

Methane oxidation in African lakes increases with phytoplankton and outweighs photosynthesis-driven oxic methane production

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Lakes are large natural sources of methane (CH₄), a potent greenhouse gas, resulting from the net balance of inputs from anaerobic and oxic methane production (OMP) and removal by methane oxidation (MOX). Here we investigate spatial patterns and causes of MOX variability in 79 African lakes. MOX is highest in the most productive lakes presumably due to methanotrophs attached to phytoplankton, as well as in lakes draining the wetlands of the Congo basin presumably due to inputs of methanotrophs from flooded forest soils. MOX represents the largest sink of dissolved CH₄ in the mixed layer (>70%) compared to the diffusive emission to the atmosphere (FCH₄). Photosynthesis-driven OMP estimated from literature data represents a small fraction of both MOX and FCH₄, and this fraction decreases with lake productivity and FCH₄ intensity. Available evidence suggests that photosynthesis-driven OMP increase supported by eutrophication can be compensated by a stronger increase in MOX.

Lakes are a strong source to the atmosphere of methane (CH₄), a potent greenhouse gas, representing globally the second-largest natural source after wetlands¹. Diffusive fluxes account for about half of these emissions, with the remainder attributed to ebullition, although the latter is more uncertain. Diffusive CH₄ emissions reflect the balance between CH₄ production - via anaerobic methanogenesis in sediments and oxic methane production (OMP) - and microbial methane oxidation (MOX). The relative contribution of MOX, either as a sink for dissolved CH₄ or in comparison to CH₄ production processes, is variable but has rarely been quantified in lakes^{2–7}. Moreover, information on the drivers of MOX rates in the water column of lakes is only available in a few oligotrophic northern systems^{4–7}, limiting

predictions of how MOX rates in the water column will respond to warming and eutrophication⁸, and thereby constraining forecasts of future lake CH₄ emissions⁹ and their feedback on atmospheric CH₄.

MOX proceeds aerobically using O₂ as an electron acceptor and anaerobically with alternatives such as SO₄²⁻, NO₃⁻, and Mn/Fe oxides. The majority of MOX in lakes occurs under aerobic conditions^{2–7,10}. Field and laboratory studies indicate that MOX is stimulated by dissolved CH₄⁶, temperature^{6,11}, PO₄^{3–7}, and dissolved inorganic nitrogen (DIN)⁸, but inhibited by NH₄⁺¹², NO₂⁻¹², low pH¹³, and light according to some studies¹⁴ but not all¹⁵. MOX is optimal at O₂ concentrations between 5 and 30 μmol L⁻¹ and is partly inhibited at concentrations below or above this range^{6,16}.

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Dissolved concentrations and emissions of CH_4 in lakes increase with phytoplankton biomass^{17,18}, in response to enhanced sedimentary anaerobic methanogenesis¹⁹ and OMP²⁰. Multiple organisms - including microalgae, vascular plants, and fungi - can produce CH_4 under oxic conditions²¹, as a response to oxidative stress²². OMP can also result from the microbial utilization of methylphosphonate (MPn)^{23–27} and methylamines^{27–29}, photoproduction³⁰, or N_2 -fixation³¹. In lakes, OMP is closely linked to phytoplankton biomass²⁰, reflecting both direct CH_4 release from phytoplankton and indirect production via microbial transformation of photosynthates^{13,21}. However, the relative contribution of OMP versus sedimentary anaerobic methanogenesis to sustain lake CH_4 emissions remains uncertain and is subject to debate^{32,33}.

CO_2 and CH_4 emissions from tropical inland waters are strongly influenced by hydrological connectivity with wetlands (e.g., flooded forests and floating macrophytes). African humid lakes bordered by wetlands exhibit higher CO_2 emissions than lakes bordered by drylands¹⁸. CH_4 emissions seem to scale with lake size irrespective of the presence of wetlands, although this conclusion was based on a limited number of samples¹⁸. African lakes bordered by wetlands are characterized by lower phytoplankton biomass due to light limitation caused by colored dissolved organic matter (CDOM)¹⁸. Therefore, different mechanisms make it plausible that wetland connectivity also influences CH_4 cycling in lakes, including MOX, which warrants further investigation using larger datasets.

Here, we investigate MOX in surface waters of 79 African lakes (Fig. 1) located within and outside the Cuvette Centrale Congolaise (CCC) - an extensive flooded forest in the Congo River basin (total surface area ~1,760,000 km^2 ; flooded area ~360,000 km^2). We examine the relationship of MOX with biogeochemical variables including chlorophyll-a (Chl-a), total suspended matter (TSM), and nutrients (NH_4^+ , NO_3^- , DIN, PO_4^{3-}). We test the hypothesis that MOX changes with the trophic state of lakes and the connectivity with flooded forests by comparing lakes within and outside the CCC, and that MOX is limited by nutrients. We compare MOX to other CH_4 fluxes in the mixed layer such as diffusive emissions to the atmosphere (FCH_4) and OMP estimated from literature data. We compare MOX in lakes with that in rivers and oceans.

Results and discussion

General settings of studied lakes

We conducted 503 measurements of MOX rates in surface waters from 79 African lakes (Fig. 1), encompassing a broad range of lake sizes (surface area: 0.01–67,075 km^2 ; maximum depth: 0.7–1470 m), mixing regimes (polymictic, meromictic), and trophic states (oligotrophic to hypereutrophic) (Table S1). Lakes were categorized into two groups: located within (17 lakes – 92 MOX measurements) and outside (62 lakes – 411 MOX measurements) the CCC (Fig. 1).

Lakes within the CCC exhibited characteristics of humic systems draining flooded forests. They had significantly lower pH, specific conductivity, O_2 , Chl-a, particulate organic carbon (POC), and TSM but higher water temperature, dissolved organic carbon (DOC), and CDOM absorbance at 350 nm (a_{350}) compared to lakes outside the CCC (Supplemental Fig. S1). These humic lakes within the CCC also had significantly higher DIN and PO_4^{3-} than those outside the CCC, likely reflecting a limitation of aquatic primary production by low pH and light attenuation caused by elevated CDOM^{18,34}. Correspondingly, they exhibited lower Chl-a concentrations and O_2 saturation levels ($\%\text{O}_2$), but significantly lower ammonium (NH_4^+) and higher nitrate (NO_3^-) levels, presumably due to active nitrification (Supplemental Fig. S1).

Cyanobacteria dominated the phytoplankton community (>50% of total abundance) in most lakes outside the CCC (57 of 65; Table S1). Other groups included chlorophytes, chrysophytes, cryptophytes or diatoms; dinoflagellates dominated in one lake and euglenophytes were consistently minor components. Colonial or filamentous forms of cyanobacteria were present in 89 examined samples and dominated in those with the highest Chl-a (Table S2). In contrast, cyanobacteria were rare (<2%) or absent in humic lakes within the CCC, where diatoms dominated the phytoplankton community (42–88% of total abundance) in 10 of 16 lakes, followed by chlorophytes, chrysophytes, cryptophytes or dinoflagellates. Raphidophytes were present in nearly all CCC lakes (13 of 16), dominated in one, but were absent from all lakes outside the CCC. Colonial forms of cyanobacteria were observed in only 3 of the 92 samples examined in CCC lakes (Table S2).

Dissolved CH_4 concentrations in surface waters varied across four orders of magnitude, ranging between 6 and 91,293 nmol L^{-1} , with median and mean values of 190 and 2498 nmol L^{-1} , respectively.

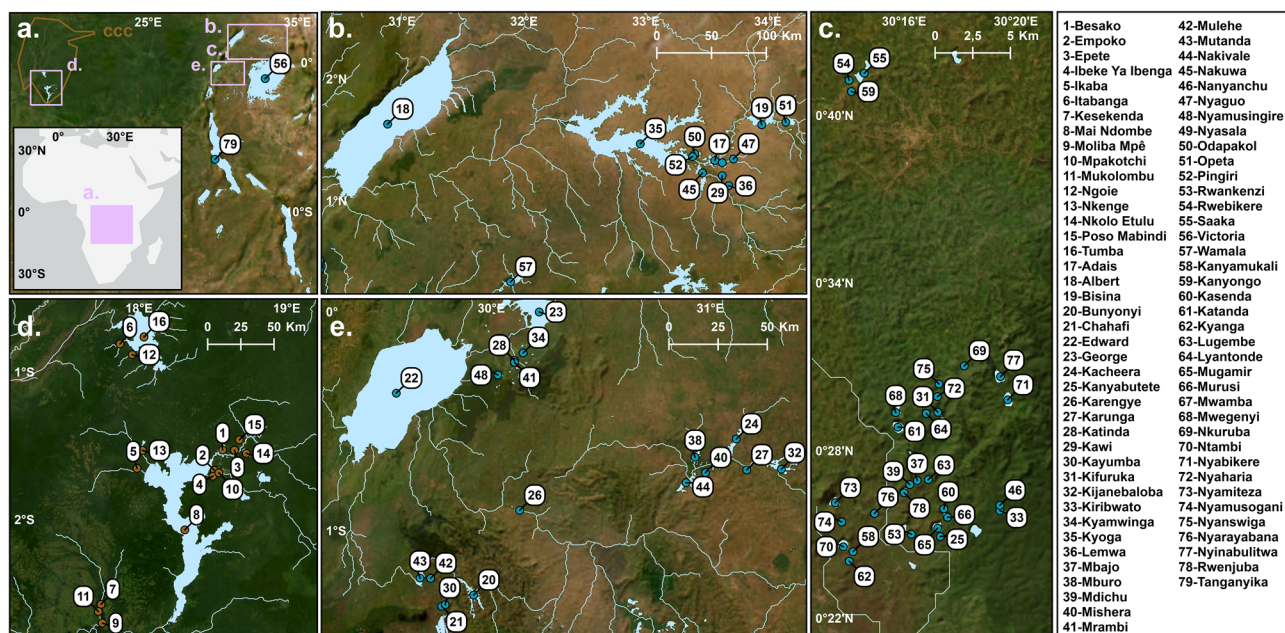


Fig. 1 | Location of sampled lakes. Map showing location of the 79 African lakes where methane oxidation was measured in surface waters, distributed in five individual quadrants (a–e). CCC=Cuvette Centrale Congolaise. Figure was created

by the authors with ArcGIS® Pro using for the background satellite images from the software's standard base map.

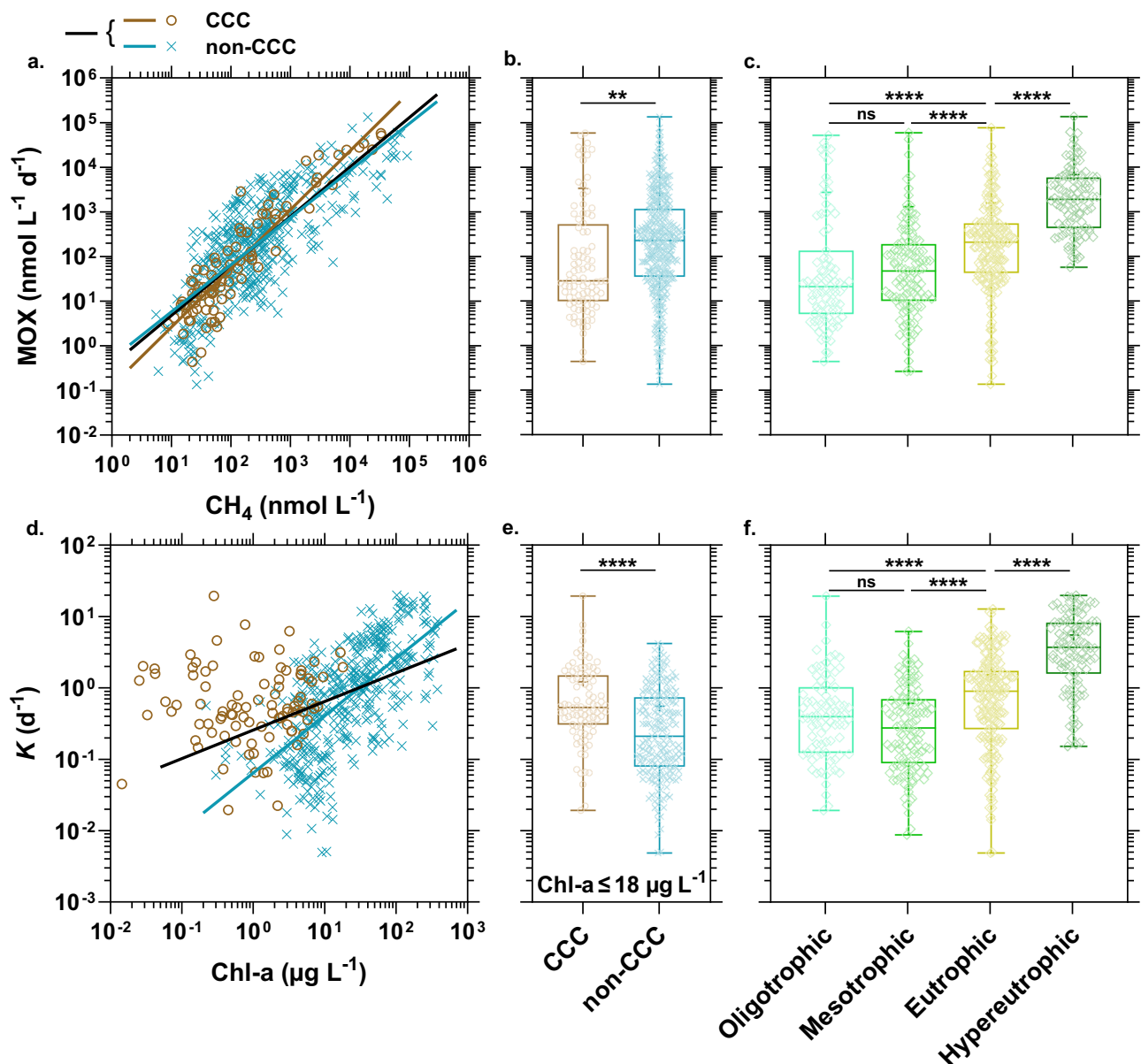


Fig. 2 | Methane oxidation (MOX) as a function of lake productivity. MOX ($\text{nmol L}^{-1} \text{d}^{-1}$) versus CH_4 dissolved concentration (nmol L^{-1} , $n = 503$, **a**) and MOX rate constant (K in d^{-1}) versus chlorophyll-*a* (Chl-*a* in $\mu\text{g L}^{-1}$, $n = 503$, **d**) concentration, in surface waters of 79 African lakes (Fig. 1) located within (CCC, $n = 92$) or outside (non-CCC, $n = 411$) the Cuvette Centrale Congolaise (**b**, **e**), and sorted by trophic state categories (**c**, **f**). For a meaningful comparison of CH_4 means between CCC and non-CCC data (**e**), the non-CCC CH_4 data were sorted for $\text{Chl-a} \leq 18 \mu\text{g L}^{-1}$

($n = 199$) that corresponds to the maximal Chl-*a* value observed in the CCC lakes. The box represents the first and third quartile, horizontal line corresponds to the median, cross to the mean, error bars to the maximum and minimum, symbols show all data points. Results of the statistical comparison of means are summarized at the top of the figures and detailed in Tables S4 and S6. Solid lines show significant linear regressions (Table S5).

