Methane production in oxic surface waters is widespread but insufficient to support methanotrophy in tropical lakes

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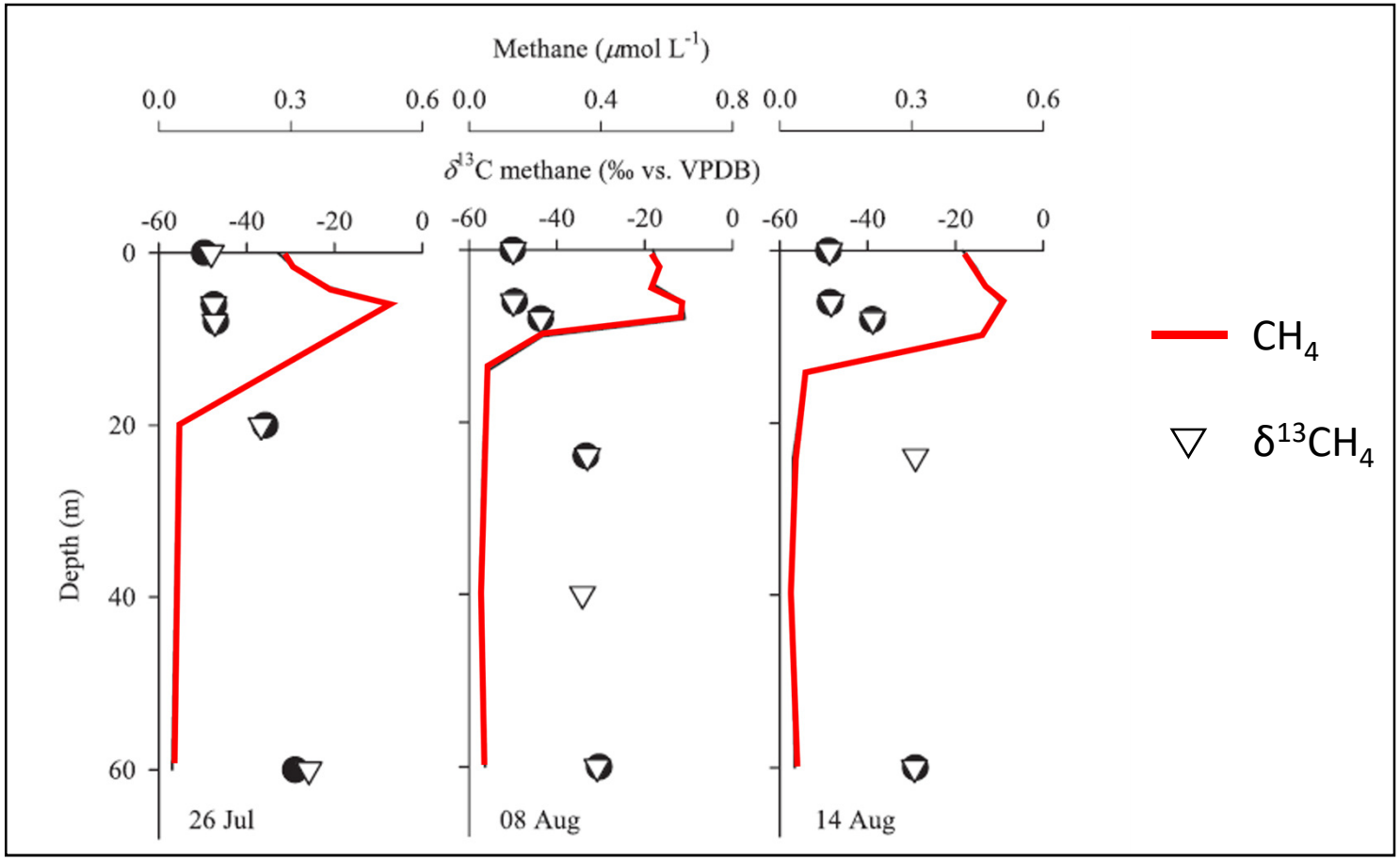
Classical view of the CH_4 dynamic in lakes

Frequently observed higher CH_4 concentration (^{13}C depleted CH_4) in epilimnion than bottom waters is a « paradox »



Adapted from Tang et al. 2014, Lake Stechlin (Germany)

Classical view of the CH_4 dynamic in lakes

No Longer a Paradox: The Interaction Between Physical Transport and Biological Processes Explains the Spatial Distribution of Surface Water Methane Within and Across Lakes

Tonya DelSontro,* Paul A. del Giorgio, and Yves T. Prairie

ARTICLE

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Oxic water column methanogenesis as a major component of aquatic CH_4 fluxes

Matthew J. Bogard[1], Paul A. del Giorgio[1], Lennie Boutet[1], Maria Carolina Garcia Chaves[1], Yves T. Prairie[1], Anthony Merante[1] & Alison M. Derry[1]

ARTICLE

DOI: 10.1038/s41467-017-01648-4 OPEN

Full-scale evaluation of methane production under oxic conditions in a mesotrophic lake

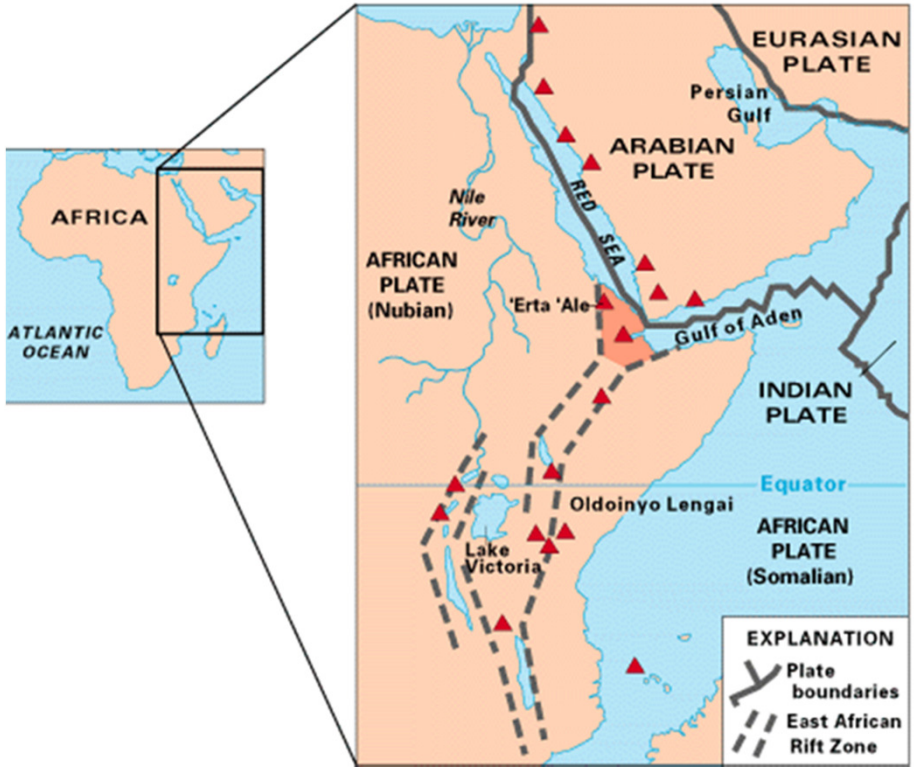
D. Donis[1], S. Flury[1,2], A. Stöckli[3], J.E. Spangenberg[4], D. Vachon[1] & D.F. McGinnis[1]

