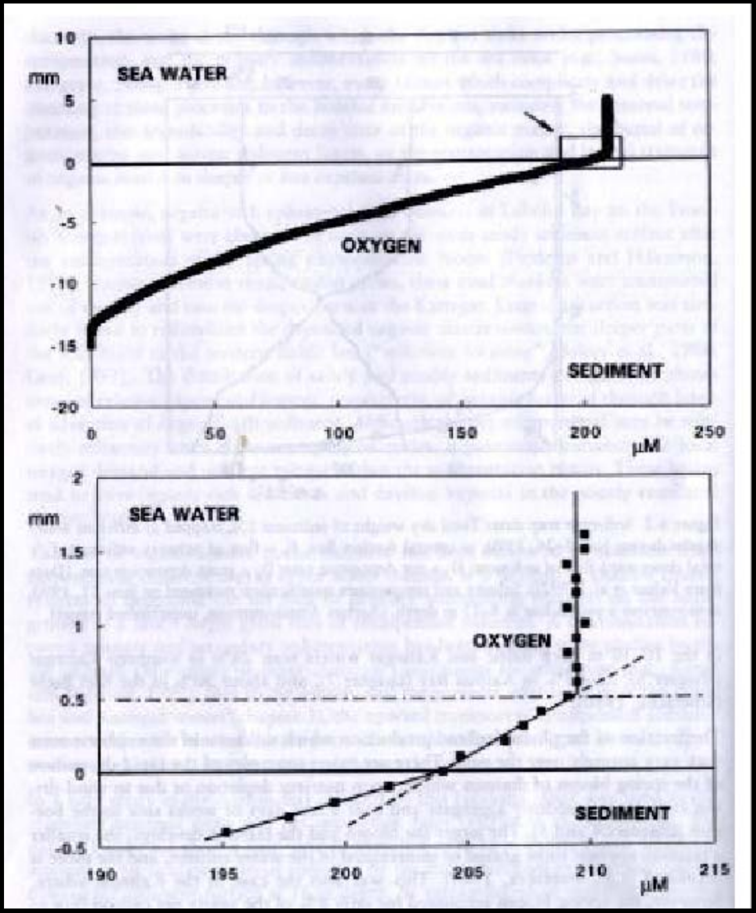
Flooded soils and sediments have a common feature: porewaters are anoxic due to:

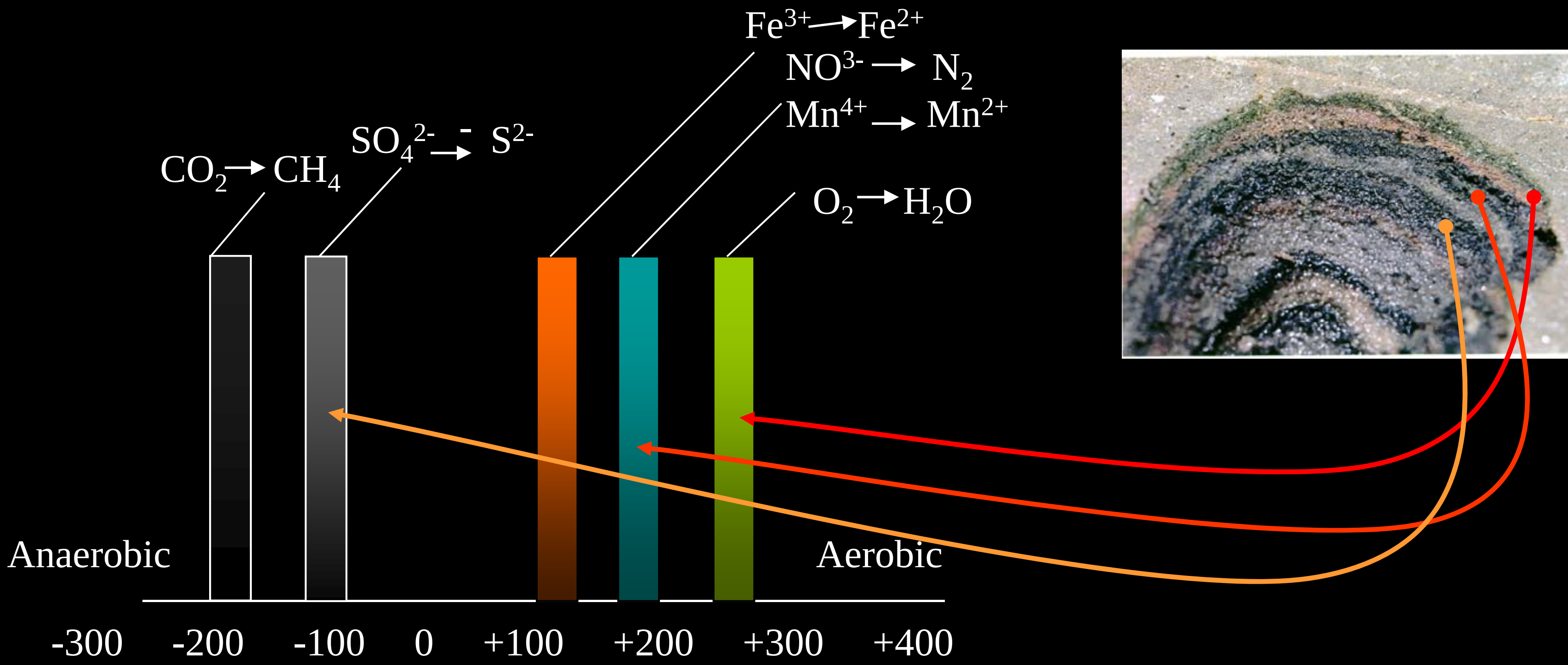
-low oxygen solubility in water
-extremely slow diffusion
-sediment porosity and tortuosity
-respiratory demand of electron acceptors for organic matter oxidation processes

Resulting anoxia can be coupled to more or less reducing conditions depending on prevailing microbial metabolism, quantity and quality of organic matter and sediment features (i.e. iron availability).