Surface waters were oversaturated in CH_4 with respect to atmospheric equilibrium, with CH_4 saturation levels ranging from 205 to 3,387,617%, with median and mean values of 7227 and 94,077 %, respectively (Supplemental Fig. S1). In lakes outside the CCC, dissolved CH_4 concentrations were negatively related to bottom depth and positively to Chl-*a* (Supplemental Fig. S2), consistent with previous observations in lakes in Africa¹⁸ and elsewhere¹⁷. These relationships likely reflect the influence of sediment proximity on CH_4 accumulation in surface waters and the role of phytoplankton biomass in enhancing sedimentary anaerobic methanogenesis¹⁹ and/or of OMP²⁰. Chl-*a* concentrations were negatively related to bottom depth (Supplemental Fig. S3), in agreement with patterns reported for lakes in Africa^{18,35} and at higher latitudes³⁶. In contrast, humic lakes within the CCC showed no significant relationship between dissolved CH_4 concentrations and

either bottom depth or Chl-*a* (Supplemental Fig. S2). At comparable bottom depths ($\leq 6.2 \text{ m}$ - maximum value in CCC lakes), dissolved CH_4 concentrations were significantly lower in CCC lakes than in those outside the CCC, highlighting the importance of phytoplankton biomass in sustaining CH_4 production through sedimentary and/or oxic pathways. This interpretation is supported by the absence of significant differences in CH_4 concentrations between lakes within and outside the CCC when compared at equivalent Chl-*a* levels ($\leq 18 \mu\text{g L}^{-1}$ - maximum value in CCC lakes) (Supplemental Fig. S2). Dissolved CH_4 concentrations in surface waters of non-CCC lakes were positively related to salinity (Supplemental Fig. S4), consistent with high CH_4 concentrations reported in an African hypersaline lake³⁷. This contrasts with the negative relationship between CH_4 emissions and salinity reported for northern lakes³⁸. Dissolved CH_4 concentrations in surface

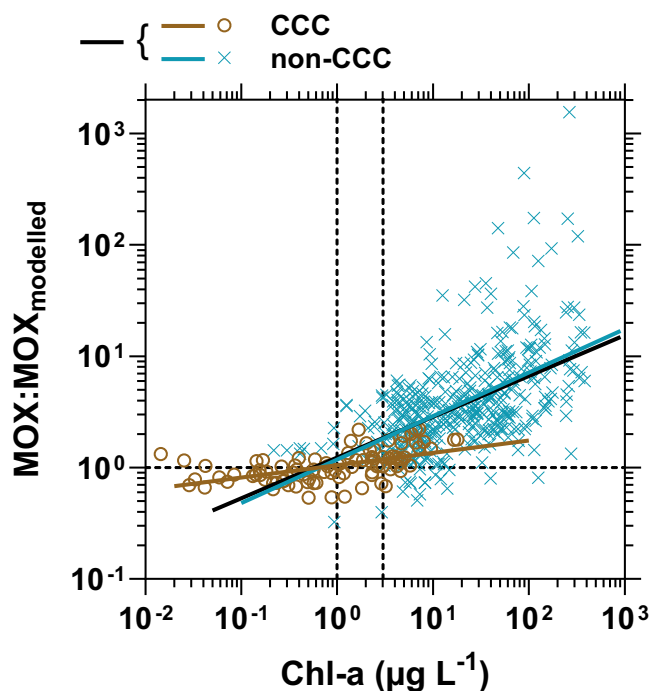


Fig. 3 | Comparison of measured and modeled methane oxidation (MOX). Ratio (unitless) of measured MOX ($\text{nmol L}^{-1} \text{d}^{-1}$) over modelled MOX ($\text{MOX}_{\text{modelled}}$ in $\text{nmol L}^{-1} \text{d}^{-1}$) versus chlorophyll-a (Chl-a in $\mu\text{g L}^{-1}$) concentration ($n = 503$) in surface waters of 79 African lakes (Fig. 1) located within (CCC) or outside (non-CCC) the Cuvette Centrale Congolaise. Solid lines show significant linear regressions (Table S5). $\text{MOX}_{\text{model}}$ was computed from a parameterization⁶ based on dissolved concentrations of O_2 and CH_4 and water temperature established from measurements in 6 small lakes situated on the Canadian Shield in the southern Québec (Canada) where surface Chl-a values ranged between 1 and $3 \mu\text{g L}^{-1}$ (indicated by the vertical horizontal dotted lines).

waters were also negatively related to the mixed layer depth (MLD) (Supplemental Fig. S4), reflecting greater influence of high hypolimnetic CH_4 concentrations on shallower mixed layers, and the greater influence of MOX as a CH_4 sink in deeper, oxygenated mixed layers³⁹.

MOX variability and drivers

Overall, MOX rates spanned six orders of magnitude, ranging from 0.1 to $132,934 \text{ nmol L}^{-1} \text{d}^{-1}$, with median and mean values of 160 and $2,275 \text{ nmol L}^{-1} \text{d}^{-1}$, respectively. MOX was positively related to CH_4 concentrations (Fig. 2). Because CH_4 concentrations were positively related to Chl-a (Supplemental Fig. S3), MOX also increased with Chl-a (Supplemental Fig. S5), and with trophic state of lakes (Fig. 2). The mean and median of MOX in hypereutrophic lakes were approximately 2.5 and 90 times higher, respectively, than those in oligotrophic lakes (Fig. 2). MOX was also significantly higher in lakes outside the CCC compared to those within (Fig. 2), consistent with their significantly higher Chl-a concentrations (Supplemental Fig. S1).

The contribution of O_2 consumption from MOX to community respiration (CR) and heterotrophic respiration (HR) was low (median = 1.8% and 3.4% for MOX:CR and MOX:HR, respectively) (Supplemental Fig. S6). MOX:CR and MOX:HR did not differ significantly in CCC and non-CCC lakes of equivalent trophic status (oligo- to meso-trophic). However, in non-CCC lakes, MOX:CR and MOX:HR increased with trophic status and Chl-a (Supplemental Fig. S6). In both CCC and non-CCC lakes, MOX:CR and MOX:HR increased with CH_4 concentrations, consistent with findings in northern lakes⁴⁰ (Supplemental Fig. S6).

The positive relationship between MOX and dissolved CH_4 concentration (Fig. 2) aligns with previous studies identifying CH_4 availability as a key driver of MOX in lakes^{6,7}. The increase of the apparent

rate constant (K , Eqs. 1 and 2) reflects a higher abundance or activity of methanotrophic bacteria driven by favorable environmental factors other than CH_4 availability. Given that aerobic methanotroph activity is mainly determined by CH_4 availability⁶, K variations should mainly reflect variations of the abundance of methanotrophs.

In the CCC lakes, K was not significantly related to Chl-a (Fig. 2). However, in the lakes outside the CCC, K was positively related to Chl-a (Fig. 2), likely due to greater abundance of methanotrophs attached to phytoplankton cells, as reported for both individual⁴¹ and colonial⁴² cyanobacteria. Phytoplankton cells provide a physical substrate for a diverse attached microbial community, as well as exudates, leading to diverse ecological interactions (mutualism, commensalism, antagonism, parasitism, and competition)^{43,44}. The association between autotrophs and methanotrophs is presumably mutually beneficial: methanotrophs supply CO_2 for photosynthesis⁴³, while autotrophs produce O_2 that supports aerobic MOX even under low O_2 conditions^{45,46}. K increased according to trophic state (Fig. 2); mean and median K values in hypereutrophic lakes were approximately five- and nine-fold higher, respectively, than those in oligotrophic lakes (Fig. 2).

Additional evidence of the importance of phytoplankton biomass in enhancing MOX and K is provided by the comparison of measured MOX in African lakes with MOX modelled ($\text{MOX}_{\text{modelled}}$) using a parameterization developed from northern lake measurements⁶, which uses dissolved concentrations of O_2 and CH_4 as drivers. Median MOX in CCC lakes was 4-fold higher than $\text{MOX}_{\text{modelled}}$, and their ratio ($\text{MOX}:\text{MOX}_{\text{modelled}}$) increased with Chl-a (Fig. 3). This pattern likely reflects the low Chl-a values ($<3 \mu\text{g L}^{-1}$) in surface waters of the northern lakes where the model was developed⁶. Adding a multiplicative factor proportional to Chl-a to the original model substantially improved model performance (Supplemental Fig. S7). The discrepancy between MOX and $\text{MOX}_{\text{modelled}}$ may also be attributable to higher water temperatures in African lakes compared to northern lakes ($<25^\circ\text{C}$). However, the divergence between MOX and $\text{MOX}_{\text{modelled}}$ was more pronounced in non-CCC lakes, which were cooler than CCC lakes (Fig. S1). Moreover, the temperature dependence of MOX (Q_{10}) in the model used ($Q_{10}=2.4$ ⁶) is comparable to that established over a broader temperature range ($5\text{--}31^\circ\text{C}$) ($Q_{10}=3.1$ ¹¹).

At equivalent Chl-a concentrations ($\leq 18 \mu\text{g L}^{-1}$), K was significantly higher in CCC lakes than those outside the CCC (Fig. 2), likely reflecting inputs from rivers draining flooded forests (wetlands), which have higher K values compared to other African rivers⁴⁷. This pattern has been attributed to higher abundance of methanotrophs in flooded soils⁴⁸ and enhanced hydrological connectivity between flooded soils and aquatic systems⁴⁹. Within the CCC, K decreased with lake surface area and with distance from shore (Supplemental Fig. S8), also reflecting the stronger influence of inputs of methanotrophs from flooded forest soils in smaller lakes or at sites closer to shore.

Among the lakes outside the CCC, K values were significantly higher in systems dominated by cyanobacteria ($>50\%$ of phytoplankton biomass) than in those dominated by other phytoplankton groups, reflecting the higher phytoplankton biomass in cyanobacteria-dominated lakes, as indicated by Chl-a (Supplemental Fig. S9). When normalized by Chl-a (i.e., $K:\text{Chl-a}$), no significant differences were observed between cyanobacteria- and non-cyanobacteria-dominated lakes, indicating that methanotroph attachment to phytoplankton was not specific to cyanobacteria (Supplemental Fig. S9). However, $K:\text{Chl-a}$ values were significantly higher in CCC lakes than in either group of lakes outside the CCC, suggesting an enhancement of methanotroph abundance independent of phytoplankton biomass, consistent with inputs from flooded forests⁴⁷. Finally, K was positively affected by TSM and POC, as previously observed in rivers⁵⁰ and ponds⁵¹, reflecting their covariation with Chl-a in this dataset (Supplemental Fig. S10).

In shallow lakes, phytoplankton—in particular cyanobacteria—can undergo cycles of deposition at the surface of the sediment, during

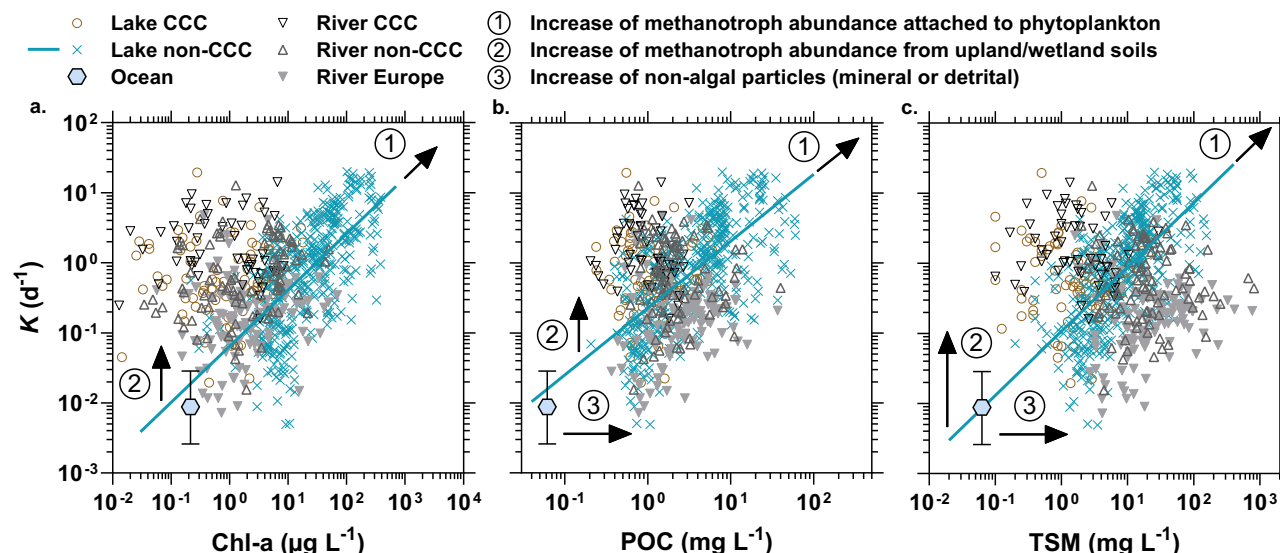


Fig. 4 | Comparison of methane oxidation rate constant (K) in lakes, rivers, and ocean. K (d^{-1}) versus chlorophyll- a (Chl- a in $\mu\text{g L}^{-1}$, **a**), particulate organic carbon (POC in mg L^{-1} , **b**), and total suspended matter (TSM in mg L^{-1} , **c**) concentrations in surface waters of African lakes located within (CCC) ($n = 92$) or outside (non-CCC) ($n = 411$) the Cuvette Centrale Congolaise (this study), European

($n = 114$) and African ($n = 148$) rivers³⁸, and in the ocean ($n = 495$). Median ($\pm$ interquartile range) K data in the ocean are from the compilation of⁶¹; global mean ocean Chl- a and TSM in surface waters were derived from independent studies^{84,85} and ocean POC was computed from Chl- a ⁸⁶. Solid lines show the linear regressions for non-CCC African lakes (Table S5).

windless conditions, and resuspension from wind induced turbulence⁵², night-time convective mixing⁵³, ebullition⁵⁴, or buoyancy adjustment of phytoplankton cells⁵⁵. Such deposition-resuspension cycles of phytoplankton should lead to the attachment on phytoplankton of sediment micro-organisms - methanotrophs included. Sediment resuspension can also lead to the inoculation of the water column by benthic methanotrophs⁵⁶. However, such benthic-pelagic interactions did not seem to explain the variations of K in our data-set, as K :Chl- a was unrelated to bottom depth in both CCC and non-CCC lakes (Supplemental Fig. S11).