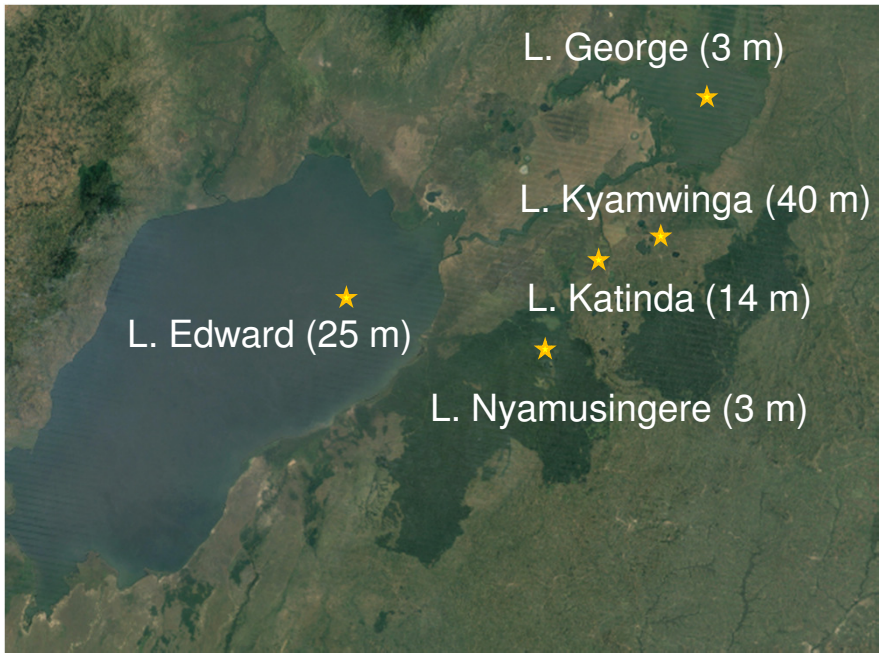
Several recent studies (mass-balance, mesocosms) **proposed that well-oxygenated surface waters are an important CH_4 production site :**

- Responsible for ~ 90% of CH_4 emissions in L. Halwill (Donis et al. 2017)
- Major cause of CH_4 oversaturation globally along with lateral transport (DelSontro et al. 2017)
- $\delta^{13}C$-CH_4 data (apparent fractionation) suggests production via acetoclastic pathway (Bogard et al. 2014) in well-oxygenated waters.

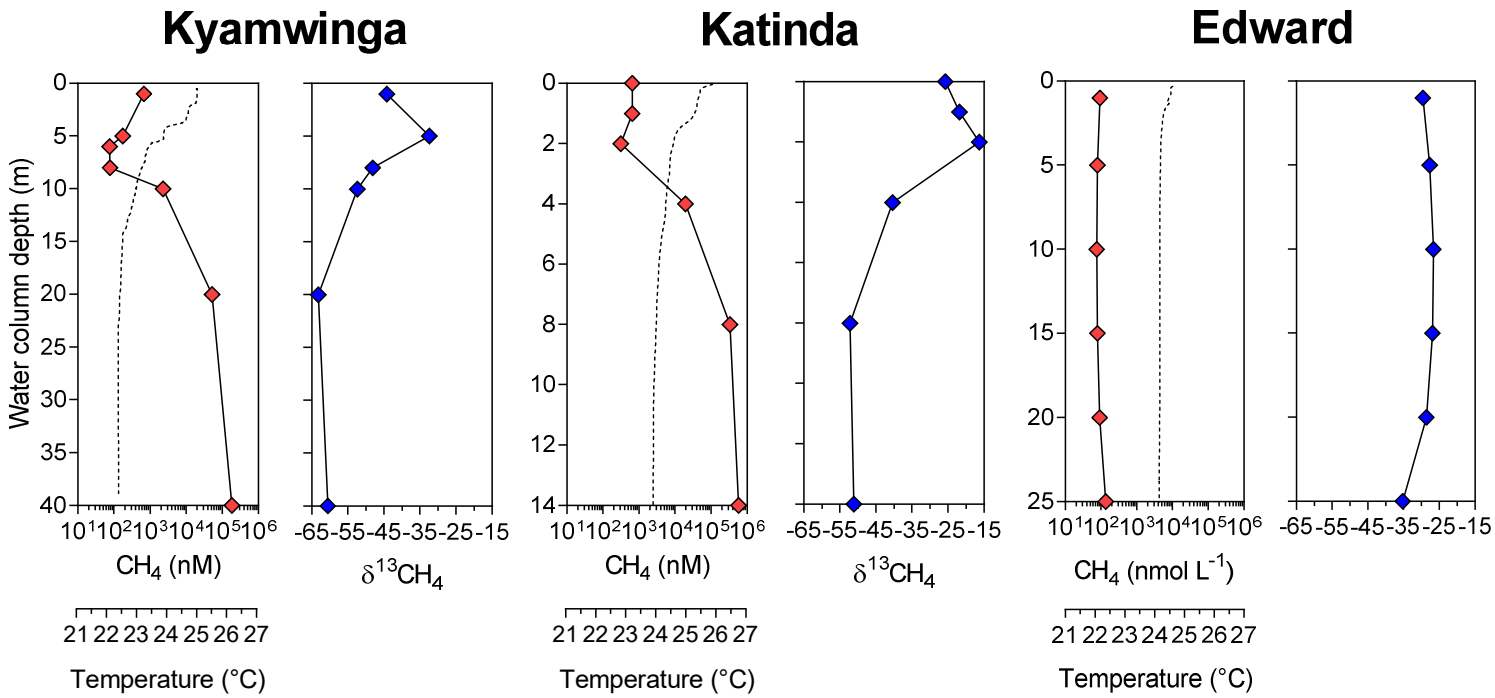
Study site

Study of the CH_4 dynamic in 5 contrasting African lakes covering a wide range of mixing regime, depth, and productivity





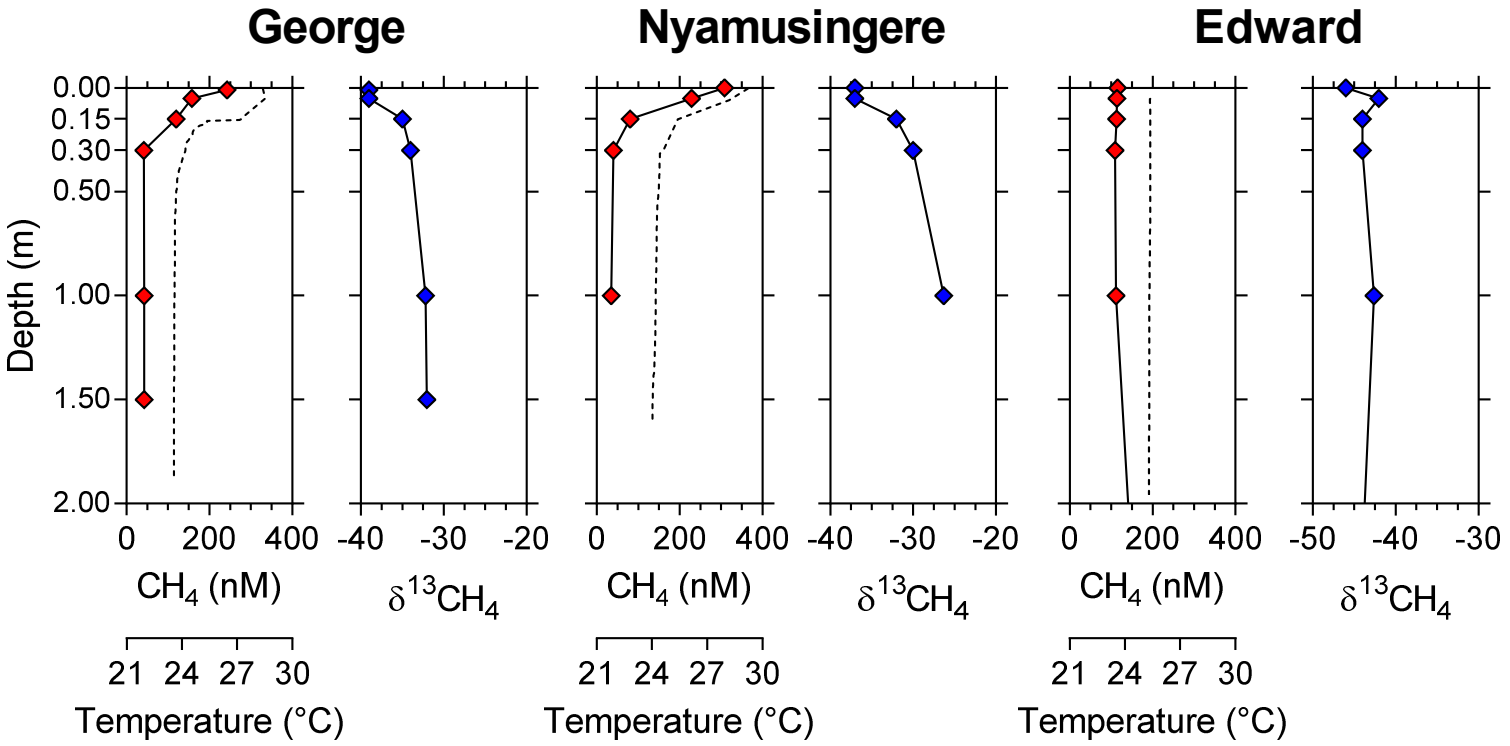
CH_4 profile in Western Ugandan lakes



At the exception of L. Edward :