guard cathode
electrolyte
cathode
< 10 µM
Oxygen microsensor

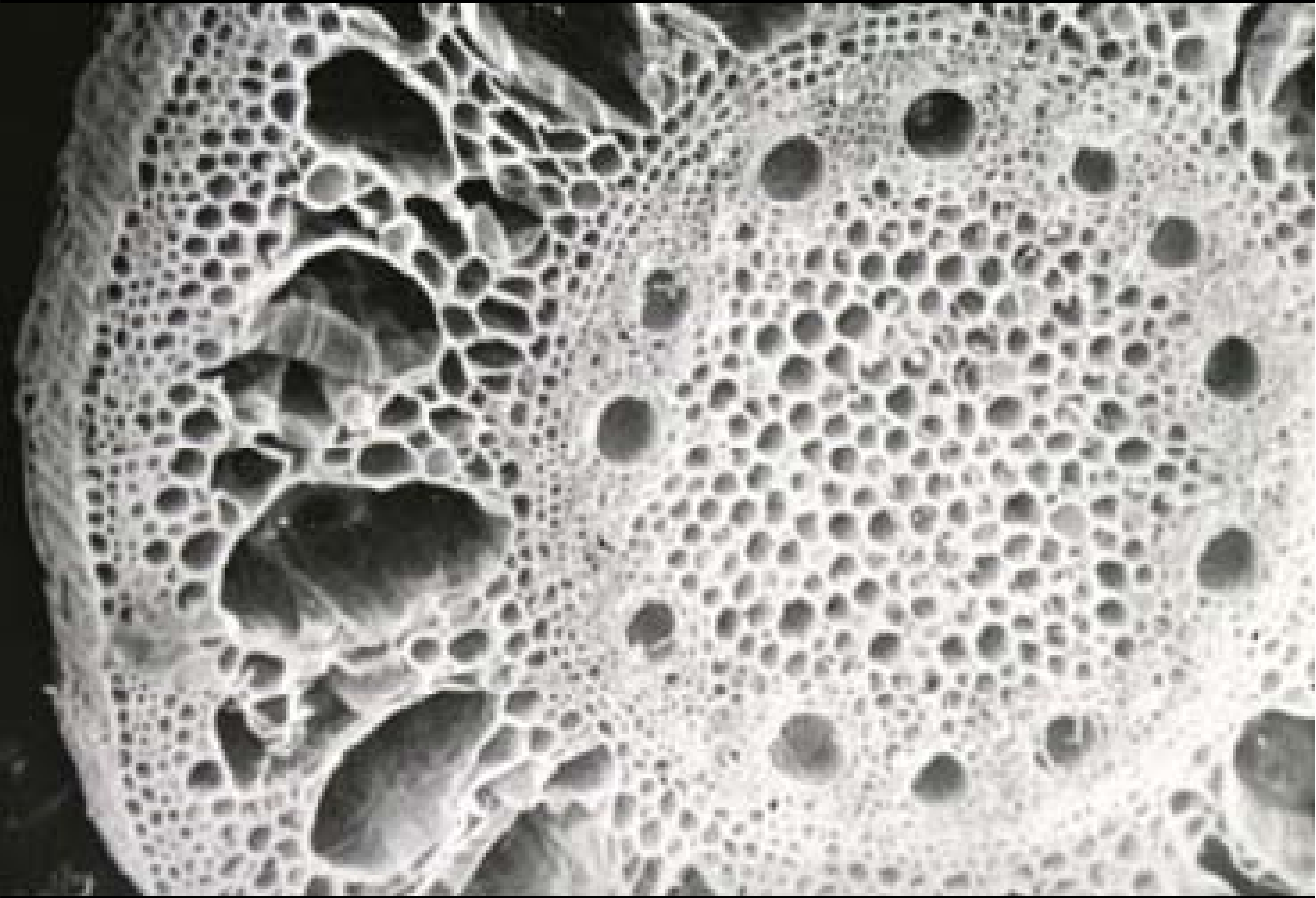
Microprofiling of sediment cores



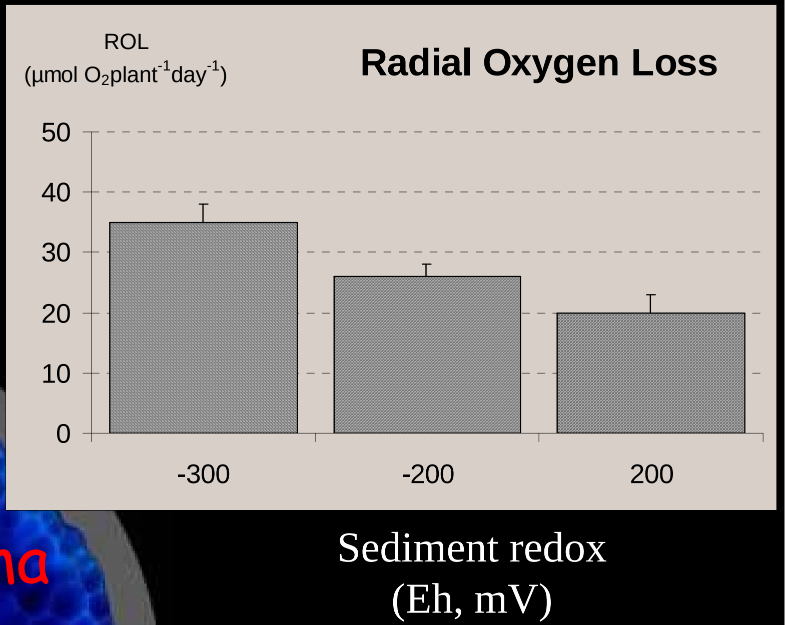


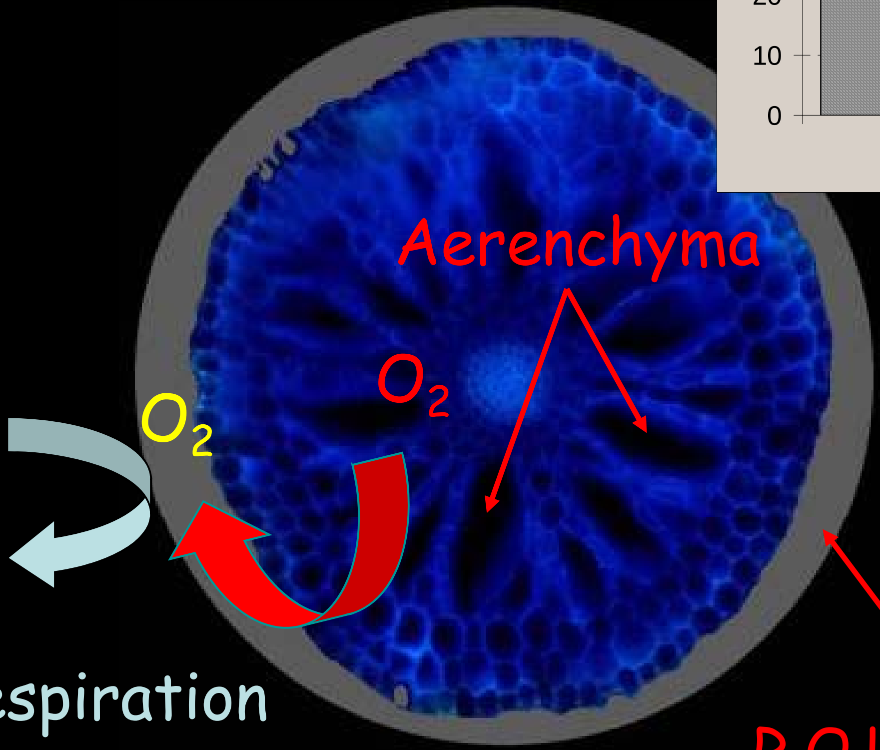
Redox sequence

Process	Electron acceptor	Energy yeld (-ΔG°, kJ mol^{-1})
Aerobic respiration	O_2	125.1
Denitrification	NO_3^-	118.8
Manganese reduction	MnO_2	94.5
Iron reduction	$Fe(OH)_3$	24.3
Sulphate reduction	SO_4^{2-}	25.4
Methanogenesis	CO_2	23.2