In lakes situated outside the CCC, K :Chl- a values were positively related to PO_4^{3-} concentrations (Supplemental Fig. S12), consistent with the hypothesis that methanotrophy can be limited by phosphorus availability⁷. In contrast, K :Chl- a values showed no significant relationships with NH_4^+ or DIN (Supplemental Fig. S12), suggesting a stronger competition of microbial communities for phosphorus than nitrogen. The absence of a relationship between K :Chl- a and NH_4^+ contradicts the notion that NH_4^+ inhibits methanotrophy¹². The observed concentrations of NH_4^+ ($\leq 19 \mu\text{mol L}^{-1}$) were several orders of magnitude lower than those ($>1000 \mu\text{mol L}^{-1}$) typically observed in pore water in lake sediments⁵⁷ where inhibitory effect on MOX has been observed. In lakes within the CCC, K :Chl- a was unrelated to PO_4^{3-} (Supplemental Fig. S12), consistent with their higher nutrient levels (Supplemental Fig. S1), which likely alleviate nutrient limitation of microbial activity.

Surface water temperature ranged from 20.5 to 33.1 °C (mean = 27.0 °C median = 26.9 °C), although most observations fell within a narrow range (interquartile range 25.5–28.5 °C). These temperatures correspond to optimal growth range of type II methanotrophs (23–34 °C)⁵⁸, whereas Type I methanotrophs have lower temperature optima (8–15 °C)⁵⁹. In non-CCC lakes, K :Chl- a was negatively related to water temperature (Supplemental Fig. S13), contrary to expectations from metabolic theory, and might reflect inhibition of K at high temperature¹¹. Alternatively, the negative relationship between K :Chl- a and temperature in CCC lakes may indicate increased competition for nutrients between methanotrophs and phytoplankton in surface waters under stronger thermal stratification. The absence of a significant statistical relationship between K :Chl- a and water temperature

in CCC lakes and across the full dataset is consistent with a study in northern lakes showing a stronger dependance of MOX on CH_4 and O_2 availability than on temperature⁶.

Surface dissolved O_2 concentrations ranged between 20 and 746 $\mu\text{mol L}^{-1}$ (mean = 259 $\mu\text{mol L}^{-1}$ median = 250 $\mu\text{mol L}^{-1}$). K :Chl- a was negatively related to O_2 concentrations in both CCC and non-CCC lakes (Supplemental Fig. S13). This negative relationship may reflect inhibition of MOX at high O_2 concentrations and the existence of an optimal O_2 range for MOX between 5 and 30 $\mu\text{mol L}^{-1}$, with inhibition of MOX for $\text{O}_2 < 5 \mu\text{mol L}^{-1}$ ^{6,16}. At $\text{O}_2 < 5 \mu\text{mol L}^{-1}$, photosynthetic O_2 production may enhance MOX, as observed at the base of the oxycline in temperate lakes^{45,46}. However, this mechanism does not explain the enhancement of K with Chl- a we observed in non-CCC lakes (Fig. 2). The negative relationship between K :Chl- a and O_2 (Supplemental Fig. S13) suggests inhibition of MOX at high O_2 concentrations^{6,16}, which should be more pronounced in productive lakes characterized by elevated O_2 concentrations (Supplemental Fig. S14).

At equivalent water temperature (≥ 25 °C) and O_2 concentrations ($\leq 261 \mu\text{mol L}^{-1}$) (the minimum and maximum values observed in CCC lakes), K :Chl- a values were significantly higher in CCC lakes than in non-CCC lakes, presumably due to inputs from flooded forests⁴⁷.

MOX in lakes, rivers, and oceans

MOX, CH_4 , and K in African lakes were compared with corresponding data from rivers⁴⁷ and marine systems⁶⁰ (Supplemental Fig. S15). MOX and CH_4 were significantly higher in the European and African rivers than in oligotrophic, mesotrophic, or eutrophic African lakes. Yet, hypertrophic African lakes exhibited MOX and CH_4 exceeding those of European and non-CCC African rivers, although they did not differ significantly from CCC rivers. K values were higher in hypereutrophic and eutrophic African lakes than in European and non-CCC African rivers, but not different from the rivers draining flooded forests, where enhanced methanotroph abundance is presumed⁴⁷. K values in CCC rivers were in fact higher than in oligo- to eu-trophic lakes.

In European rivers, K varied with Chl- a in a pattern similar to that observed in African lakes outside the CCC (Fig. 4), consistent with methanotrophs attached to phytoplankton^{41,42}. K values in European rivers were lower than those predicted by POC and TSM relationships

for African lakes outside the CCC (Fig. 4), reflecting a greater contribution of detrital or soil-derived POC and mineral particles to TSM in European rivers. Conversely, K values in African rivers exceeded those in African lakes outside the CCC at equivalent Chl-a, POC, and TSM (Fig. 4), likely due to the inputs of methanotrophs from soils rather than development of methanotrophs attached to particles, consistent with previous findings for these rivers⁴⁷.

Across all river and lake types, MOX, CH₄, and K values were significantly higher than in the ocean (Fig. 4). The lower K in the ocean corresponded with reduced POC and TSM, underscoring the role of particle-attached methanotroph abundance in regulating K and MOX. Notably, K values in oceanic waters aligned closely with the regression model based on Chl-a, POC, and TSM derived from African lakes outside the CCC.

Relative CH₄ sink from MOX and diffusive emissions

The contribution of MOX to the total dissolved CH₄ removal (MOX_{removal}) incorporating both MOX and FCH₄, ranged from 2.8% to 96.6%, with a median and mean of 81.5 and 73.7%, respectively. MOX_{removal} increased with K (Fig. 5) and with MLD (Supplemental Fig. S16) in lakes both within and outside the CCC. It was higher in lakes outside CCC and in hypereutrophic or eutrophic systems than in oligotrophic and mesotrophic ones (Fig. 4), consistent with the respective patterns in K that increased with the trophic state and Chl-a (Fig. 2) due to methanotrophs attached to phytoplankton. In northern lakes, % MOX_{removal} was on average 40%⁶, lower than the mean in African lakes (74%), possibly due to lower phytoplankton biomass (Chl-a < 3.0 µg L⁻¹). In African rivers⁴⁷, MOX_{removal} was significantly lower than in lakes (Supplemental Fig. S17), with a median and mean of 22.6 and 34.8%, respectively. Although MOX itself was higher in rivers than in most lakes (except hypereutrophic ones, Supplemental Fig. S15), the lower MOX_{removal} in rivers resulted from higher FCH₄ and shallower depths (Supplemental Fig. S17).

OMP as a source of CH₄ supporting MOX

Photosynthesis-driven OMP in our lake dataset was calculated from Chl-a using an average OMP:Chl-a ratio derived from measurements in

five African lakes (ref.¹⁴, Table S3) where OMP was evaluated from incubations of lake water amended with ¹³C-HCO₃⁻ (the resulting estimates are referred to as OMP_{in.situ}). The OMP_{in.situ} estimates correspond to CH₄ produced in relation to photosynthesis by phytoplankton directly or possibly also from photosynthates by other micro-organisms¹⁴. In the five African lakes (Edward, George, Nyamusigere, Katinda, and Kyamwinda) where the incubations were conducted, the phytoplankton community was dominated by cyanobacteria³⁵, and Chl-a concentrations ranged from 5 to 150 µg L⁻¹¹⁴.

To assess the potential of photosynthesis-driven OMP as an input of CH₄ to sustain the sinks of dissolved CH₄ in surface waters of the sampled lakes, OMP_{in.situ} estimates were compared to the two loss terms of dissolved CH₄ in the mixed layer (MOX and FCH₄) (Fig. 6). The OMP_{in.situ}:MOX ratio ranged from 3 × 10⁻⁶ to 307% (median = 0.4%; mean = 3.5%), was <1% for 359 cases, and >100% for only 2 estimates. The OMP_{in.situ}:FCH₄ ratio ranged from 3.7 × 10⁻⁵ to 136% (median = 1.6%; mean = 9.7%), and was <10% for 375 cases, and > 100% for only 2 estimates. FCH₄ was computed with a gas transfer velocity (k) parameterization as a function of wind speed⁶¹ that has been considered conservative by some studies⁶². Higher FCH₄ values based on higher k values would further decrease the OMP_{in.situ}:FCH₄ ratio values. Looking at both loss terms of dissolved CH₄, OMP_{in.situ}:(MOX + FCH₄) ratio ranged from 3 × 10⁻⁶ to 71% (median = 0.3%; mean = 1.6%).

Because OMP was calculated from Chl-a, OMP_{in.situ}:MOX, and OMP_{in.situ}:FCH₄ ratios were lower in lakes inside the CCC than those outside the CCC (Supplemental Fig. S18), reflecting lower Chl-a (Supplemental Fig. S1). In lakes outside the CCC, the OMP_{in.situ}:MOX ratios decreased with increasing Chl-a (Fig. 6), reflecting the increase of MOX with phytoplankton biomass (Supplemental Fig. S5) offsetting the increase of OMP. Conversely, in humic CCC lakes, the OMP_{in.situ}:MOX and OMP_{in.situ}:FCH₄ ratios increased with Chl-a (Fig. 6), indicating that sites with low Chl-a and OMP but high CH₄, MOX, and FCH₄ were influenced by inputs from the flooded forest, such as near-shore areas vs central areas, and small vs large lakes (Supplemental Figs. S20 and S21).

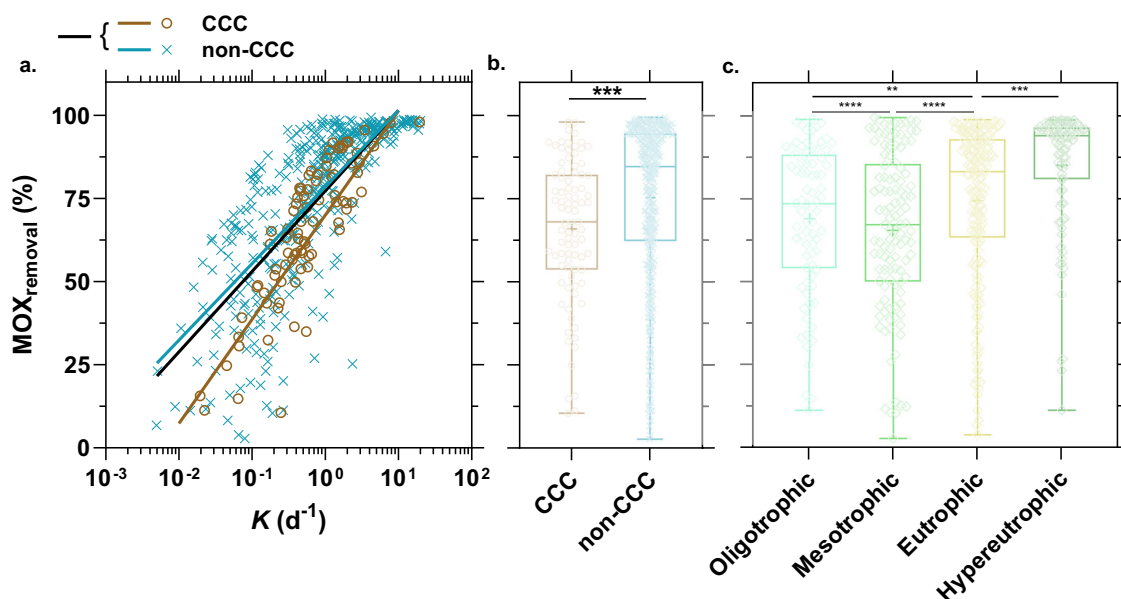


Fig. 5 | Contribution of methane oxidation (MOX) to total dissolved CH₄ methane removal including degassing to the atmosphere (MOX_{removal}) in African lakes. MOX_{removal} (%) versus MOX rate constant (K in d⁻¹, **a**) in surface waters of 79 African lakes (Fig. 1) located within (CCC) ($n = 87$) or outside (non-CCC) ($n = 396$) the Cuvette Centrale Congolaise (**b**), and sorted by trophic state

categories (**c**). The box represents the first and third quartile, horizontal line corresponds to the median, cross to the mean, error bars to the maximum and minimum, symbols show all data points. Results of the statistical comparison of means are summarized at the top of the figures and detailed in Tables S4 and S6. Solid lines show significant linear regressions (Table S5).