- **Local increase of CH_4 concentration in epilimnion**
- **^{13}C-depleted CH_4 in surface waters**

CH_4 profile in Western Ugandan lakes



At the exception of L. Edward :

- **Local increase of CH_4 concentration in epilimnion (0.3 deep gradient in shallow L. George & L. Nyamusingere).**
- **^{13}C-depleted CH_4 in surface waters**

Investigating the role of CH_4 production in surface waters

Is CH_4 produced in well-oxygenated surface waters ?

Is it linked to phytoplankton metabolism ?

Time course ^{13}C labelling experiments with potential CH_4 precursor molecules :

* $NaH^{13}CO_3$; hereafter ^{13}C-DIC
* $^{13}C_{methyl}$-methionine
* $^{13}C_{(1,2)}$-acetate

Water samples were incubated :

(1) under light,

(2) under light with a photosynthesis inhibitor (DCMU)

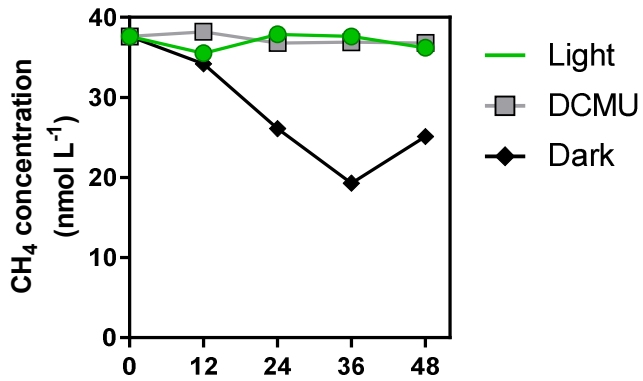
(3), or in the dark

Investigating the role of CH_4 production in surface waters

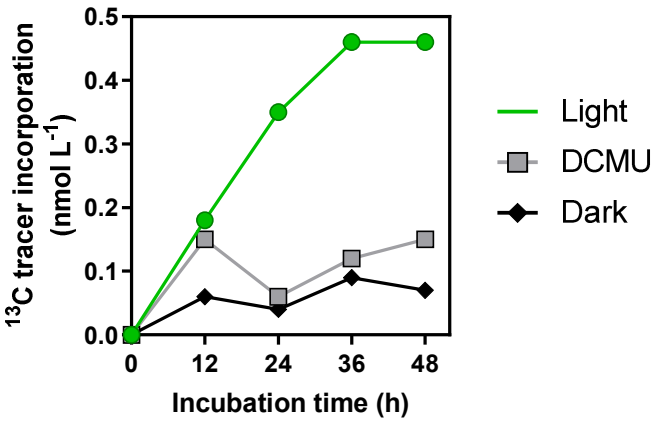
Is CH_4 produced in well-oxygenated surface waters ?

L. Edward kinetics (^{13}C-DIC)

$NaH^{13}CO_3$



Constant CH_4 concentration in bottles incubated under light (-DCMU & +DCMU), but decreased in the dark …



… CH_4 production from ^{13}C-DIC in the light treatment when photosynthesis was not inhibited (-DCMU)

Investigating the role of CH_4 production in surface waters

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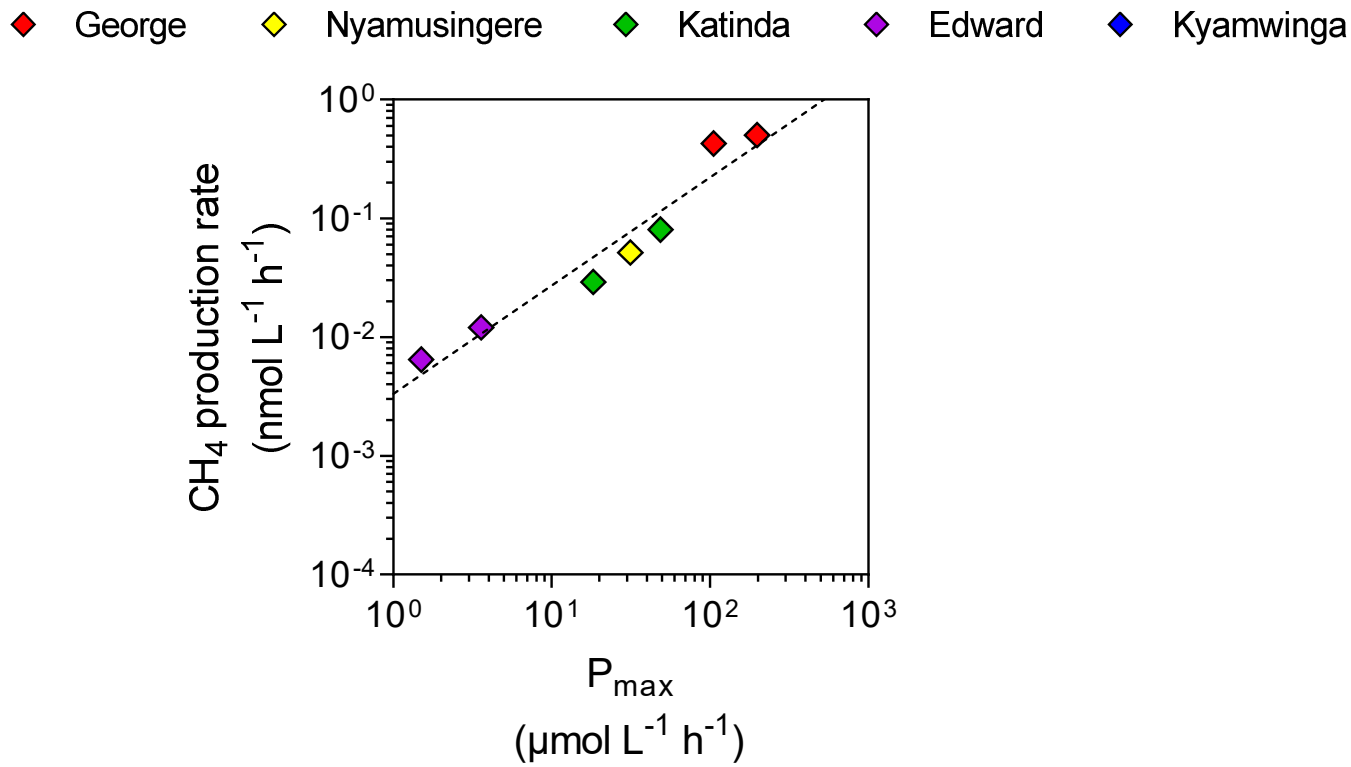
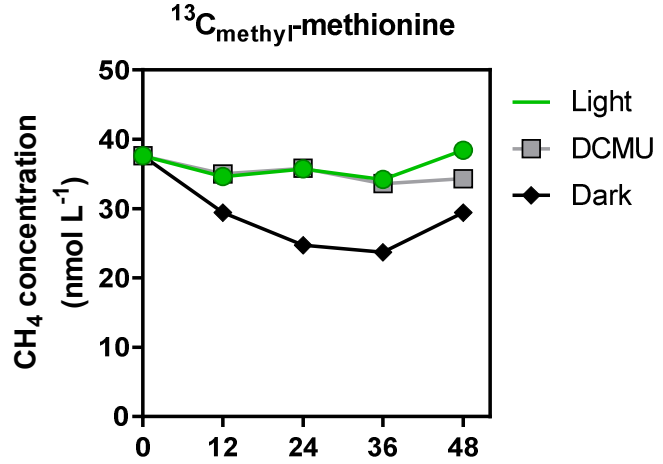


Very good relationship between photosynthesis rate and epilimnetic CH_4 production from DIC

Investigating the role of CH_4 production in surface waters

Is CH_4 produced in well-oxygenated surface waters ?