Biogeochemical processes at the sediment/rhyzosphere interface



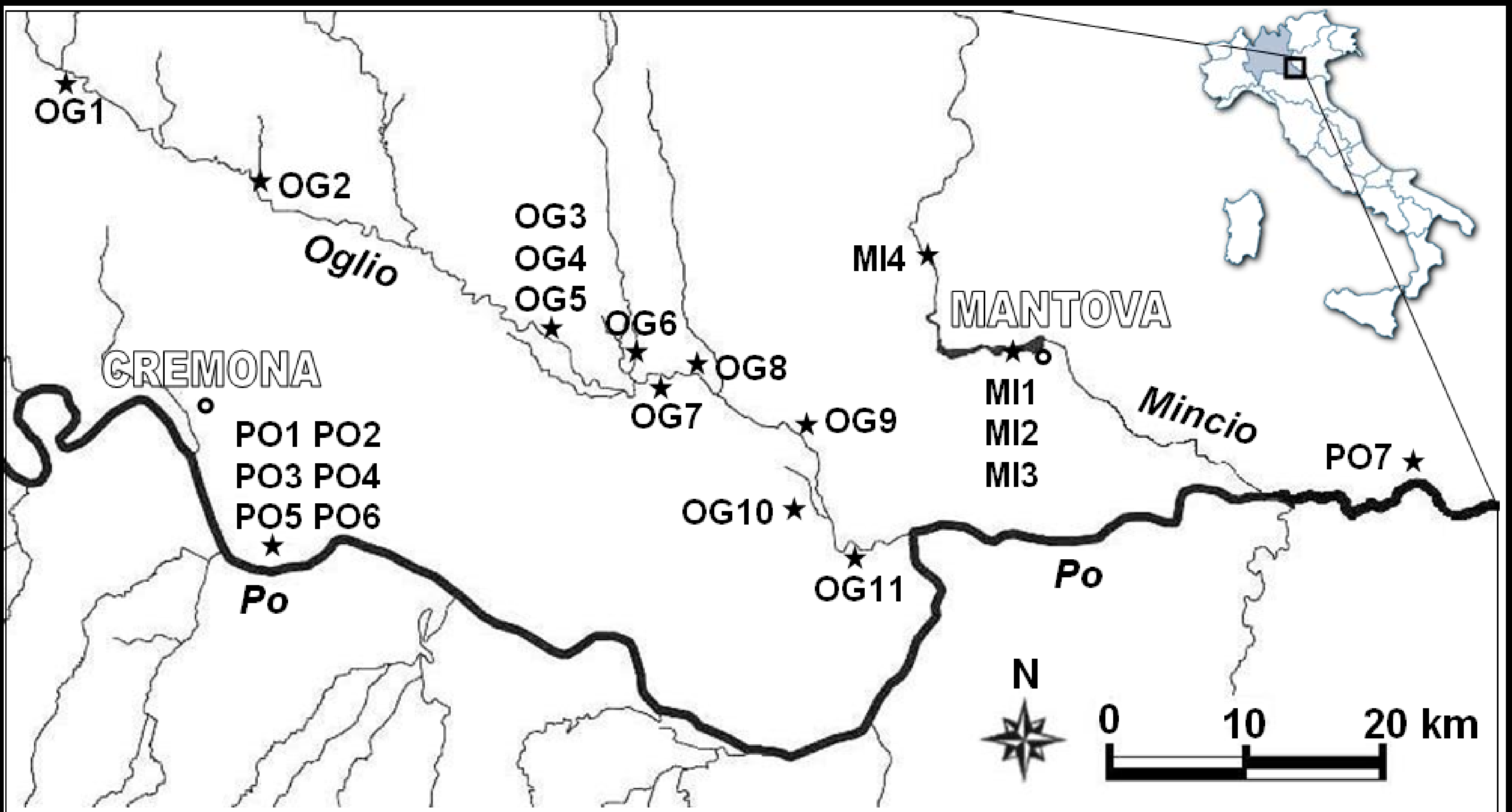


Coupled oxidation

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

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

Study area



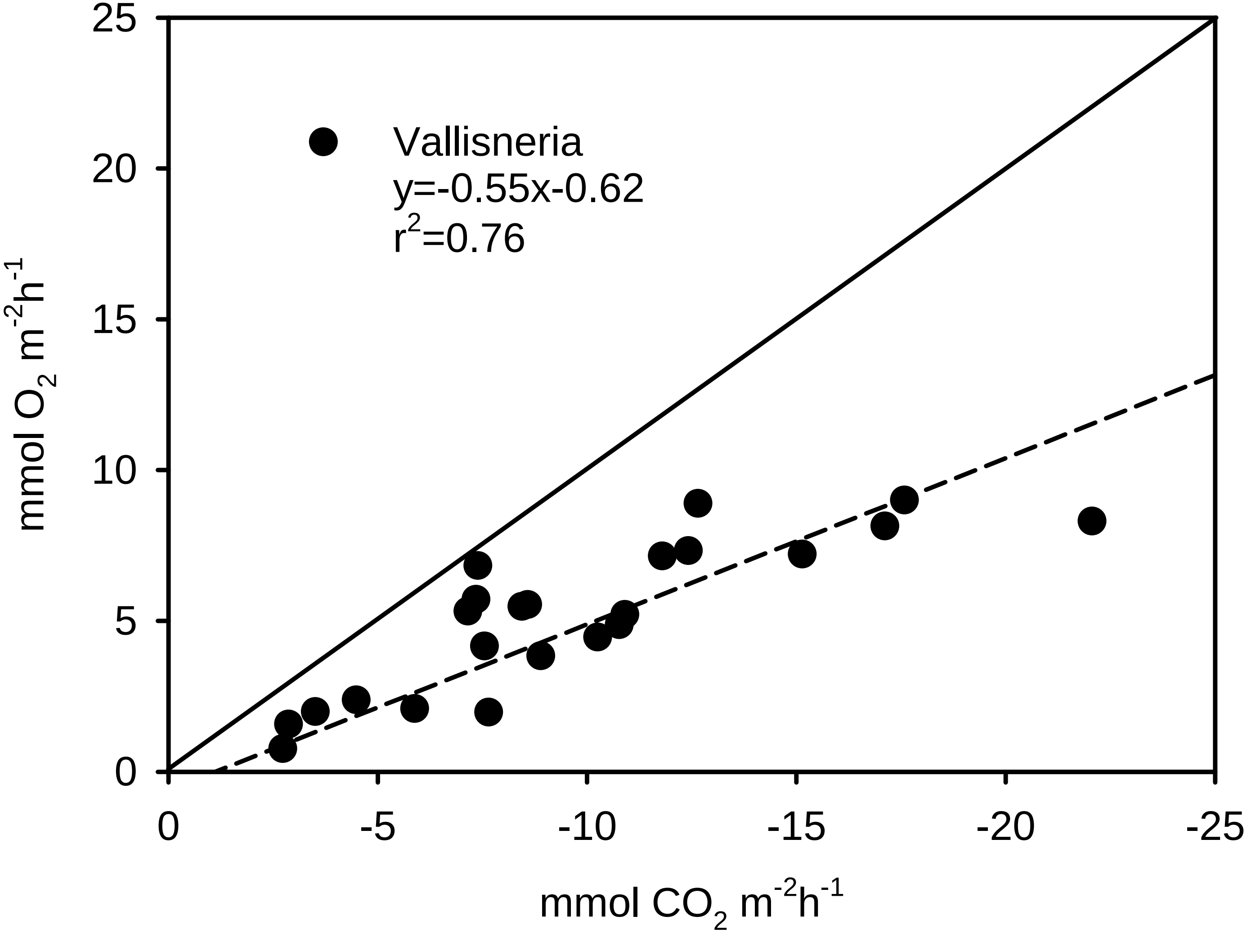
Riverine wetlands, oxbow lakes, peat bogs, shallow eutrophic lakes