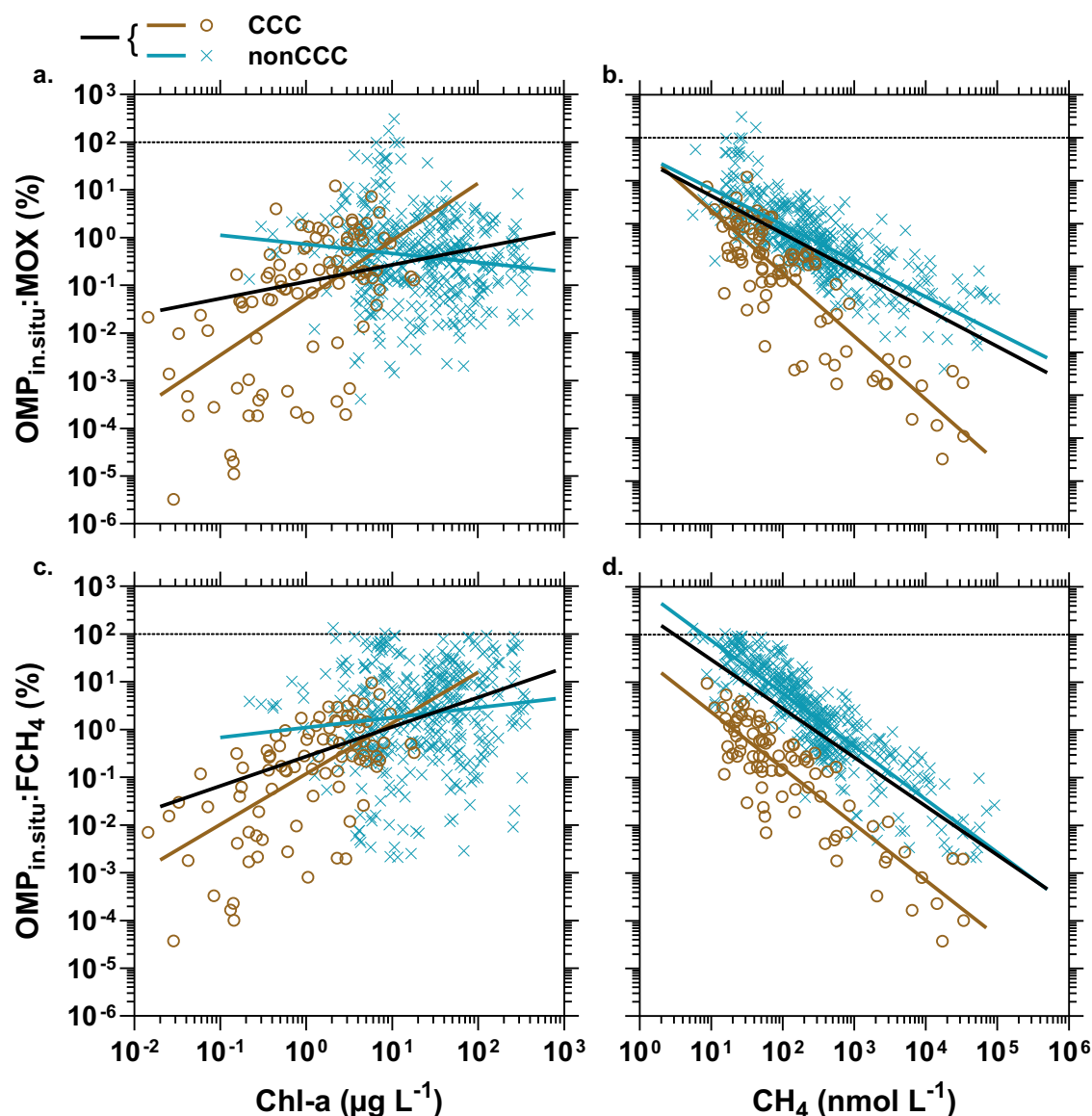


Fig. 6 | Relative importance of oxic methane production (OMP_{in.situ}) to methane oxidation (MOX) and to diffusive CH₄ emissions to the atmosphere (FCH₄) decreases with lake productivity and methane concentrations. Ratio (%) of OMP_{in.situ} to MOX ($n = 503$) and to FCH₄ ($n = 483$) (converted into volumetric units using the mixed layer depth) versus chlorophyll-a (Chl-a, **a,c) and CH₄ (**b,d**) concentrations in surface waters of 79 African lakes (Fig. 1) located within (CCC) or outside (non-CCC) the Cuvette Centrale Congolaise. Solid lines show the linear**

regressions (Table S5). OMP_{in.situ} was computed from measured Chl-a concentrations and OMP_{in.situ} ratios to Chl-a obtained from incubations with lake water amended with ¹³C-HCO₃⁻ in five African lakes¹⁴ (Table S3). Supplemental Fig. S25 shows the OMP:MOX and OMP:FCH₄ ratios based on OMP computed from OMP ratios to Chl-a from pure cultures of five cyanobacteria species and two diatom species reported in literature^{21,64} (Table S3).

Ratios of OMP_{in.situ}:MOX and OMP_{in.situ}:FCH₄ declined with CH₄ and FCH₄ in lakes both inside and outside the CCC (Fig. 6 and Supplemental Fig. S21), indicating that OMP contributions to MOX and FCH₄ were lowest in lakes where diffusive CH₄ emissions to the atmosphere were highest. This means that FCH₄ is primarily sustained by sedimentary anaerobic CH₄ production rather than OMP in lakes with the highest CH₄ dissolved concentrations and emissions.

Uncertainty on MOX and OMP estimates

The low values of OMP_{in.situ} relative to MOX may result from an overestimation of measured MOX rates and/or underestimation of computed OMP rates. The biomass of heterotrophic bacteria can remain constant, but in some cases may increase during incubations in enclosed containers⁶³. The incubation environment may also favor certain micro-organisms while suppressing others⁶³. Although studies

specifically testing this effect on methanotrophs are lacking, MOX may be negatively affected by depletion of O₂ during incubations. Conditions remained oxic throughout all MOX incubations, and O₂ concentrations at the end of the incubations were above the threshold value (5 μmol L⁻¹) below which MOX inhibition occurs¹⁶ (Supplemental Fig. S22). As an independent verification, MOX rates derived from incubations (MOX_{inc}) were compared with paired rates obtained from an isotopic fractionation model (MOX_{iso}) (Supplemental Fig. S23). Both approaches were linearly related, but the median of MOX_{iso} were 1.2–2.2 times higher than paired MOX_{inc} median, depending on the assumed initial value of ¹³C/¹²C ratio of CH₄ (δ¹³C-CH₄) (−70 or −80‰, respectively) used in the isotopic fractionation model (Supplemental Fig. S23). The isotopic fractionation model uses FCH₄ as an input, calculated with a *k*-wind parameterization⁶¹ considered conservative by some studies⁶². Higher FCH₄ values based on larger *k* values would

further increase the discrepancy between MOX_{inc} and MOX_{iso} estimates. The sensitivity of MOX_{iso} to FCH_4 was confirmed by the larger differences between MOX_{iso} and MOX_{inc} in rivers compared with lakes, consistent with higher FCH_4 in rivers (Supplemental Fig. S24). The higher MOX_{iso} values relative to MOX_{inc} may reflect the fact that the isotopic fractionation model integrates CH_4 consumption by MOX over a long timescale since the formation of CH_4 by methanogenesis in sediments, whereas incubations reflect rates directly related to CH_4 concentration at the start of the incubation.

Photosynthesis-driven OMP was also estimated from OMP:Chl-*a* ratios derived from measurements in pure cultures of cyanobacteria²¹ and diatoms⁶⁴ (the resulting estimates are referred to as OMP_{cult}). Mean OMP_{cult} :Chl-*a* ratios were ~19-fold higher than $OMP_{in.situ}$:Chl-*a* for cyanobacteria and ~1.4-fold lower for diatoms (Table S3). One possible explanation could be greater oxidative stress in well-illuminated laboratory cultures compared with field conditions, where light is attenuated by depth, CDOM, and TSM. Alternatively, the $^{13}C-HCO_3^-$ amended incubations used to measure $OMP_{in.situ}$ may not account for all biogeochemical processes associated with OMP (see below). Mean OMP_{cult} :Chl-*a* values from diatoms were applied to the fraction of measured Chl-*a* attributed to diatoms, whereas mean cyanobacterial OMP_{cult} :Chl-*a* values were applied to all non-diatom phytoplankton. This assumes that all non-diatom phytoplankton groups have OMP_{cult} :Chl-*a* ratios similar to those of cyanobacteria, which may not be the case. Other groups may exhibit lower OMP rates, consistent with the lower OMP_{cult} :Chl-*a* ratios observed in diatoms compared with cyanobacteria (Table S3).

The general patterns of OMP_{cult} : MOX and OMP_{cult} : FCH_4 were similar (Supplemental Figs. S21, S25) to those of $OMP_{in.situ}$: MOX and $OMP_{in.situ}$: FCH_4 (Fig. 6, Supplemental Fig. S21). OMP_{cult} estimates were higher than $OMP_{in.situ}$ but remained low relative to MOX and FCH_4 . The OMP_{cult} : MOX ratio ranged from 7×10^{-6} to 1,159% (median = 5.3%; and mean = 30.7%). The OMP_{cult} : FCH_4 ratio ranged from 9×10^{-6} to 2,453% (median = 24.1% and mean = 139%). The OMP_{cult} :($MOX + FCH_4$) ratio ranged from 7×10^{-6} to 539% (median = 4.1% and mean = 17%).

OMP was estimated assuming a dependence on photosynthesis based on incubations from cultures (OMP_{cult}) or lake water ($OMP_{in.situ}$). However, OMP can also occur independently of photosynthesis through microbial utilization of MPn^{23–27} or methylamines^{27–29}, photoproduction³⁰, or N_2 -fixation³¹.

Phosphonates have been detected in lakes, although quantitative estimates remain scarce and suggest low relative concentrations compared to total dissolved organic phosphorus⁶⁵. Only a fraction of phosphonates corresponds to MPn in oligotrophic marine waters⁶⁶, but the actual concentrations of MPn in lakes, including African lakes, remain unknown. Substantial OMP ($103 \text{ nmol L}^{-1} \text{ d}^{-1}$) was observed when both MPn and glucose were added to water samples from Flathead Lake, a large oligotrophic freshwater lake in northwest Montana²³. The median MOX rate in our dataset was 1.6-fold higher than this OMP rate obtained in treatments amended with $1 \mu\text{mol L}^{-1}$ MPn, a concentration approximately 71-fold higher than expected MPn concentrations in oligotrophic lake waters - assuming typical dissolved organic phosphorus concentrations of $0.2 \mu\text{mol L}^{-1}$ ⁶⁷, of which ~7% may correspond to MPn⁶⁶. In the same Flathead Lake study²³, however, the addition of MPn and NO_3^- did not substantially increase OMP ($< 3 \text{ nmol L}^{-1} \text{ d}^{-1}$), yielding rates close to those measured in unamended controls ($< 1 \text{ nmol L}^{-1} \text{ d}^{-1}$). These rates are 53- and 160- fold lower than the median MOX measured in our dataset. Moreover, the addition of MPn and PO_4^{3-} inhibited OMP in Flathead Lake²³, consistent with activation of microbial MPn utilization at PO_4^{3-} concentrations $< 0.09 \mu\text{mol L}^{-1}$ ⁶⁸. Production of CH_4 following MPn amendments has been reported in other temperate lakes^{24–27}, although OMP was undetectable in control (unamended) treatments^{24–27} or treatments amended with low levels of Mn²⁷. OMP associated with methylamines utilization has also been reported in several temperate lakes, although CH_4 production was

undetectable in control (unamended) treatments or treatments amended with low levels of methylamines^{27,28}.

Reported CH_4 photoproduction rates in large lakes³⁰ range from 0.04 to $1.3 \text{ nmol m}^{-2} \text{ d}^{-1}$, which are 3600- and 120- fold lower than the median MOX measured in our dataset (after conversion to volumetric rates using the median MLD of 4.5 m in our dataset). Similar low CH_4 photoproduction rates ($0.1 \text{ nmol m}^{-2} \text{ d}^{-1}$) were reported in Saguenay River⁶⁹.

CH_4 can also be produced during N_2 -fixation through accidental reduction of CO_2 by nitrogenase³¹. OMP associated with N_2 -fixation is expected to be lower than OMP associated with photosynthesis because N_2 -fixation typically supplies less than 5% of the nitrogen required for photosynthesis⁷⁰. Furthermore, CH_4 produced via N_2 fixation exhibits large hydrogen isotope fractionation⁷¹, yet such extremely low δ^2H-CH_4 signatures have to the best of our knowledge not been reported in natural environments, suggesting that N_2 -fixation-derived CH_4 represents a negligible fraction of the natural CH_4 pool. The fraction of CH_4 produced during N_2 -fixation (mol CH_4 per mol N_2 fixed) remains poorly constrained but is likely small. Assuming a likely overestimated value of 1% CH_4 production per N_2 fixed, the resulting OMP would be $1.9 \text{ nmol L}^{-1} \text{ d}^{-1}$ based on the median N_2 -fixation rate reported for 85 tropical lakes⁷². This value is 85-fold lower than the median MOX measured in our dataset.

Estimates of OMP supported by microbial utilization of MPn or methylamines, photoproduction, or N_2 -fixation, compiled from literature, are based on a limited number of measurements - mostly in temperate lakes and none in African lakes - and should be interpreted cautiously due to their inherent uncertainty, which warrants further investigation. Nevertheless, these alternative OMP pathways estimates were equivalent or lower than the estimated $OMP_{in.situ}$ (median = 0.4 , mean = $1.5 \text{ nmol L}^{-1} \text{ d}^{-1}$) and OMP_{cult} (median = 6.2 , mean = $27.1 \text{ nmol L}^{-1} \text{ d}^{-1}$) calculated in our lakes, and were lower than the measured MOX rates.

We reported an extensive dataset of MOX ($n = 503$) in 17 lakes within the CCC characterized by higher DOC and nutrients and lower Chl-*a* and in 62 lakes outside the CCC. In this study, MOX represented the dominant sink of dissolved CH_4 in the mixed layer of 79 African lakes (>70%), a proportion higher than previously reported for northern lakes (40%). This highlights the potential importance of MOX in mitigating future changes in lake CH_4 emissions. Indeed, production of CH_4 in lake sediments is projected to increase in response to eutrophication and rising temperatures. The extent to which this will translate into increased diffusive CH_4 emissions to the atmosphere will depend partly on the response of MOX to eutrophication (Fig. 7). Our results in non-CCC lakes suggest that MOX may increase with eutrophication through two mechanisms. First, our results indicate a potential PO_4^{3-} limitation of K , possibly due to competition between methanotrophs and phytoplankton for PO_4^{3-} . Second, and more importantly, K in non-CCC lakes increased strongly with phytoplankton biomass, most likely reflecting an increase in the abundance of methanotrophs attached to phytoplankton cells. Comparison with European rivers further supports this interpretation. At equivalent TSM concentrations, K was lower in European rivers than in lakes. In rivers, TSM is typically dominated by a mixture of organic and inorganic particles derived from soils, whereas in lakes TSM was strongly correlated with Chl-*a*, indicating a greater contribution from living phytoplankton cells. This suggests that methanotroph abundance increases specifically through attachment to phytoplankton. However, K was not related to Chl-*a* in CCC lakes, and at comparable Chl-*a* concentrations, K was higher in CCC lakes than in non-CCC lakes. This suggests that additional processes contribute to K and that the phytoplankton-driven enhancement of K is context dependent, potentially reflecting differences in connectivity with wetlands.

Our ability to predict the response of MOX to eutrophication depends on the drivers and processes included in MOX models.