L. Edward kinetics ($^{13}C_{methyl}$-methionine)



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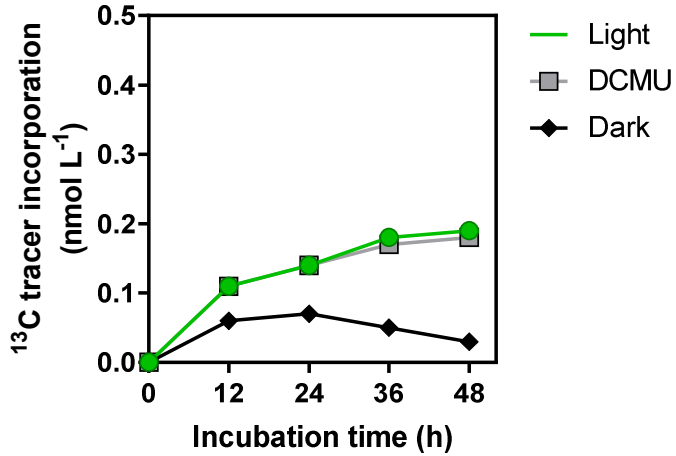
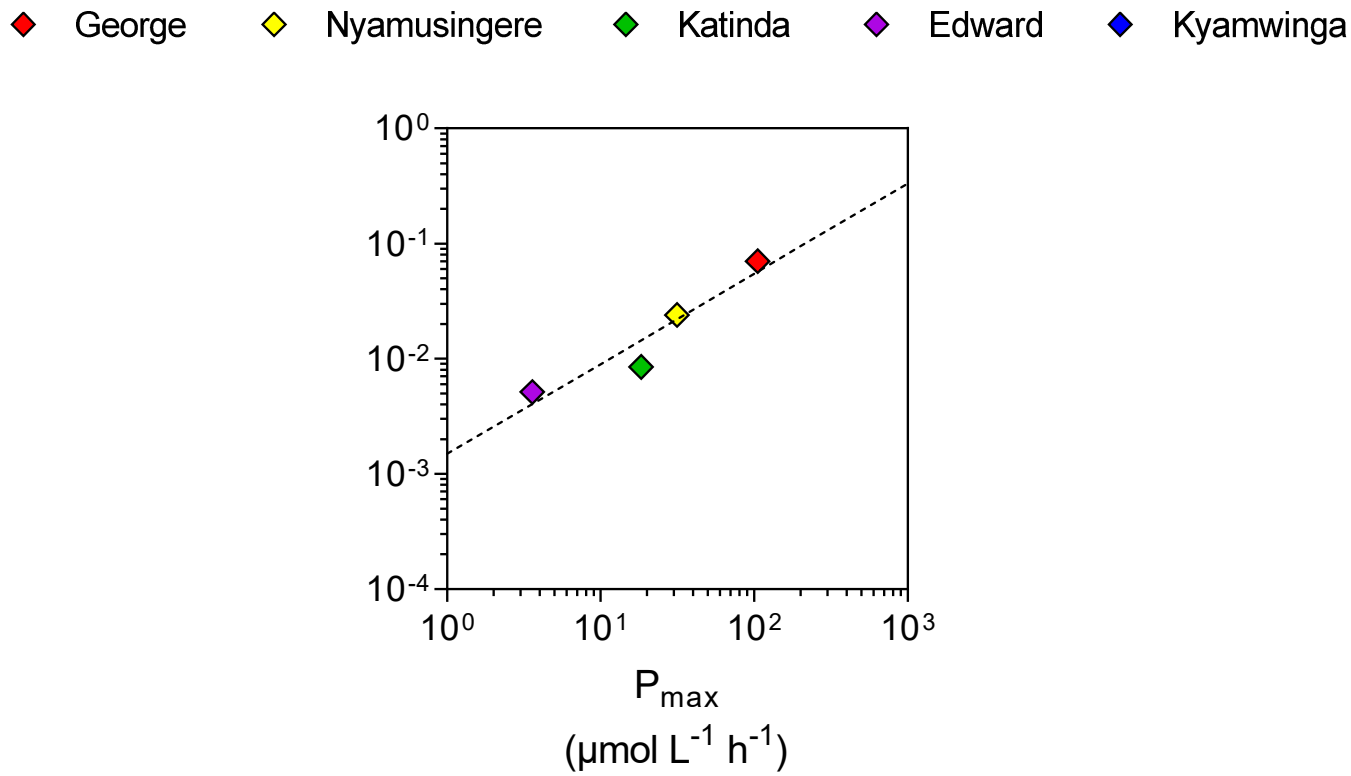


… CH_4 production from ^{13}C-DIC in the light treatment regardless of photosynthesis inhibition (-DCMU & +DCMU)

Investigating the role of CH_4 production in surface waters

Is CH_4 produced in well-oxygenated surface waters ?

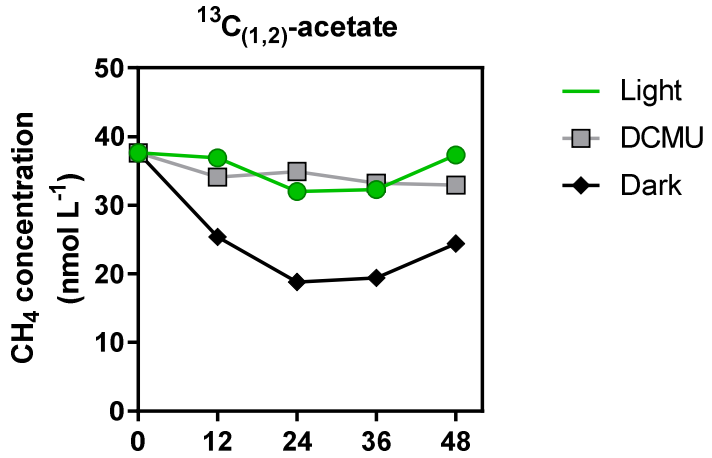


Very good relationship between photosynthesis rate and water column CH_4 production from methionine

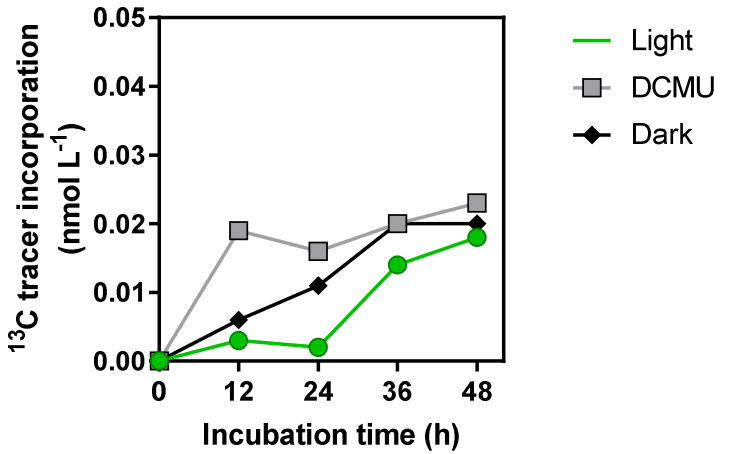
Investigating the role of CH_4 production in surface waters

Is CH_4 produced in well-oxygenated surface waters ?