Measurements on *V. spiralis*

- Leaf marking
- Intact cores incubation (light and dark)
- Transplanting, *in situ* growth, incubations under controlled conditions
- Isotope pairing and nitrification coupled denitrification (injection of $^{15}NH_4^+$ in porewater)
- Porewater analyses during early sediment colonisation stages

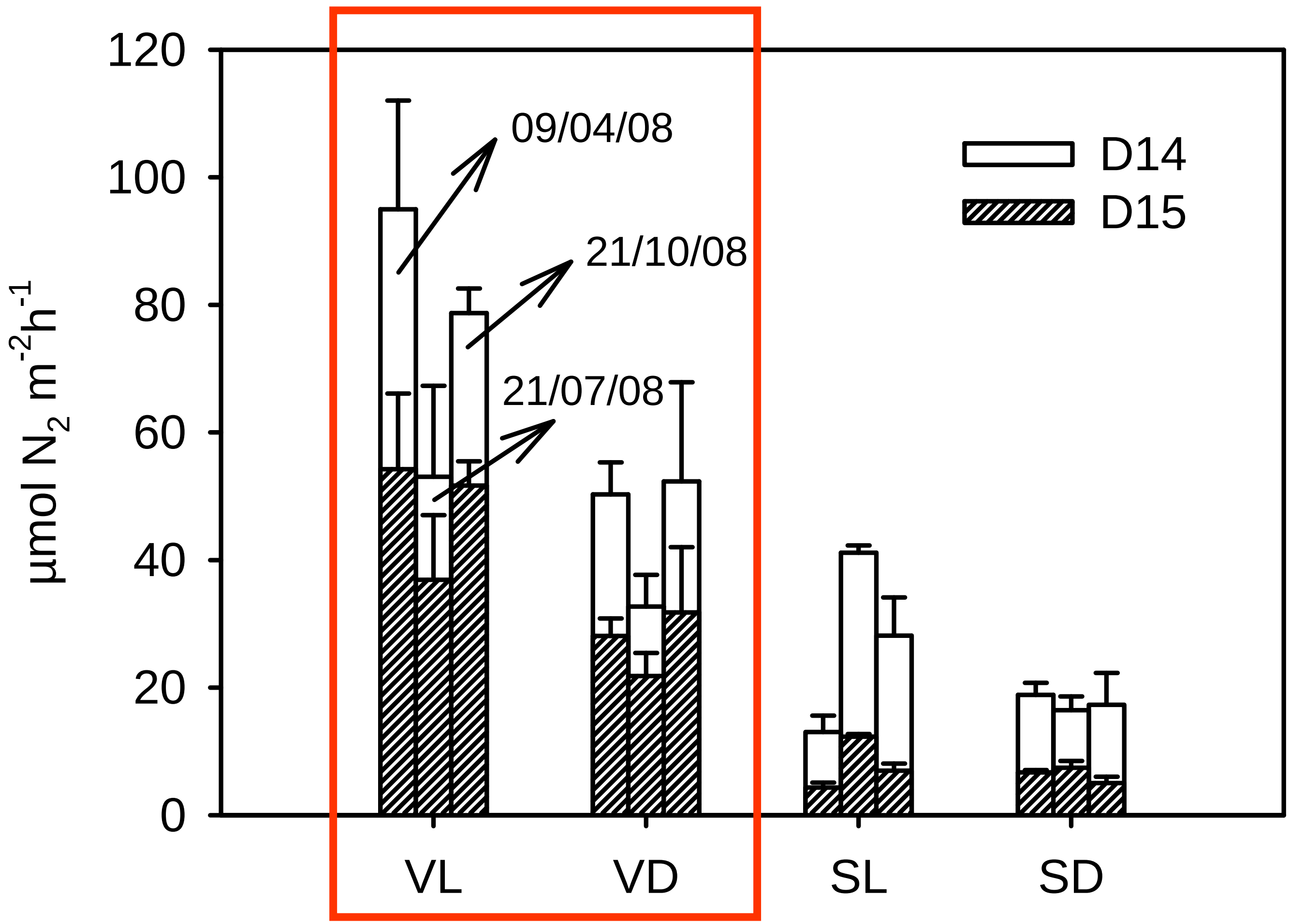
Sand Jensen, 1975; Risgaard Petersen & Jensen, 1997 Daslgaard et al., 2000