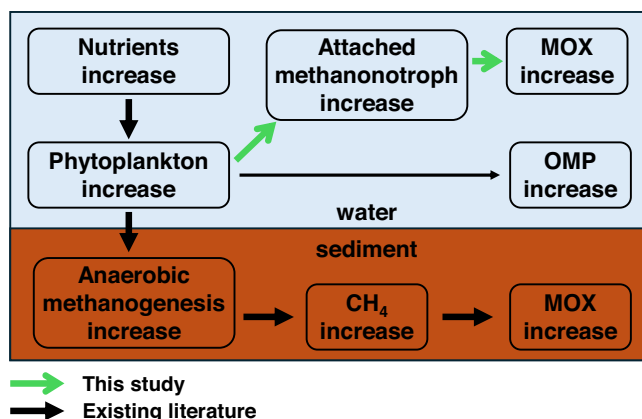


Fig. 7 | Impact of eutrophication on methane oxidation (MOX). Summary of the responses to nutrient increase (eutrophication) of oxic methane production (OMP) and MOX in the water column and sediments of lakes, based on existing literature⁹ and on the increase of methanotrophs attached to phytoplankton cells inferred from the increase of MOX rate constant as a function of chlorophyll-*a* concentration shown by the present study (Fig. 2) in agreement with direct organismal observations reported in literature^{41,42}. The increase of MOX is assumed stronger than OMP based on the decrease of OMP:MOX as a function of chlorophyll-*a* and dissolved CH₄ concentration shown in non-CCC lakes by the present study (Fig. 6).

Existing models typically parameterize MOX as function of the two substrates (CH₄ and O₂) and water temperature. Such formulation should allow to capture the increase of MOX associated with higher CH₄ dissolved concentrations resulting from enhanced methanogenesis in response to eutrophication. However, a model developed using data in oligotrophic northern lakes substantially underestimated MOX in African lakes because it did not account for the enhancement of MOX associated with methanotrophs attached to phytoplankton. Indeed, the discrepancy between model predictions and measured MOX rates increased with increasing Chl-*a*. Incorporating a simple multiplicative term dependent on Chl-*a* into the existing model substantially improved its ability to reproduce MOX observations in African lakes.

These findings indicate that the response of MOX to eutrophication is more complex than previously assumed. The increase in MOX in surface waters driven by a higher abundance of methanotrophs attached to phytoplankton represents a mechanism that is largely independent of increases in dissolved CH₄ arising from enhanced sedimentary anaerobic methanogenesis—the mechanism that has been the primary focus of previous studies looking into effects of eutrophication (Fig. 7).

Eutrophication is also expected to increase photosynthesis-driven OMP (Fig. 7). In contrast, OMP related to MPn degradation should decrease as PO₄³⁻ availability increases. The photosynthesis-driven OMP pathway could become particularly important if phytoplankton communities shift toward cyanobacteria, which exhibit higher OMP rates than diatoms. However, our results show that *K* increased with Chl-*a* in non-CCC lakes regardless of whether cyanobacteria or other phytoplankton groups dominated, indicating that MOX should partially mitigate OMP regardless of shifts in phytoplankton community composition.

Moreover, photosynthesis-driven OMP contributed only minimally to sustaining MOX. Median OMP:MOX ratios ranged between 0.4% and 5.3% based on in situ incubations in five African lakes and laboratory culture data, respectively. Photosynthesis-driven OMP also contributed only minimally to sustaining diffusive CH₄, with median contributions between 1.6% and 24.1% for OMP_{in.situ} and OMP_{cult}, respectively. Furthermore, OMP:FCH₄ ratios decreased with increasing Chl-*a*, dissolved CH₄ concentrations, and FCH₄. This indicates that

photosynthesis-driven OMP contributed less to diffusive CH₄ emissions in the most eutrophic lakes, which were also the strongest CH₄ emitters and where, consequently, emissions were primarily driven by sedimentary anaerobic methanogenesis.

The connectivity between wetlands and inland waters in sustaining CH₄ emissions is an increasingly recognized conceptual framework in both tropical and higher-latitude regions. Our results provide an additional perspective on this framework. Lakes connected to flooded forests within the CCC exhibited higher *K* values than lakes outside the CCC, which are largely disconnected from extensive wetlands (within equivalent ranges of depth and Chl-*a*). We hypothesize that this enhancement of *K* in CCC lakes may be related to inputs of methanotrophs from the soils of flooded forests. The inoculation of methanotrophs from soils could also explain the higher *K* values in African rivers compared to African lakes at equivalent TSM and POC values. These hypotheses should be tested through future studies quantifying the abundance and diversity of methanotrophic microorganisms.

Methods

Sampling and laboratory analysis

Sampling was conducted using small fishing boats or research vessels, depending on lake size (e.g., Maman Benita on Lake Tanganyika, RV Hammerkop on Lake Victoria, and ISP-Gombe on Lakes Tumba and Mai Ndombe). In small lakes, one or two sites were sampled, typically in the central basin and nearshore. In larger lakes, several sites were sampled along depth gradients, from littoral to the deepest zones. Each lake was sampled at least twice - once during the rainy and once during the dry season - during daylight hours. Although phytoplankton composition and primary production vary among African lakes³⁵, seasonal variability is relatively small compared to higher-latitude systems⁷³. Only surface waters were sampled, as the objective was to assess the relative importance of MOX in relation to diffusive CH₄ emissions and to OMP, assumed to be associated with photosynthesis in illuminated surface waters.

Depth was measured with a portable echosounder (Plastimo Echotest-II or Humminbird Helix 5 G2). Vertical profiles of water temperature, specific conductivity, pH, dissolved O₂ were recorded with an YSI EXO-II multi-parameter probe, calibrated according to manufacturer's specifications, with commercial pH buffers (4.00, 7.00, 10.00), and with a 1000 μS cm⁻¹ conductivity standard. Minutes before each CTD profile, depth was zeroed and the O₂ probe calibrated. Surface water for MOX measurements was collected with a horizontally held Niskin bottle (~20 cm below the surface) and transferred with a silicone tubing into five 60 mL borosilicate serum bottles (Wheaton). Bottles were immediately sealed with a butyl stopper (Wheaton) and crimped with an aluminium cap. The initial incubation sample (T₀) was stopped immediately after collection with 200 μL of a saturated solution of HgCl₂ injected with a 1 mL syringe mounted with a stainless-steel needle stuck through the butyl stopper and a second needle allowed the ejection of water displaced by the addition of the solution of HgCl₂. The remaining four bottles (T₁-T₄) were kept in the dark in a cool-box containing lake water and sequentially stopped with HgCl₂ addition at regular time intervals ranging from 30 min to 12 h depending on the lake and chosen based on an approximate estimation of phytoplankton biomass based on Secchi disk depth measurements. The exact time of HgCl₂ addition at each time step of the MOX incubation was logged.

Dissolved CH₄ concentrations were determined via the headspace technique using a gas chromatograph (GC) with a flame ionization detector. A headspace (20 mL) was made with ultra-pure N₂ (Air Liquide™ Belgium) in the serum bottles. After overnight equilibration at room temperature a sub-sample of 12 mL of headspace was injected into the GC (SRI™ 8610 C) calibrated with CH₄:N₂ gas mixtures with mixing ratios of 1, 10, 30, 509, and 2011 ppm, manufactured and

certified at $\pm 2\%$ by Air Liquide™ Belgium. The precision of measurements was $\pm 3\%$ and the detection limit was 0.5 nmol L^{-1} .

Samples for $\delta^{13}\text{C-CH}_4$ were also collected in a 60 mL serum bottle and biological activity stopped with the addition of HgCl_2 . The $\delta^{13}\text{C-CH}_4$ was measured in the headspace gas (20 mL of synthetic air, Air Liquide™ Belgium) equilibrated overnight at room temperature with 40 mL of water sample. When headspace partial pressure of CH_4 ($p\text{CH}_4$) exceeded 10 ppm, gas samples were diluted to ~ 6 ppm to fall within the manufacturer's recommended instrumental operational range (2–10 ppm). The (un)diluted gas samples were analyzed with a cavity ring-down spectrometer (Picarro™ G2201-i) equipped with a Small Sample Introduction Module 2 (Picarro™). Data were corrected using calibration curves relating $\delta^{13}\text{C-CH}_4$ to $p\text{CH}_4$, prepared from dilutions of two certified standards ($-23.9 \pm 0.3 \text{ ‰}$ and $-69.0 \pm 0.3 \text{ ‰}$ Airgas™ Specialty Gases) referenced to Vienna Pee Dee Belemnite. Analytical precision based on repeated analysis of the two standards was better than $\pm 1.0 \text{ ‰}$.

For CR measurements, six biological oxygen demand (BOD) borosilicate bottles of 60 mL were filled with a tubing from the Niskin bottle. O_2 concentration was measured in 3 BOD bottles immediately after collection with a YSI Pro-ODO optical O_2 probe, and after 24 h in the 3 other BOD bottles incubated in the dark in a cool box filled with in-situ water. CR ($\mu\text{mol L}^{-1} \text{ d}^{-1}$) was computed from the difference of O_2 concentration ($\mu\text{mol L}^{-1}$) at the start and end of the incubation divided by the time interval (d).

Two liters of surface water were collected for ancillary measurements. Water was filtered through pre-combusted (450°C , >4 h) Whatman glass fibre filters (GF/F grade, $0.7 \mu\text{m}$ porosity) for POC (25 mm diameter filters), phytoplankton pigments, and TSM (47 mm diameter filters). Filters for POC and TSM were stored dry at room temperature, and filters for pigments were stored frozen (-20°C). Filters for POC analysis were decarbonated with HCl fumes for 4 h and dried before encapsulation into silver cups; POC concentration was analysed on an EA-IRMS (Thermo FlashHT with DeltaV Advantage), with a reproducibility better than $\pm 5\%$. Data were calibrated with certified (IAEA-600: caffeine) and in-house standards (leucine and muscle tissue of Pacific tuna) that were previously calibrated versus certified standards. Filters used for the determination of TSM were weighed with an analytical microscale with $\pm 0.1 \text{ mg}$ precision after drying at 50°C during 12 h before and after filtration of a known volume of water, with a precision of the final TSM value of $\pm 10\%$. Phytoplankton pigments were analyzed on 90% acetone extracts by high-performance liquid chromatography with a Waters HPLC chain (fluorescence and photodiode array detectors), with a reproducibility for Chl-a of $\pm 0.5\%$ and a detection limit of $0.01 \mu\text{g L}^{-1}$. Water samples (250–500 mL) for microscopic examination were preserved with formaldehyde (3% final concentration). Samples were examined at the microscope (Leitz Laborlux S and Motic BA 400) for identification of phytoplankton to species level whenever possible.

The water filtered through GF/F Whatman glass fibre filters was collected and further filtered through polyethersulfone syringe encapsulated filters ($0.2 \mu\text{m}$ porosity) for samples to determine DOC that were stored at ambient temperature and in the dark in 40 mL brown borosilicate vials with polytetrafluoroethylene (PTFE) coated septa and preserved with $50 \mu\text{L}$ of H_3PO_4 (85%)², a_{350} that were stored at 4°C and in the dark in 15 mL brown borosilicate vials with PTFE coated septa, and NO_3^- , NH_4^+ , and PO_4^{3-} that were stored frozen (-20°C) in 50 mL polypropylene vials. DOC concentration was determined with a wet oxidation total organic carbon analyzer (IO Analytical Aurora 1030 W), with a typical reproducibility better than $\pm 5\%$. a_{350} was calculated from water absorbance measurements from 190 to 900 nm at 1 nm increments with a Perkin-Elmer UV/Vis 650S spectrophotometer with a 1 cm quartz cuvette, using ultra-pure water as a blank. NO_3^- was determined with the sulfanilamide colorimetric reduction method, NH_4^+ with the dichloroisocyanurate-salicylate-

nitroprussiate colorimetric method, and PO_4^{3-} with the ammonium molybdate, ascorbic acid, and potassium antimony tartrate colorimetric method. Precisions were ± 0.05 , ± 0.02 , and $\pm 0.02 \mu\text{mol L}^{-1}$ for PO_4^{3-} , NH_4^+ , and NO_3^- , respectively. Detection limits were 0.03, 0.05, and $0.02 \mu\text{mol L}^{-1}$ for PO_4^{3-} , NH_4^+ , and NO_3^- , respectively.

Computations

The CH_4 concentration at each time step ($\text{CH}_{4(t)}$ nmol L^{-1}) was fitted as a function of time (t in d) through the 5 data points (T_0 – T_4)⁷:

$$\text{CH}_{4(t)} = \text{CH}_{4(T_0)} e^{-Kt} \quad (1)$$

where $\text{CH}_{4(T_0)}$ is the initial CH_4 concentration at T_0 , K (d^{-1}) is the fitted coefficient corresponding to the apparent MOX rate constant, allowing to compute MOX ($\text{nmol L}^{-1} \text{ d}^{-1}$) according to:

$$\text{MOX} = K \times \text{CH}_{4(T_0)} \quad (2)$$

Thermal stratification was defined as a temperature difference $\geq 0.2^\circ\text{C}$ between surface and bottom waters. Although no universal definition of lake stratification exists, thresholds based on differences or gradients of temperature or density are commonly used⁷⁴. In this study, differences in dissolved O_2 concentration between surface and bottom waters were used as an additional indicator of thermal stratification, reflecting the segregation of biogeochemical processes between surface and bottom layers. In most cases, a difference in dissolved O_2 concentration $> 50 \mu\text{mol L}^{-1}$ coincided with a temperature difference $\geq 0.2^\circ\text{C}$ between surface and bottom waters; this value was therefore adopted as the stratification threshold. The Inter-Sectoral Impact Model Intercomparison Project lake sector protocol defines stratified conditions globally based on a density difference of 0.1 kg m^{-3} between surface and bottom waters⁷⁵, corresponding to a temperature difference of approximately 0.4°C at 25°C . This threshold is higher than the one used in our study, reflecting the weaker vertical density gradients typically observed in tropical lakes compared with higher-latitude systems⁷⁶.

MLD corresponded to the depth of the change of slope in the vertical profiles of temperature that occurred between the transition of the bottom of the mixed layer and the top of the thermocline. The visual inspection of the temperature profiles was contextualized with the vertical profiles of O_2 because, in most cases, the oxycline coincided with the thermocline but changes in O_2 were more marked than those of temperature. The presence of anoxic or hypoxic bottom waters was assumed to indicate a stable stratification rather than a transient diurnal stratification. MLD estimate disregarded the shallow thermocline (within the top 3 m) resulting from diurnal stratification.