L. Edward kinetics (^{13}C-acetate)

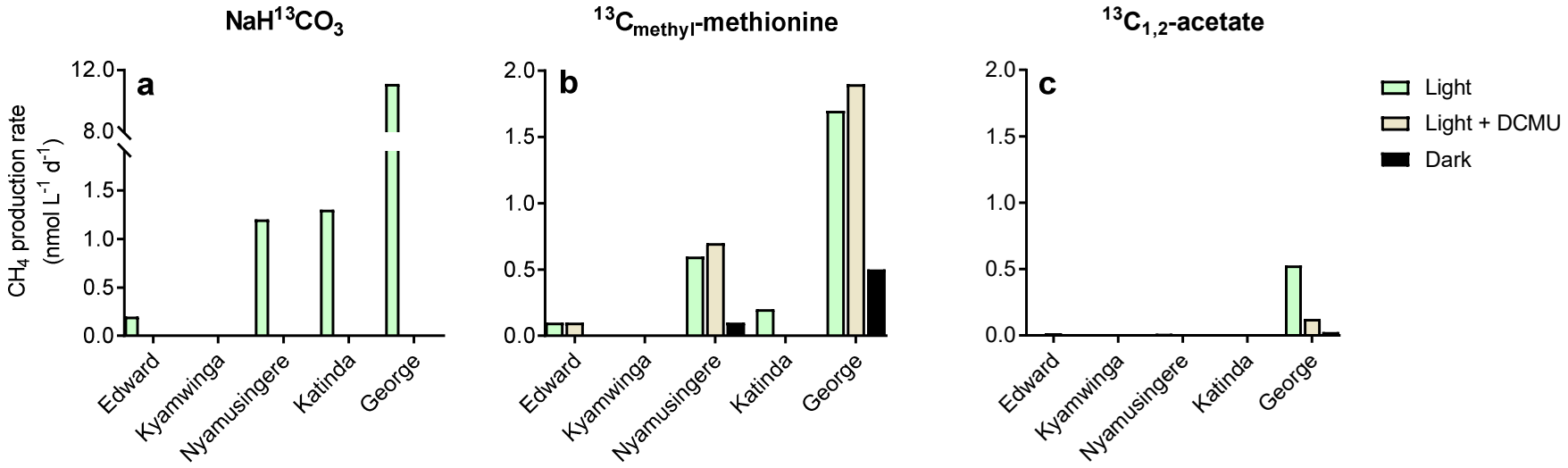


Constant CH_4 concentration in bottles incubated under light (-DCMU & +DCMU), but decreased in the dark …



… Similar CH_4 production in all treatment but at significantly lower rates than other precursors

Investigating the role of CH_4 production in surface waters



- Direct link between CH_4 formation in oxic waters and phytoplankton metabolism
- Acetate would fuel at the maximum 5% of the water column CH_4 production while the majority would sustained by DIC
  - ► contradiction with most earlier studies investigating CH_4 production in well-oxygenated waters

Methionine, a precursor of CH_4 in surface waters

1) Inorganic carbon could be a indirect source of C for CH_4

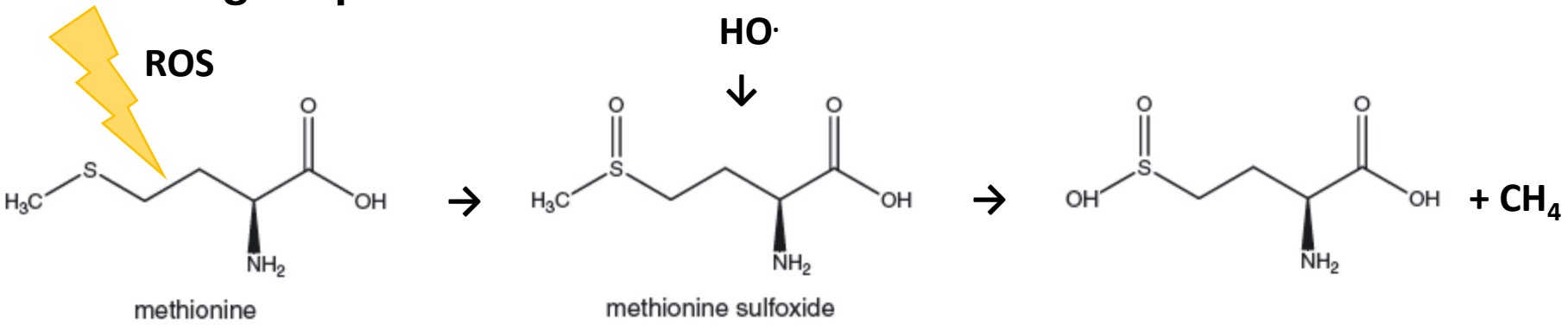
Via processing of (methylated) freshly produced molecules excreted by phytoplankton, such as methionine

- Amino acids would represent up to 4% of the organic matter excreted by phytoplankton and are rapidly consumed by heterotrophs

Our experiments showed methionine was a CH_4 precursors in bottles incubated under light, even when photosynthesis was inhibited

-> relation with photo-oxidative stress ?

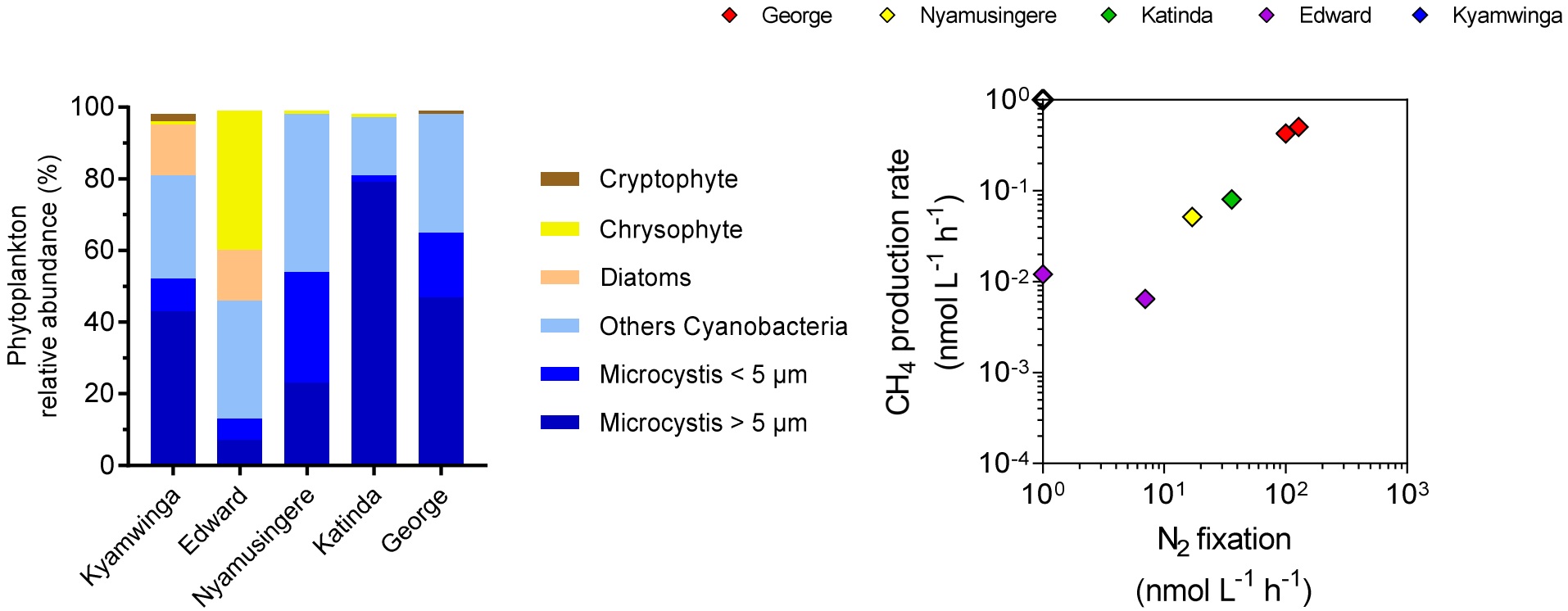
Methionine is an effective ROS scavenger and a CH_4 precursor in higher plant