Photosynthetic quotient



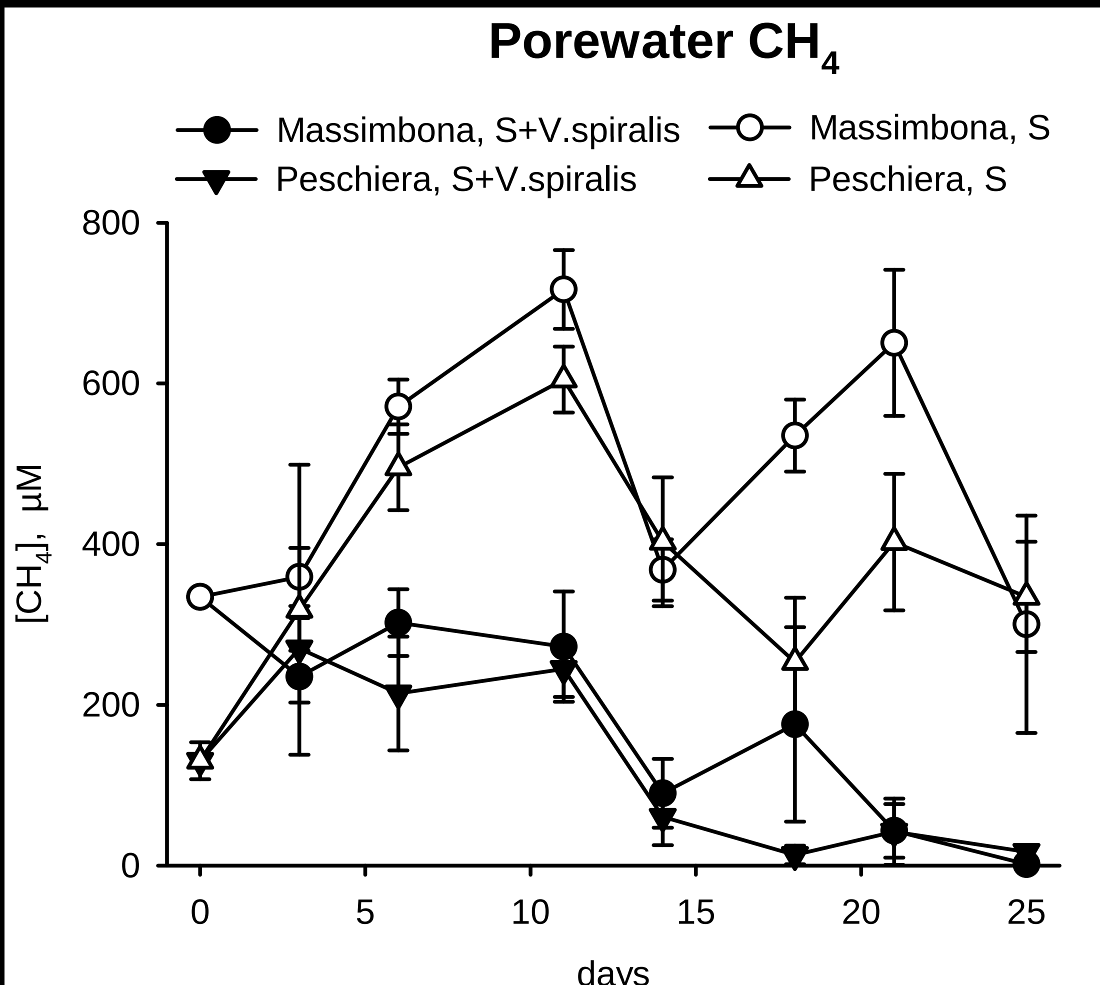
Pinardi et al., 2009. Journal of Limnology

Nitrification coupled denitrification

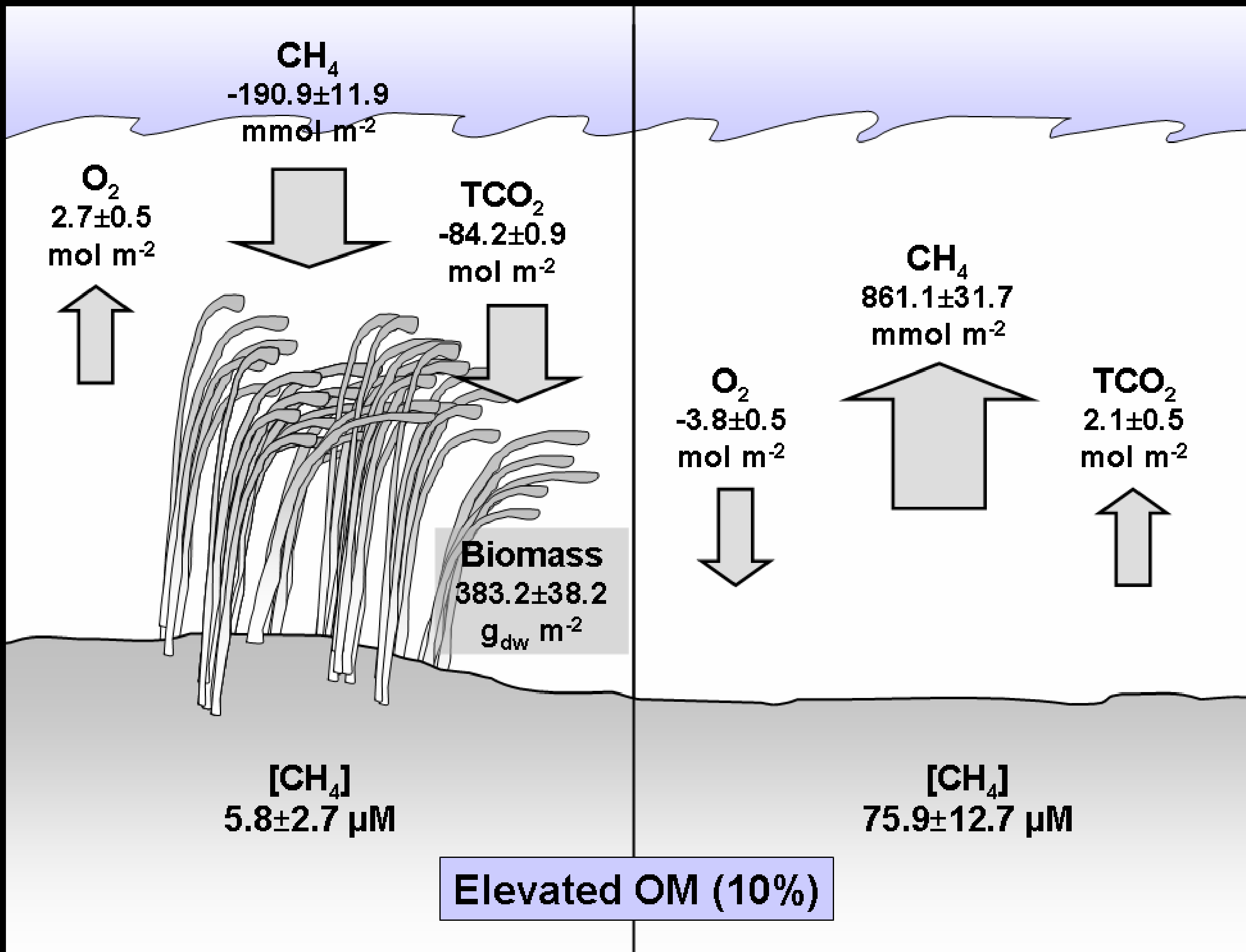


Evidences of oxygen transport during the light and dark phase,
Partial accumulation of nitrate in the porewater

Racchetti et al., in preparation


Porewater CH_4
Massimbona, S+V.spiralis
Massimbona, S
Peschiera, S+V.spiralis
Peschiera, S
$[CH_4]$, µM
800
600
400
200
0
0
5
10
15
20
25
days