The abundance of phytoplankton classes was derived with CHEMTAX⁷⁷. OMP_{cult} was calculated from ratios of OMP as function of Chl-a from incubations in pure phytoplankton cultures (Table S3) for cyanobacteria²¹ and diatoms⁶⁴. The mean OMP:Chl-a ratio for cyanobacteria ($0.7390 \text{ nmol-CH}_4 \mu\text{g-Chl-a}^{-1} \text{ d}^{-1}$) was applied to all non-diatom Chl-a derived from CHEMTAX while the mean OMP:Chl-a ratio for diatoms ($0.0286 \text{ nmol-CH}_4 \mu\text{g-Chl-a}^{-1} \text{ d}^{-1}$, Table S3) was applied to diatom Chl-a. $\text{OMP}_{\text{in.situ}}$ was calculated by applying the mean OMP:Chl-a ratio ($0.0393 \text{ nmol-CH}_4 \mu\text{g-Chl-a}^{-1} \text{ d}^{-1}$, Table S3), derived from incubations with $^{13}\text{C-HCO}_3^-$ in five African lakes¹⁴, to measured Chl-a concentrations, irrespective of phytoplankton composition.

The trophic state index (TSI) was estimated from Chl-a according to⁷⁸:

$$\text{TSI} = 9.81 \ln(\text{Chl} - a) + 30.6 \quad (3)$$

allowing to classify lakes as oligotrophic ($\text{TSI} < 40$), mesotrophic ($40 \leq \text{TSI} < 50$), eutrophic ($50 \leq \text{TSI} < 70$), and hypereutrophic ($\text{TSI} \geq 70$).

F_{CH_4} between surface waters and the atmosphere was computed according to:

$$F_{\text{CH}_4} = k_t \cdot \Delta\text{CH}_4 \quad (4)$$

where ΔCH_4 is the air-water gradient of CH_4 concentration derived from measured dissolved CH_4 concentration and from the atmospheric $p\text{CH}_4$ of 1.9 ppm and the Henry constant of CH_4 , and k_t is the gas transfer velocity (m d^{-1}) derived with the Schmidt number of CH_4 for fresh water and k_{600} (m d^{-1}) computed according to⁶¹:

$$k_{600} = 0.497 + 0.0516u_{10}^{1.7} \quad (5)$$

where u_{10} is wind speed (m s^{-1}) that was retrieved from WorldClim (monthly means)⁷⁹.

For the comparison with MOX and OMP, F_{CH_4} was converted to volumetric units ($\text{nmol L}^{-1} \text{d}^{-1}$) by dividing the original values per m^2 by the MLD.

The fraction of oxidized CH_4 (FOX) was calculated with a closed-system Rayleigh fractionation model:

$$\ln(1 - \text{FOX}) = \left[\ln(\delta^{13}\text{C} - \text{CH}_{4_initial} + 1000) - \ln(\delta^{13}\text{C} - \text{CH}_4 + 1000) \right] / [\alpha - 1] \quad (6)$$

where $\delta^{13}\text{C}-\text{CH}_{4_initial}$ is the signature of dissolved CH_4 as produced by methanogenesis in sediments, $\delta^{13}\text{C}-\text{CH}_4$ is the signature of dissolved CH_4 measured in-situ, and α is the fractionation factor.

We used $\alpha = 1.016$ based on field measurements in a tropical lake⁸⁰. For $\delta^{13}\text{C}-\text{CH}_{4_initial}$, we used two values (-60 and -70 ‰) that correspond to the upper and lower bounds of the range of values of $\delta^{13}\text{C}-\text{CH}_4$ typically encountered in lake sediments⁸¹.

MOX_{iso} was calculated as²:

$$\text{MOX}_{\text{iso}} = F_{\text{CH}_4} \times \frac{\text{FOX}}{1 - \text{FOX}} \quad (7)$$

HR was computed from CR and autotrophic respiration (AR):

$$\text{HR} = \text{CR} - \text{AR} \quad (8)$$

AR was estimated from a carbon (C) specific respiration rate for phytoplankton of 0.1 d^{-1} ⁸² and phytoplankton C content estimated from Chl-a with a C:Chl-a ratio of 50.

CR and HR ($\mu\text{mol O}_2 \text{ m}^{-2} \text{ d}^{-1}$) were parameterized as a function of Chl-a ($\mu\text{g L}^{-1}$) and DOC (mg L^{-1}). AR should be directly proportional to phytoplankton biomass, and HR should depend both on photosynthates (hence also proportional to Chl-a) but potentially also on allochthonous DOC. Parameterizations were established separately for CCC and non-CCC due to distinct patterns (Supplemental Fig. S26).

For non-CCC lakes:

$$\begin{aligned} \text{Log}(\text{CR}) = & 0.415 (\pm 0.055) + 0.506 (\pm 0.064) \times \text{log}(\text{DOC}) \\ & + 0.368 (\pm 0.041) \times \text{log}(\text{Chl} - a) (r^2 = 0.53p < 0.0001n = 181) \end{aligned} \quad (9)$$

$$\begin{aligned} \text{Log}(\text{HR}) = & 0.237 (\pm 0.092) + 0.684 (\pm 0.107) \times \text{log}(\text{DOC}) + 0.184 \\ & (\pm 0.069) \times \text{log}(\text{Chl} - a) (r^2 = 0.26p < 0.0001n = 181) \end{aligned} \quad (10)$$

For CCC lakes:

$$\begin{aligned} \text{CR} = & 16.34 (\pm 2.56) - 0.1916 (\pm 0.073) \times \text{DOC} + 0.505 (\pm 0.856) \times \\ \text{Chl} - a (r^2 = 0.63p < 0.034n = 7) \end{aligned} \quad (11)$$

$$\begin{aligned} \text{CR} = & 16.31 (\pm 2.56) - 0.2005 (\pm 0.073) \times \text{DOC} + 0.089 (\pm 0.856) \times \\ \text{Chl} - a (r^2 = 0.67p < 0.025n = 7) \end{aligned} \quad (12)$$

Statistical analysis

All statistical analysis (linear regressions and comparison of means) were performed in GraphPad Prism version 10.6.0. Data points (measurements) were taken from distinct samples. Data were $\log_{10}$ transformed prior to analysis. Comparisons of means among groups were made via one-way ANOVA with Tukey's post-hoc tests, and pairwise differences by unpaired t -tests at 0.05 level.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

The data used in this study are available in Zenodo at <https://zenodo.org/records/18959976>⁸³.

Source Data of figures are available from Figshare at <https://doi.org/10.6084/m9.figshare.32615049>. Source data are provided with this paper.

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Author contributions

Conceptualization: A.V.B. Data curation: A.V.B., C.M., and S.B. Formal analysis: A.V.B., C.M. Funding acquisition: A.V.B., and S.B. Investigation: A.V.B., C.M., L.D., W.O., P.I., P.O., I.A.K., J.-P.D., W.C., and S.B. Project administration: A.V.B., and S.B. Writing—original draft: A.V.B. Writing—review & editing: A.V.B., C.M., L.D., W.O., P.I., P.O., I.A.K., J.-P.D., W.C., and S.B.

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Competing interests

The authors declare no competing interests.

Additional information

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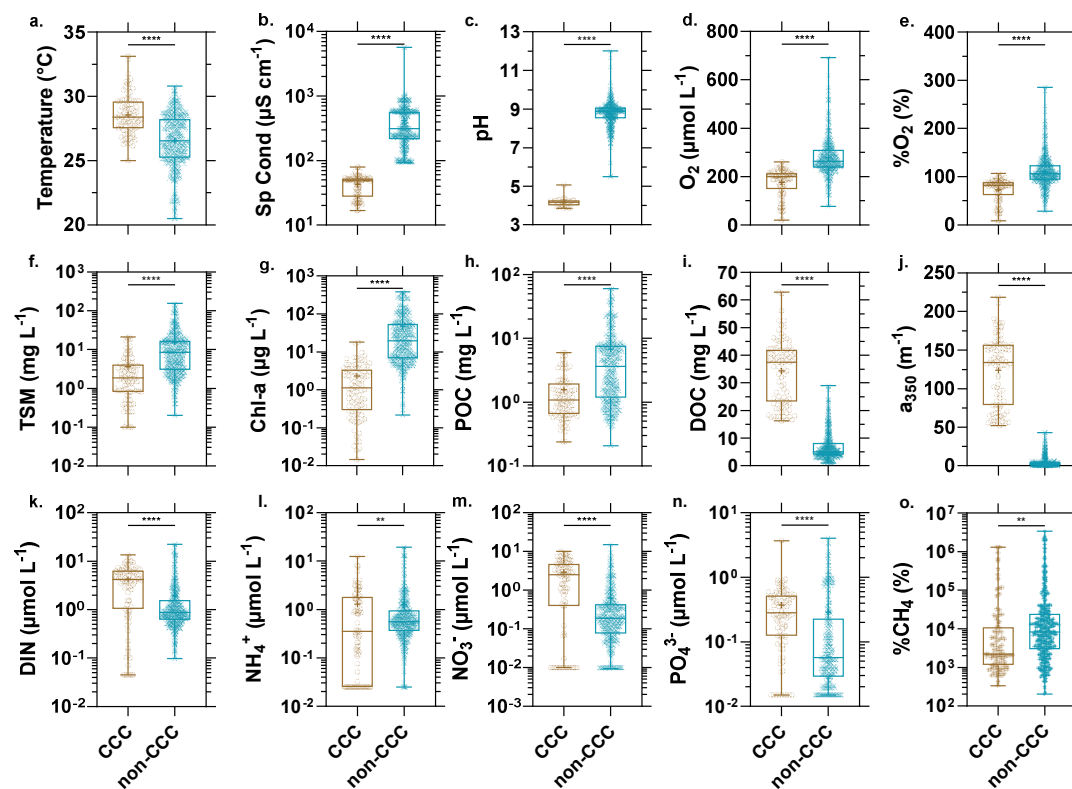


Figure S1 Comparison of biogeochemical variables in surface waters of lakes within and outside the Cuvette Centrale Congolaise. Water temperature (°C, **a**) (n=92;411), specific conductivity (Sp Cond in $\mu\text{S cm}^{-1}$, **b**) (n=92;407), pH (**c**) (n=31;407), dissolved oxygen concentration (O_2 in $\mu\text{mol L}^{-1}$, **d**) (n=92;344), dissolved oxygen saturation level (% O_2 in %, **e**) (n=92;344), total suspended matter (TSM in mg L^{-1} , **f**) (n=92;411), chlorophyll-a (Chl-a in $\mu\text{g L}^{-1}$, **g**) (n=92;411), particulate organic carbon (POC in mg L^{-1} , **h**) (n=92;403), dissolved organic carbon (DOC in mg L^{-1} , **i**) (n=91;399), coloured dissolved organic matter absorbance at 350 nm (a_{350} in m^{-1} , **j**) (n=92;397), dissolved inorganic nitrogen (DIN in $\mu\text{mol L}^{-1}$, **k**) (n=92;396), ammonium (NH_4^+ in $\mu\text{mol L}^{-1}$, **l**) (n=92;396), nitrate (NO_3^- in $\mu\text{mol L}^{-1}$, **m**) (n=92;396), phosphate (PO_4^{3-} in $\mu\text{mol L}^{-1}$, **n**) (n=92;292) concentrations, and dissolved CH_4 saturation level (% CH_4 in %, **o**) (n=92;411) in surface waters of 79 African lakes (Fig. 1) located within (CCC) or outside (non-CCC) the Cuvette Centrale Congolaise. Results of the statistical comparison of means are summarized at the top of the figures and detailed in Table S4.

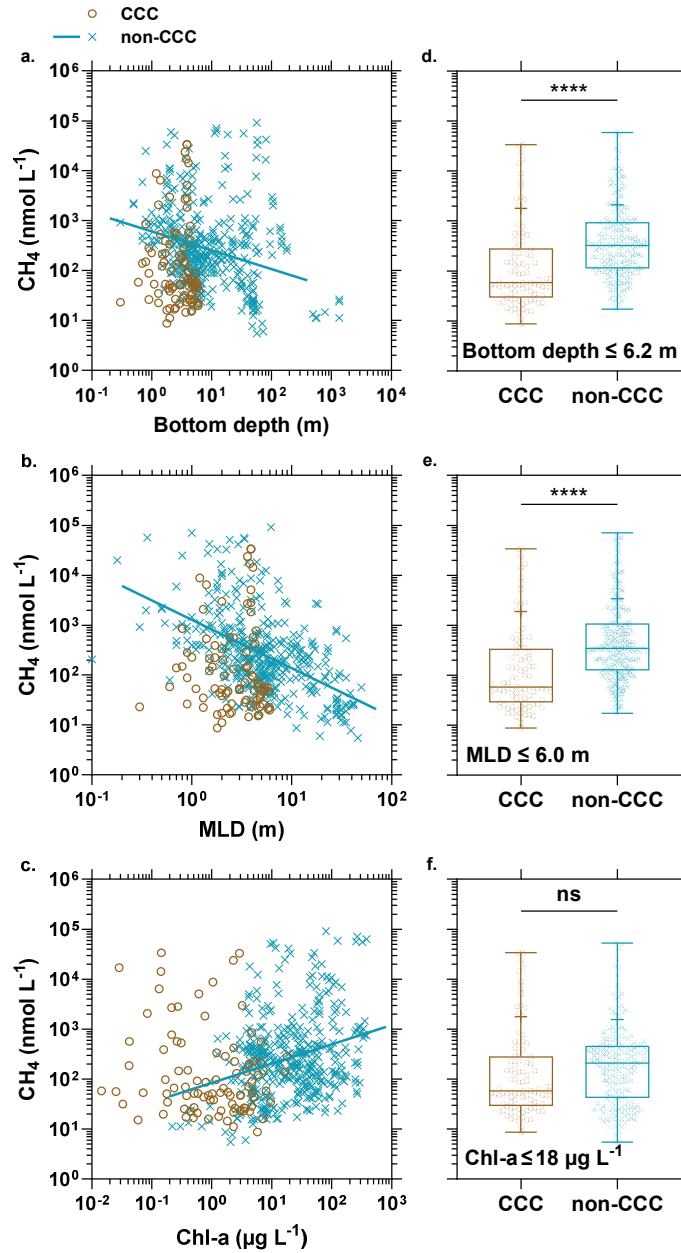


Figure S2 Methane in African lakes driven by lake morphometry and productivity. Relation between dissolved CH₄ concentrations (nmol L⁻¹) and bottom depth (at sampling site in m, **a,d**) (n=92;411), mixed layer depth excluding daily thermocline (MLD in m, **b,e**) (n=92;411), and chlorophyll-a concentration (Chl-a in μg L⁻¹, **c,f**) (n=92;411) in surface waters of 79 African lakes (Fig. 1) located within (CCC) or outside (non-CCC) the Cuvette Centrale Congolaise. The box represents the first and third quartile, horizontal line corresponds to the median, cross to the mean, error bars to the maximum and minimum, symbols show all data points. Results of the statistical comparison of means are summarized at the top of the figures and detailed in Table S4. Solid lines show significant linear regressions (Table S5). For a meaningful comparison of CH₄ means between CCC (n=92) and non-CCC data (**d,e,f**), the non-CCC CH₄ data were sorted for a bottom depth ≤ 6.2 m (n=203), a MLD ≤ 6.0m (n=241), or Chl-a ≤ 18 μg L⁻¹ (n=199) that correspond to the maximal values of those quantities observed in the CCC lakes.