Inorganic carbon sustains CH_4 production in surface waters

2) Inorganic carbon could be a direct source of C for CH_4

► CO_2 reduction by hydrogenotrophic archaea in anoxic microsite located near cyanobacteria heterocyst



High abundance of Cyanobacteria in every lakes and good relationship with N_2 fixation
1 mole of N_2 fixed = 1 mole of H_2 produced)

Inorganic carbon sustains CH_4 production in surface waters

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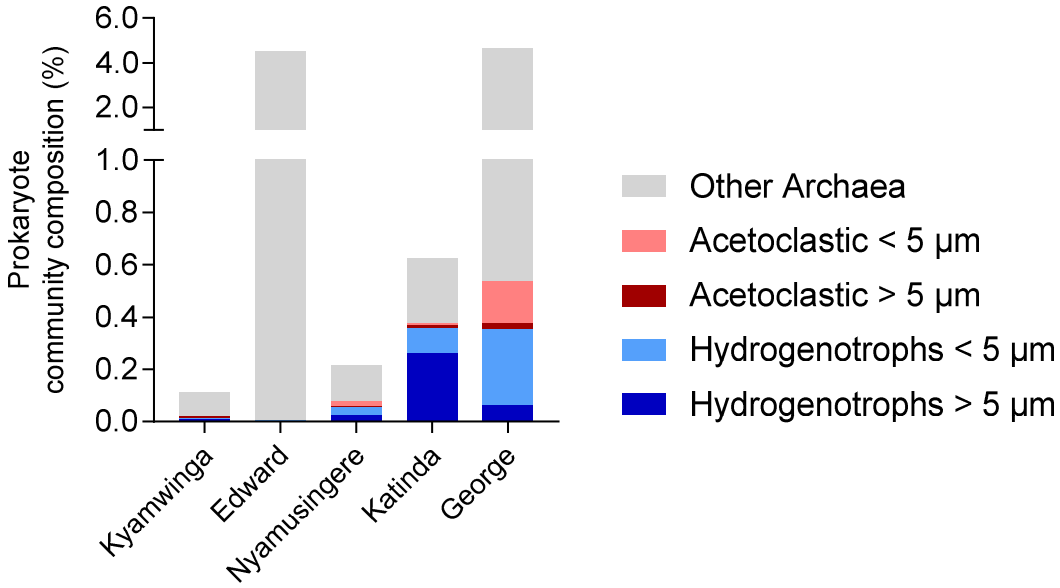
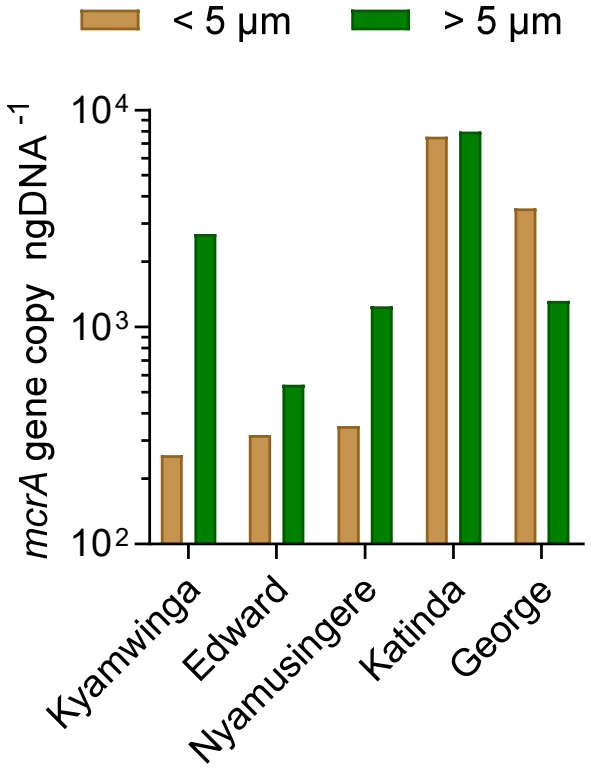


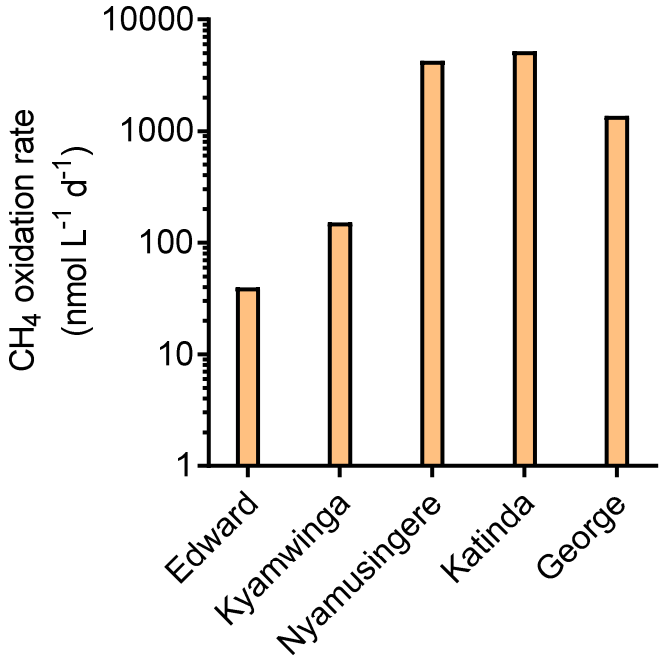


Presence of hydrogenotrophs in most of the samples (16S rRNA gene sequencing, qPCR mcrA gene), predominantly attached to phytoplankton.

CH_4 oxidation is an important process in surface waters

Would CH_4 production be able to sustain CH_4 oxidation rates ?

CH_4 oxidation in surface waters

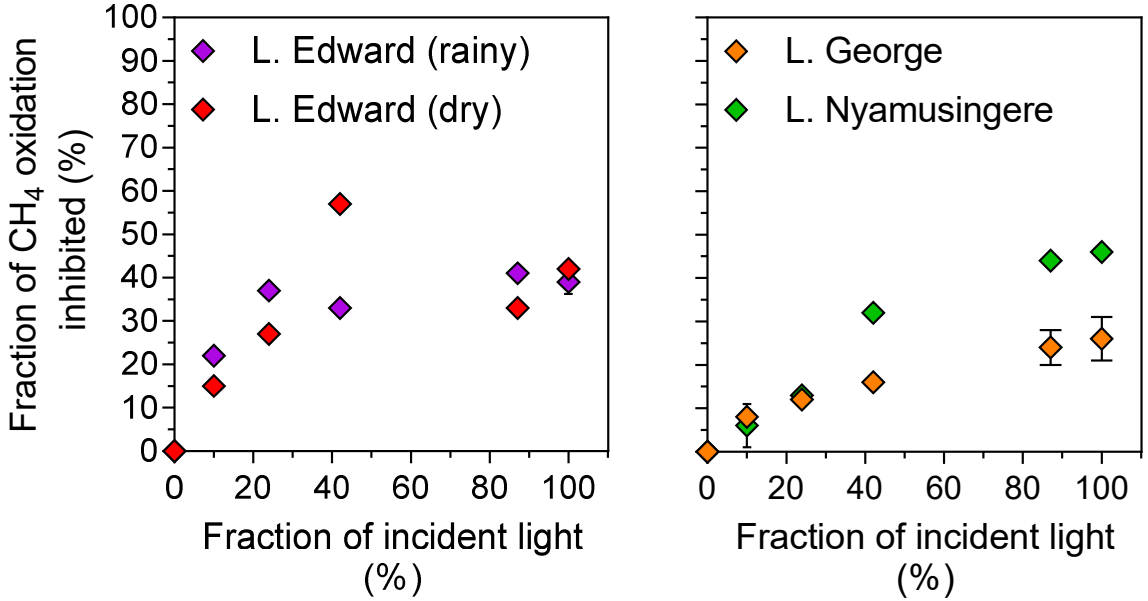


CH_4 oxidation was relatively high in every lakes :

- Ambient CH_4 turnover < 12h in all lakes except L. Edward (3 days)

… but is dramatically affected by sunlight radiation

Would CH_4 production be able to sustain CH_4 oxidation rates ?