Submerged macrophyte meadows alter benthic fluxes

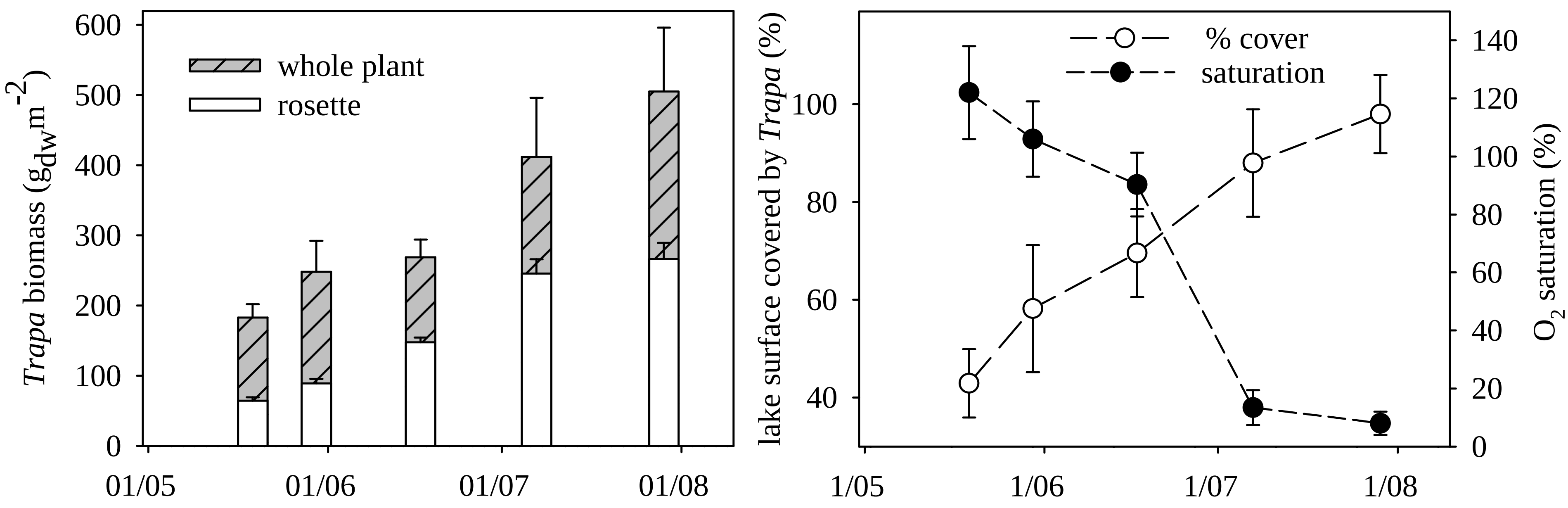


Measurements on *T. natans*

- Biomass evolution
- Net gas Exchange (static chambers), light and dark, 2 weeks frequency, from April to September, with and without plants
- Water column characterisation

Seasonal monitoring of *T.natans* growth:

Implications for key water column parameters (i.e. dissolved oxygen)



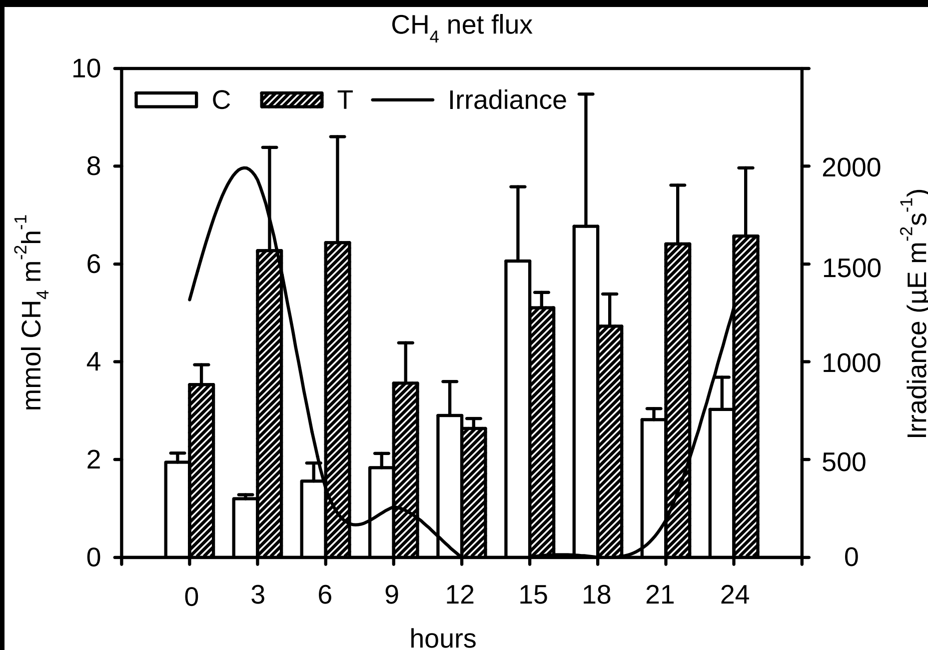
Caraco & Cole, 2002

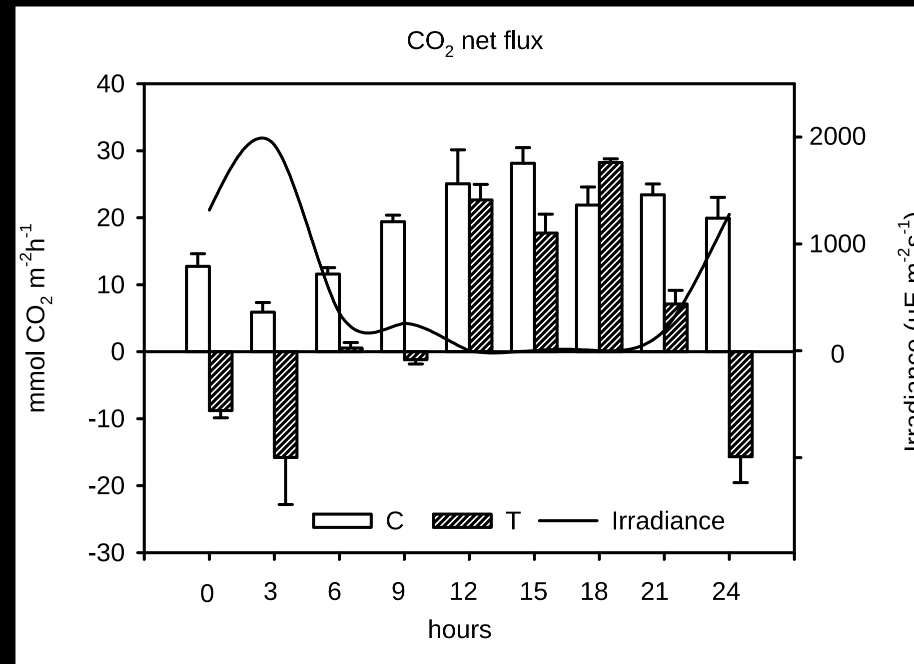
Table 1. Physico-chemical features of the water column at the sampled stations C (control site: water column devoid of plants) and T (Trapa natans); S=surface, B=bottom. Minimum and maximum values were recorded during a 24 hours cycle of investigation carried out on 29 July 2005

	temperature (°C)		pH		O_2 (µM)		CO_2 (mM)		CH_4 (µM)		NH_4^+ (µM)	
	C	T	C	T	C	T	C	T	C	T	C	T
S	25.1÷30.7	25.5÷30.7	6.77÷6.93	6.70÷6.93	6÷215	2÷351	1.24÷2.78	0.97÷2.69	42÷190	90÷223	1.1÷4,3	0.6÷3.8
B	24.6÷28.6	25.1÷28.7	6.68÷6.79	6.67÷6.89	0÷50	0÷47	1.82÷2.83	1.94÷3.86	184÷325	199÷425	2.1÷15	3.5÷26.5