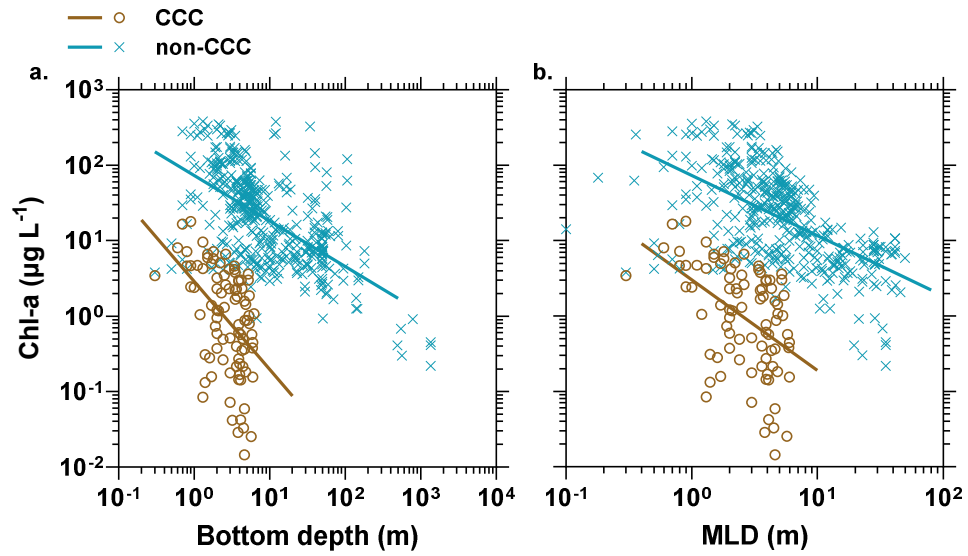


Figure S3 Productivity in African lakes driven by depth and mixing. Chlorophyll-a concentration (Chl-a in $\mu\text{g L}^{-1}$) versus bottom depth at sampling station (m, **a**) and mixed layer depth excluding daily thermocline (MLD in m, **b**) in surface waters of 79 African lakes (Fig. 1) located within (CCC) (n=92) or outside (non-CCC) (n=411) the Cuvette Centrale Congolaise. Solid lines show significant linear regressions (Table S5).

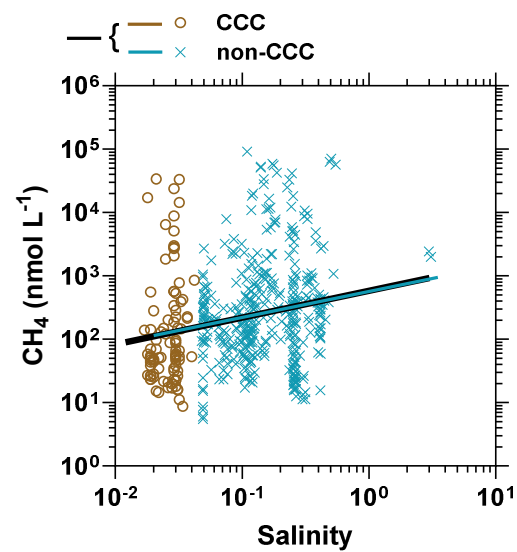


Figure S4 Methane in African lakes driven by salinity. Dissolved CH_4 concentrations (nmol L^{-1} , $n=503$) versus salinity computed from conductivity measurements (1) in surface waters of 79 African lakes (Fig. 1) located within (CCC) ($n=92$) or outside (non-CCC) ($n=411$) the Cuvette Centrale Congolaise. Solid lines show significant linear regressions (Table S5).

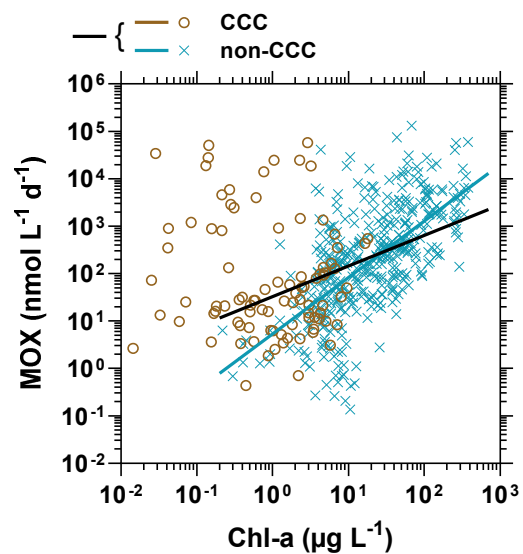


Figure S5 Methane oxidation rate (MOX) driven by phytoplankton biomass. MOX (nmol L⁻¹ d⁻¹) versus chlorophyll-a (Chl-a in μg L⁻¹) concentration in surface waters of 79 African lakes (Fig. 1) located within (CCC) (n=92) or outside (non-CCC) (n=411) the Cuvette Centrale Congolaise. Solid lines show significant linear regressions (Table S5).

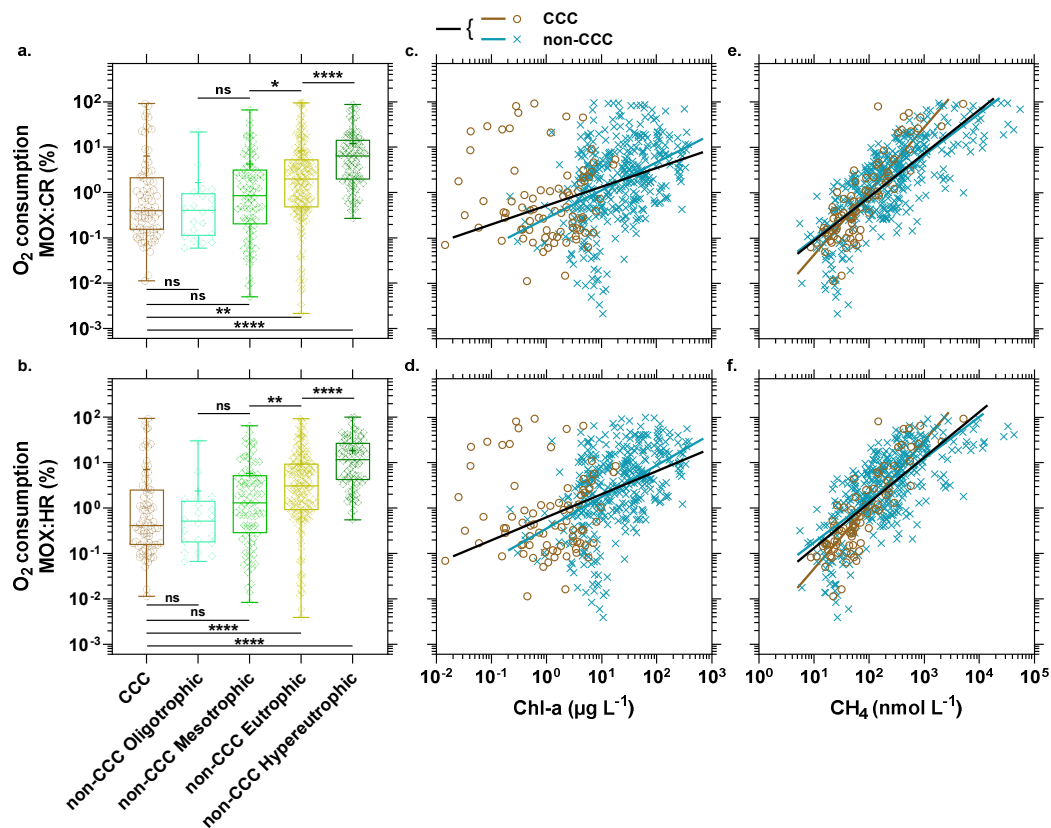


Figure S6 Relative importance of methane oxidation (MOX) and respiration driven by phytoplankton biomass. Ratio of O₂ consumption from MOX and community respiration (CR) and heterotrophic respiration (HR) as a function of trophic state (**a,b**), versus the concentration of Chlorophyll-a (Chl-a in μg L⁻¹, **c,d**), and versus CH₄ concentration (nmol L⁻¹, **e,f**) in surface waters of 79 African lakes (Fig. 1) located within (CCC) (n=81) or outside (non-CCC) (n=395) the Cuvette Centrale Congolaise. Individual fluxes in μmol L⁻¹ d⁻¹. O₂ consumption from MOX was computed from measured MOX rates using a O₂:CH₄ ratio of 2:1. CR and HR were computed with parametrizations as a function of chlorophyll-a and dissolved organic carbon concentrations, established from O₂ decrease during incubations during 24h obtained in 21 African lakes (n=188).

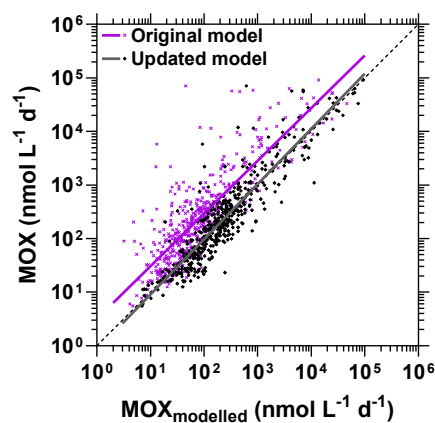


Figure S7 Update of existing model of methane oxidation rate (MOX) in lakes. MOX (nmol L⁻¹ d⁻¹) measured by incubations in surface waters of 79 African lakes (Fig. 1) versus modelled MOX (MOX_{model} in nmol L⁻¹ d⁻¹) with the original and an updated version of the model (n=503). Solid lines show significant linear regressions (Table S5). MOX_{model} was computed from a parameterization (6) based on dissolved concentrations of oxygen and CH₄ established from measurements in 6 small lakes situated on the Canadian Shield in the southern Québec (Canada) where surface Chl-a values ranged between 1 and 3 µg L⁻¹. The updated model applies a factor dependent on Chl-a derived from the a polynomial fit to data in Figure 3 to the original MOX model (2): $\ln \text{MOX} = \ln(10^{(0.0783 \cdot \log(\text{Chl-a})^2 + 0.2412 \cdot \log(\text{Chl-a}) + 0.0838)}) + (20.08 + 0.79 \cdot \ln(\text{CH}_4) - 5669.61/T + \ln(\exp(-0.01 \cdot \text{O}_2) - \exp(-(0.01 + 0.18) \cdot \text{O}_2)))$ where MOX is in µmol L⁻¹ d⁻¹, Chl-a in µg L⁻¹, CH₄ and O₂ in µmol L⁻¹, and temperature (T) in Kelvin

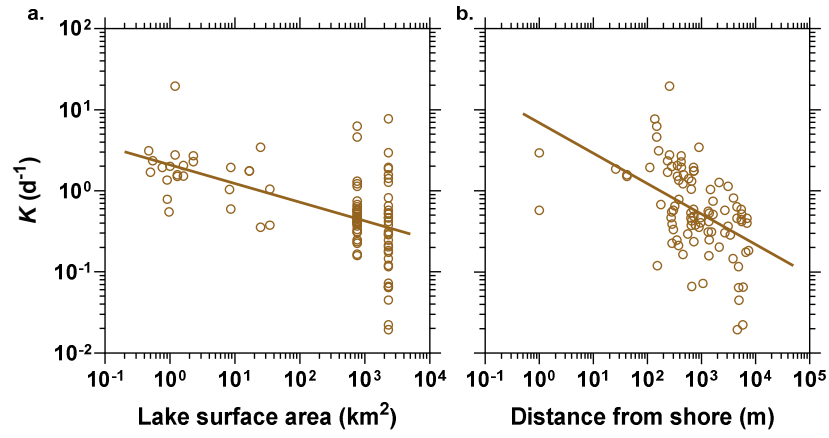


Figure S8 Methane oxidation rate constant (K) driven by inputs of flooded forests. K (d⁻¹) versus lake surface area (km², **a**) and distance from shore (m, **b**) in surface waters of 16 African lakes (Fig. 1) located within the Cuvette Centrale Congolaise (Lakes Mai Ndombe and Tumba plus 14 smaller adjacent lakes) (n=92). Solid lines show the linear regressions (Table S5).