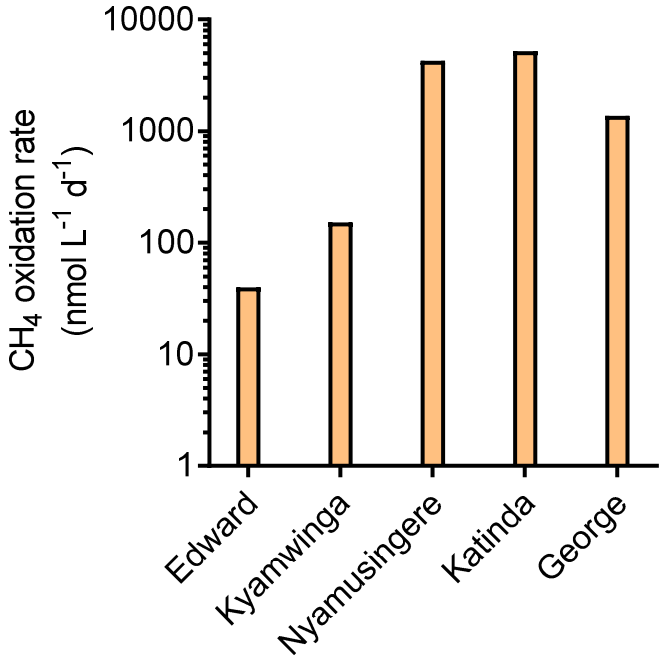
Light-induced inhibition effect

Up to 50% of CH_4 oxidation activity is inhibited at full solar intensity

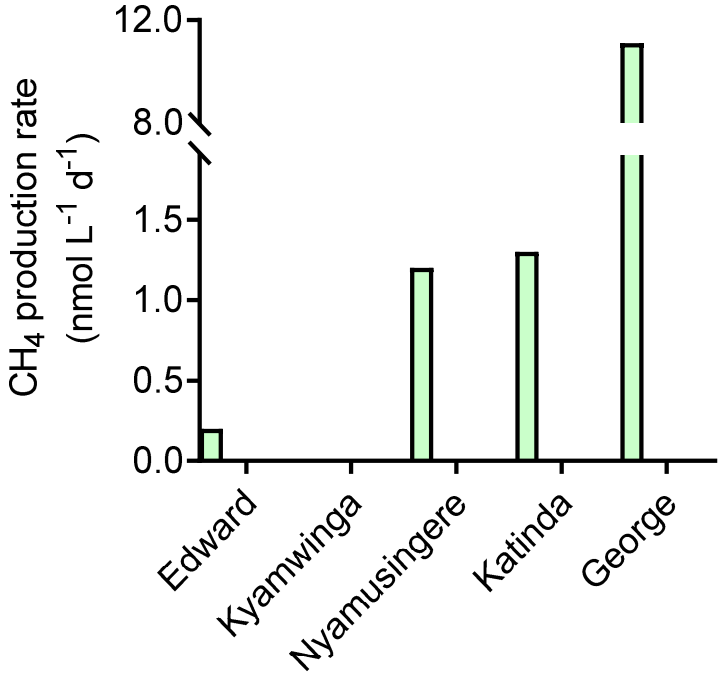
CH_4 oxidation largely exceeds CH_4 production in surface

Could CH_4 production in well-oxygenated surface waters sustain microbial CH_4 oxidation ?