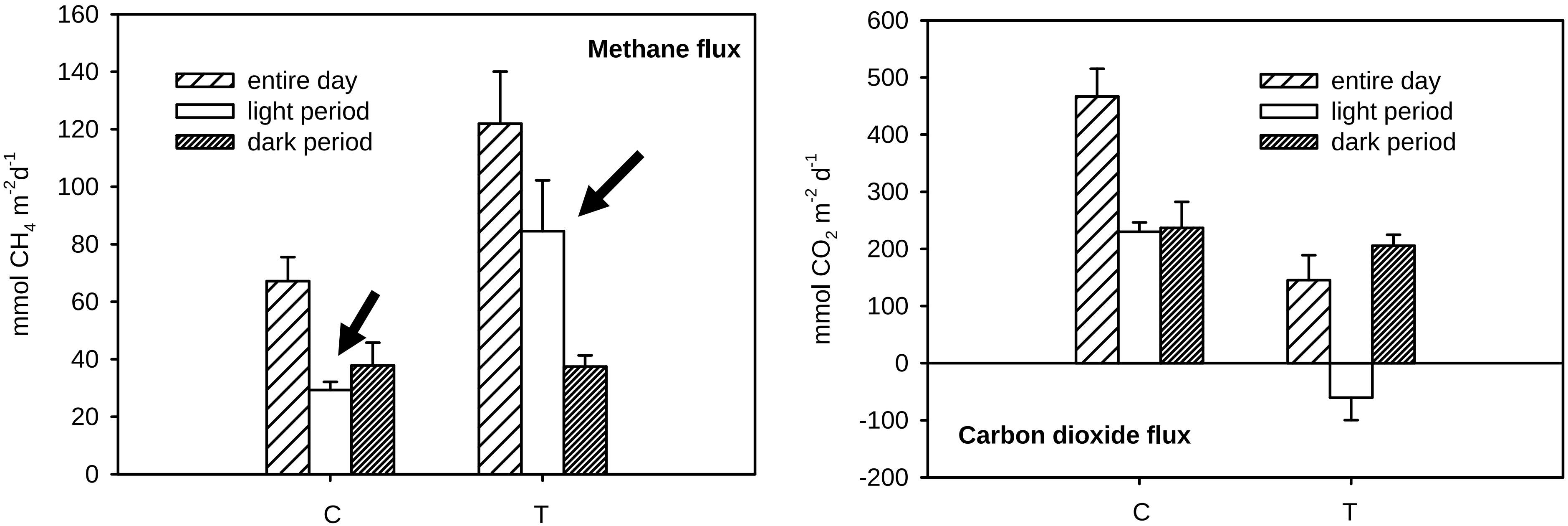

CH_4 and CO_2 fluxes across the water-atmosphere at *T. natans* biomass peak





Each bar is the average±standard deviation of 3 replicate incubations, positive values means efflux to the atmosphere, continuous line represents irradiance.

Daily fluxes of CO_2 and CH_4 at *T.natans* biomass peak



Data integrated over the vertegative period:

-10.38 ± 3.86 mol CO_2 m^{-2} $period^{-1}$
$+8.82 \pm 3.29$ mol CH_4 m^{-2} $period^{-1}$

CH_4 rel:CO_2 fix =0.85

Temperate reed wetland, annual study
50 mol CO_2 fixed; 4 mol CH_4 released (13 mol reoxidised)
CH_4 rel:CO_2 fix=0.09

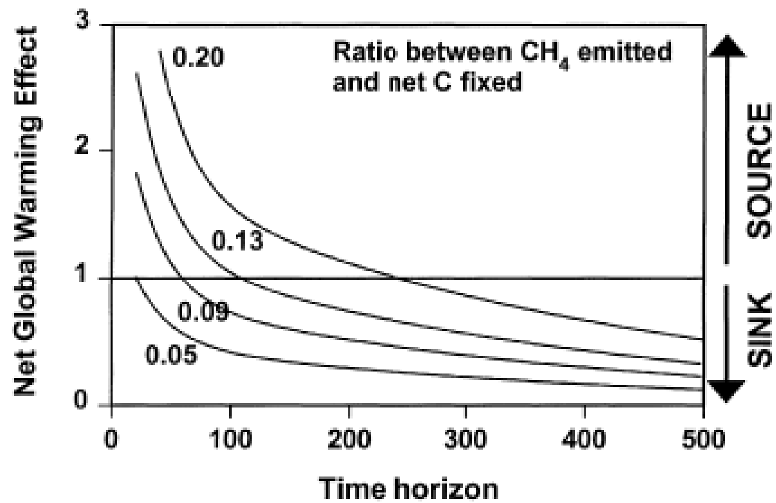
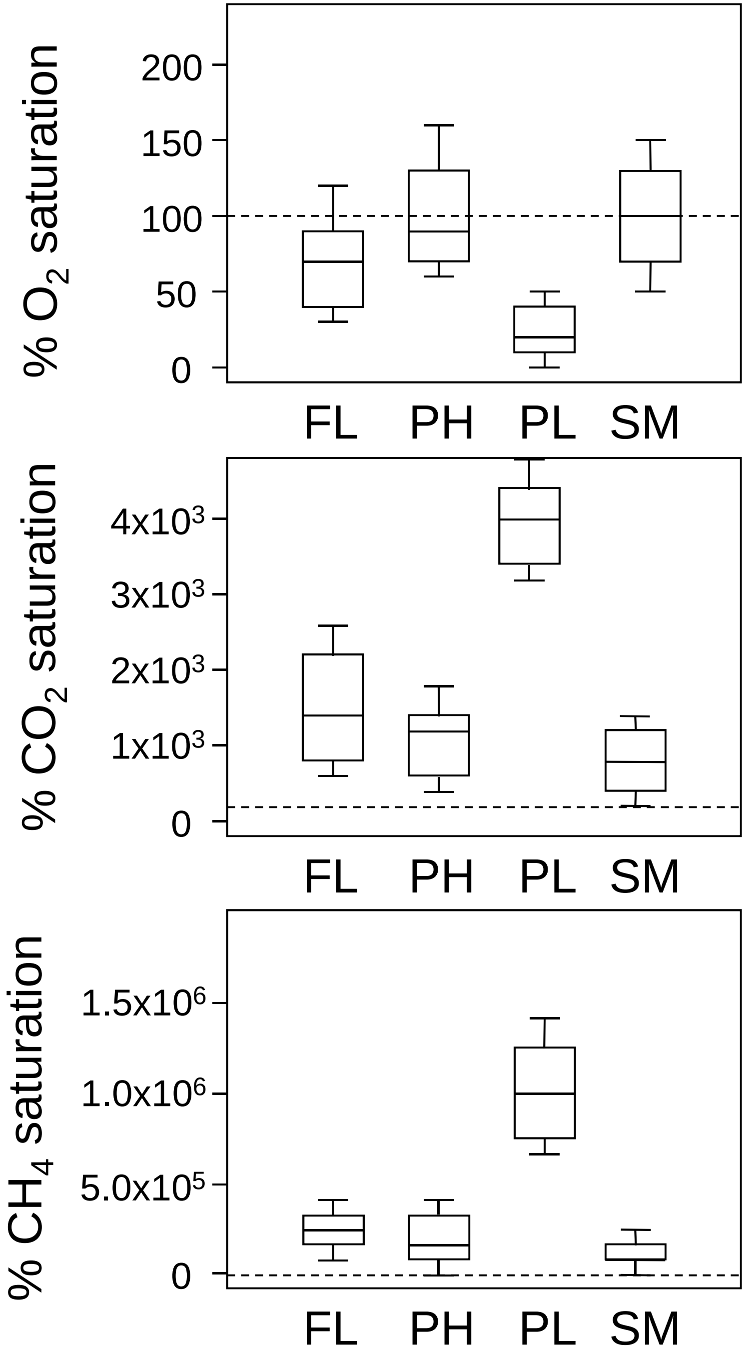


Fig. 5. The relative net radiative forcing (relative to CO_2) over time for wetlands where the molar ratio between CH_4 emitted and net C fixed is 0.20, 0.13, 0.09 and 0.05, respectively. Whiting and Chanton (1997) reported that the ratio between CH_4 emitted and net C fixed for a range of wetlands generally varies between 0.05 and 0.13. In the present study, a ratio of 0.09 for a temperate *Phragmites* wetlands was found. When the curves are located above 1, the wetland can be regarded as a source for greenhouse gases and so will increase the global warming, and if the curves are located below 1, the wetland can be regarded as a sink for greenhouse gases and thus will attenuate the global warming.



FL=floating leaved (*Nuphar, Nymphaea, Nelumbo*)

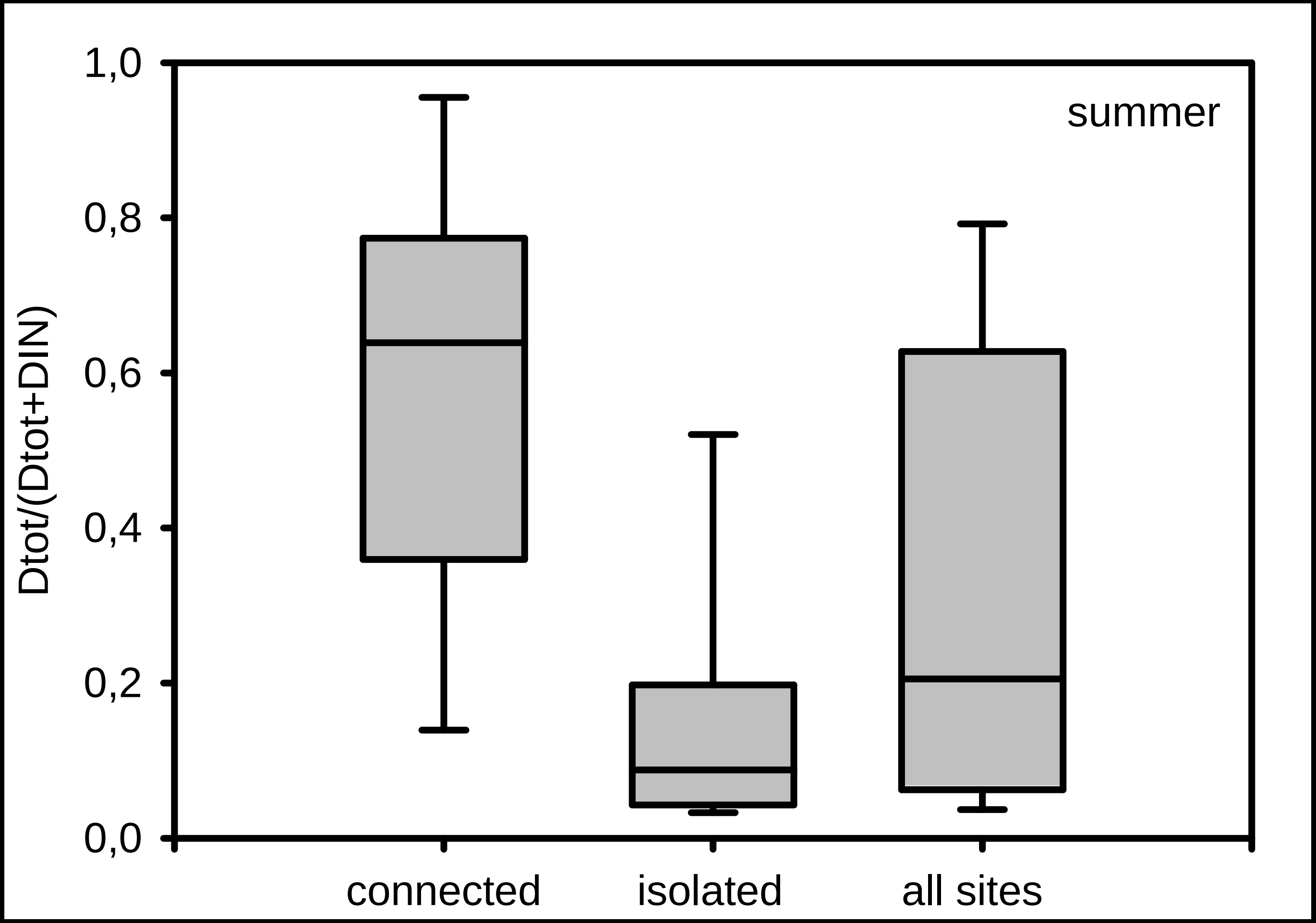
PH=phytoplankton

PL=pleustophytes (*Lemna, Trapa, Salvinia*)

SM=submersed macrophytes (*Vallisneria, Ceratophyllum*)

Loss of lateral connectivity with main water bodies and loss of functions:

Denitrification efficiency



Most of isolated sites, characterised by NH_4^+ (and PO_4^{3-}) recycling, host PL

Conclusions

Increasing pressures in shallow aquatic environments lead to loss of macrophytes biodiversity, increase of dominance (monospecific stands) and loss of ecosystemic functions

Consequences

Altered biogeochemical pathways
Sediment and water anoxia
Lower denitrification
Higher recycling of N and P
Higher emission of CH_4

Thank you for your attention