CH_4 oxidation in surface waters

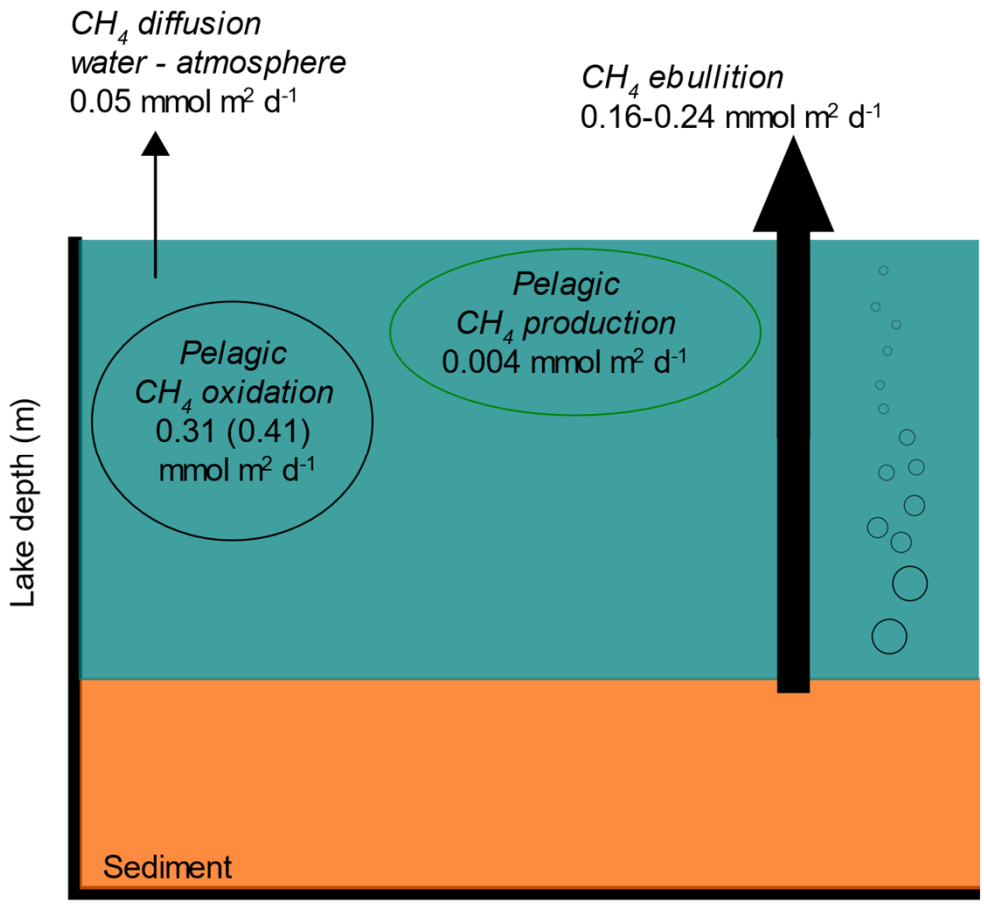


CH_4 production in surface waters



Water column can not fuel CH_4 oxidation alone

CH_4 mass balance in L. Edward



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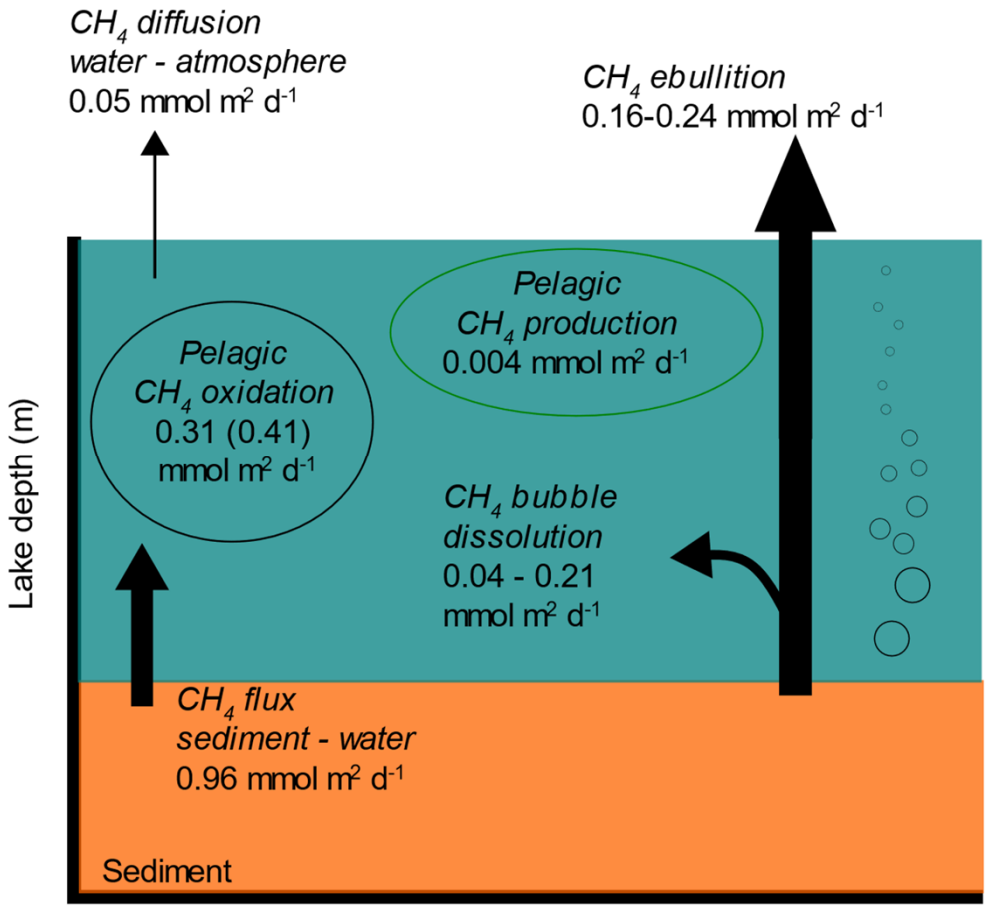

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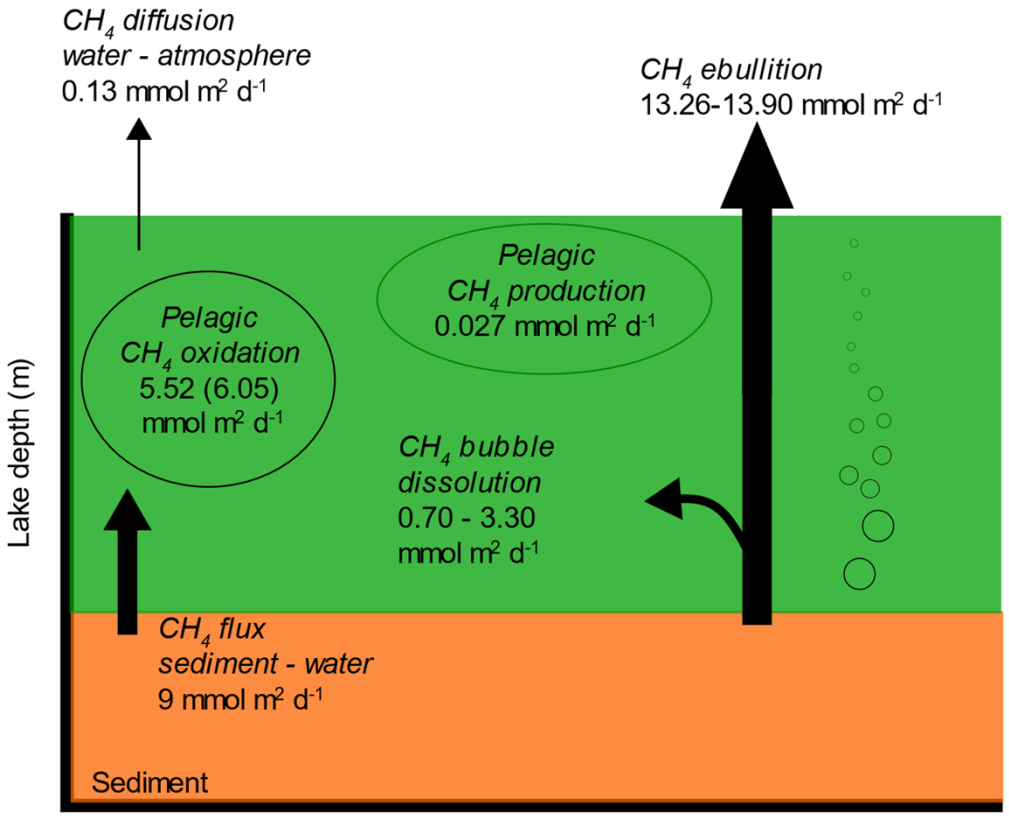


Conclusions

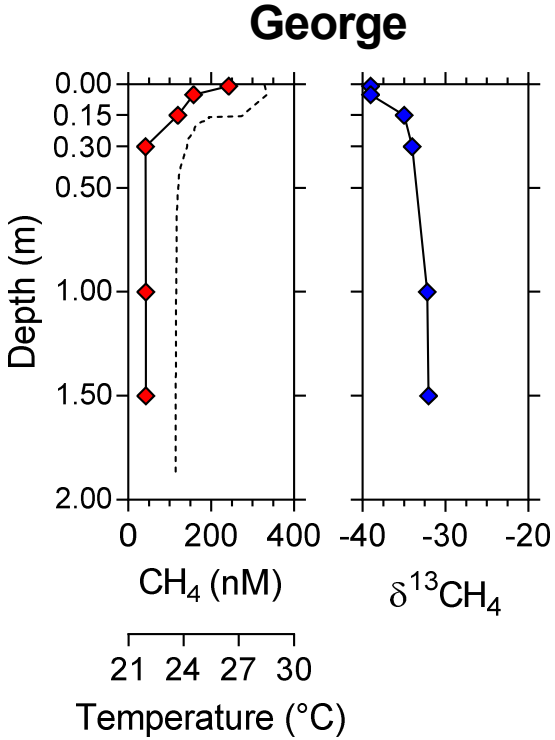
- **Production of CH_4 in well-oxygenated waters seems widespread and directly linked to phytoplankton activity, but is unimportant at the ecosystem-scale in our tropical lakes**

- Ebullition overwhelms diffusive flux is a key element of the CH_4 dynamic in tropical lakes, even the deep one (L. Edward 20 m).

Conclusions

- **Production of CH_4 in well-oxygenated waters seems widespread and directly linked to phytoplankton activity, but is unimportant at the ecosystem-scale in our tropical lakes**

Patterns of accumulation of ^{13}C-depleted CH_4 in surface could be explained by the combined effect of :



► Dissolution of CH_4 rising bubbles

► Photoinhibition of microbial CH_4 oxidation in well-illuminated, surface waters.

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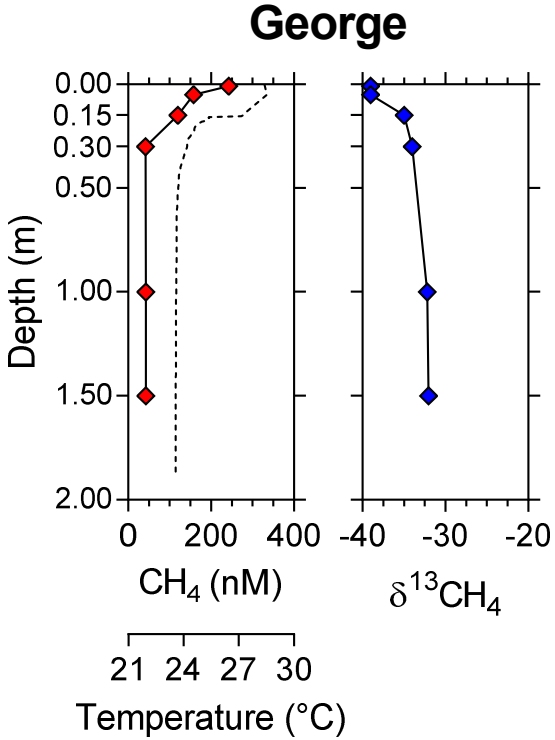

► Dissolution of CH_4 rising bubbles

► Photoinhibition of microbial CH_4 oxidation in well-illuminated, surface waters.

Sunlight irradiance is an overlooked but important factor determining the CH_4 dynamics in surface waters, affecting the production and consumption of this potent greenhouse gas.

Thank you for your attention