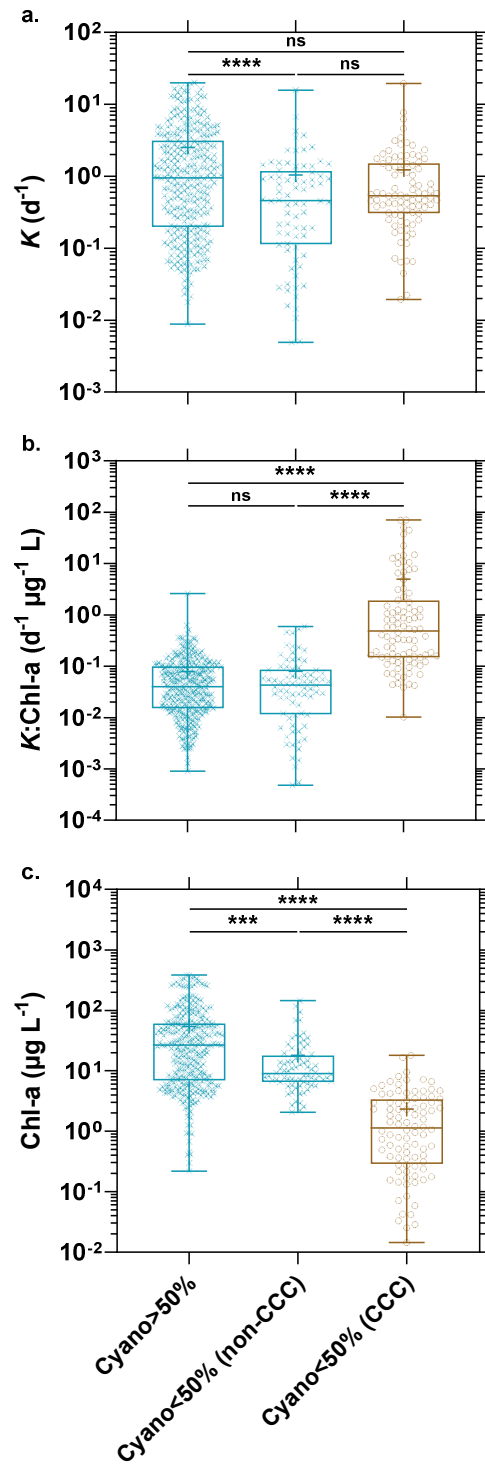


Figure S9 Impact of phytoplankton composition on methane oxidation. Methane oxidation rate constant (K in d^{-1} , **a**), K normalized by chlorophyll-a (Chl-a) concentration ($K:\text{Chl-a}$ in $\text{d}^{-1} \mu\text{g}^{-1} \text{L}$, **b**), and Chl-a ($\mu\text{g L}^{-1}$, **c**) in surface waters of 79 African lakes (Fig. 1) located within (CCC) or outside (non-CCC) the Cuvette Centrale Congolaise separated according to the abundance ($>$ or $<50\%$) of cyanobacteria (cyano) ($n=335;168$). Results of the statistical comparison of means are summarized at the top of the figures and detailed in Table S6.

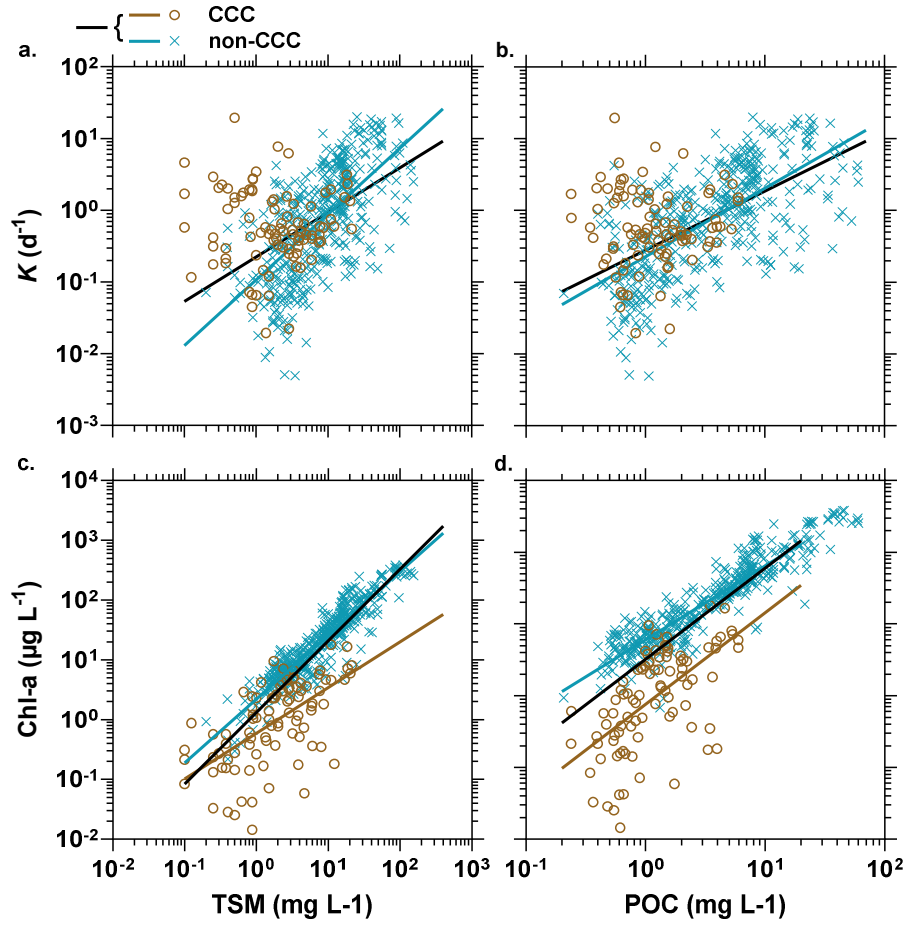


Figure S10 Impact of suspended matter on methane oxidation. Methane oxidation rate constant (K in d^{-1}) and chlorophyll-a (Chl-a in $\mu\text{g L}^{-1}$) versus total suspended matter (TSM in mg L^{-1} **a,c**) ($n=92;411$) and particulate organic carbon (POC in mg L^{-1} **b,d**) ($n=92;405$) in surface waters of 79 African (Fig. 1) lakes located within (CCC) or outside (non-CCC) the Cuvette Centrale Congolaise. Solid lines show significant linear regressions (Table S5).

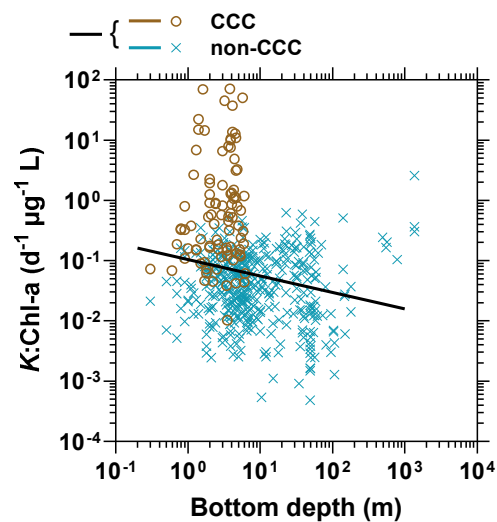


Figure S11 Impact of benthic-pelagic coupling on methane oxidation. Methane oxidation rate constant normalized by chlorophyll-a (Chl-a) concentration ($K:\text{Chl-a}$ in $\text{d}^{-1} \mu\text{g}^{-1} \text{L}$) versus bottom depth (m) in surface waters of 79 African lakes (Fig. 1) located within (CCC) (n=92) or outside (non-CCC) (n=411) the Cuvette Centrale Congolaise. Solid lines show significant linear regressions (Table S5).

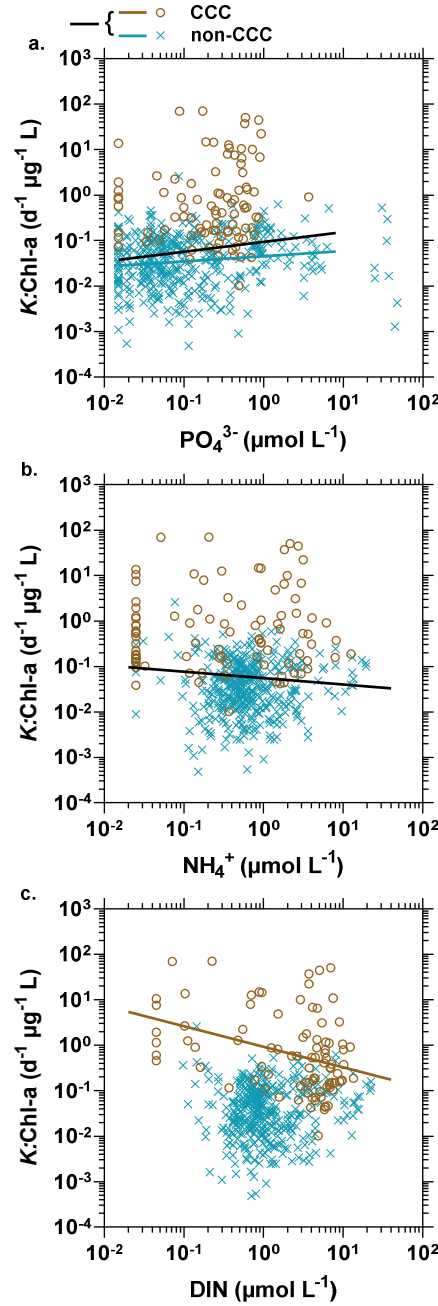


Figure S12 Impact of nutrient availability on methane oxidation. Methane oxidation rate constant normalized by chlorophyll-a (Chl-a) concentration ($K:\text{Chl-a}$ in $\text{d}^{-1} \mu\text{g}^{-1} \text{L}$) versus PO_4^{3-} ($\mu\text{mol L}^{-1}$, **a**), NH_4^+ ($\mu\text{mol L}^{-1}$, **b**), and dissolved inorganic nitrogen (DIN in $\mu\text{mol L}^{-1}$, **c**) in surface waters of 79 African lakes (Fig. 1) located within (CCC) ($n=92$) or outside (non-CCC) ($n=411$) the Cuvette Centrale Congolaise. Solid lines show significant linear regressions (Table S5). The normalization of K by Chl-a allows to explore the effect of other drivers of K than Chl-a (PO_4^{3-} , NH_4^+ , and DIN), given that K strongly depends on Chl-a (Fig 2). The negative relation between $K:\text{Chl-a}$ in the lakes within the CCC and DIN presumably reflects spatial gradients and the variable influence riverine inputs rich in DIN and methanotrophs from flooded forest soils.

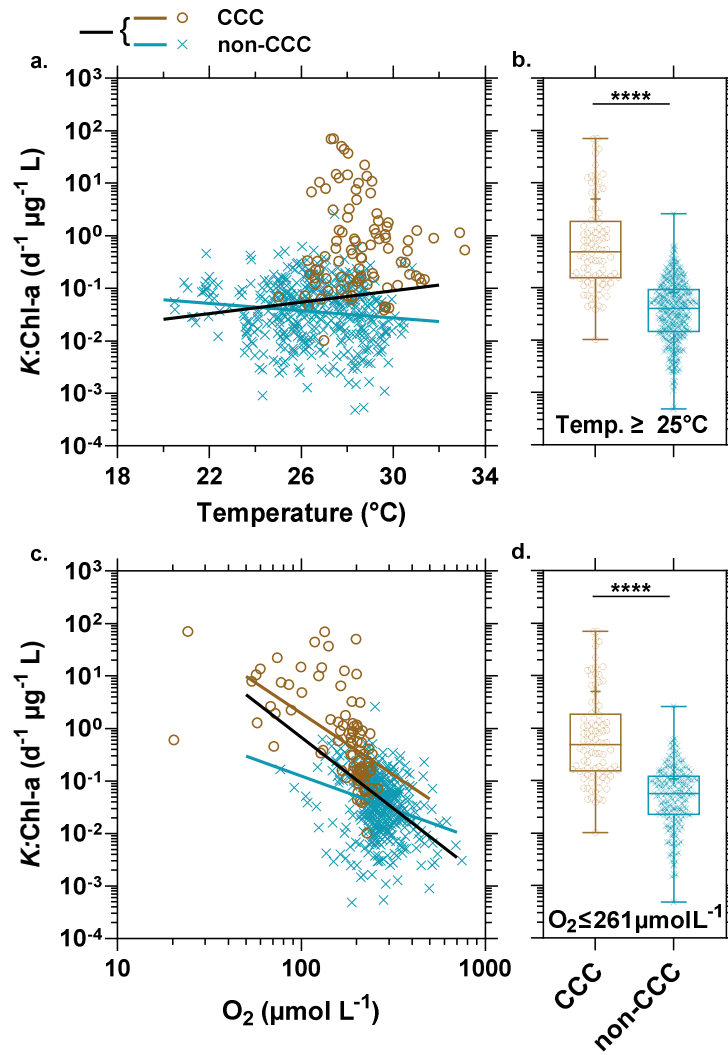


Figure S13 Impact of oxygen availability and temperature on methane oxidation. Methane oxidation rate constant normalized by chlorophyll-a (Chl-a) concentration ($K:\text{Chl-a}$ in $\text{d}^{-1} \mu\text{g}^{-1} \text{L}$) versus water temperature ($^{\circ}\text{C}$) and dissolved O_2 concentration ($\mu\text{mol L}^{-1}$) in surface waters of 79 African lakes (Fig. 1) located within (CCC) ($n=92$) or outside (non-CCC) ($n=411$) the Cuvette Centrale Congolaise (a,c) and corresponding box-plots (b,d). The box represents the first and third quartile, horizontal line corresponds to the median, cross to the mean, error bars to the maximum and minimum, symbols show all data points. For a meaningful comparison of $K:\text{Chl-a}$ means between CCC ($n=92$) and non-CCC data (b,d), the non-CCC CH_4 data were sorted for temperature (Temp) $\geq 25^{\circ}\text{C}$ ($n=330$) and $\text{O}_2 \leq 261 \mu\text{mol L}^{-1}$ ($n=198$) that correspond, respectively, to the minimal and maximal values observed in the CCC lakes. Solid lines show significant linear regressions (Table S5). Results of the statistical comparison of means are summarized at the top of the figures and detailed in Table S4.

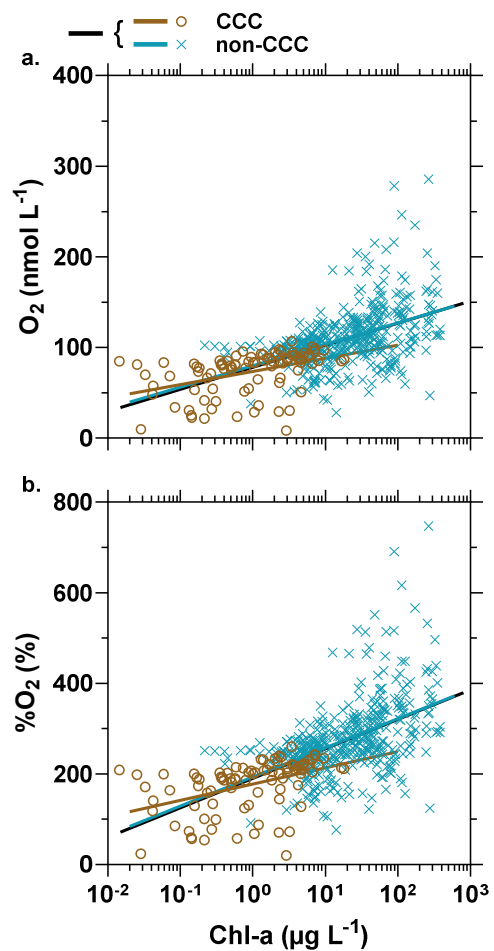


Figure S14 Oxygen availability depends on phytoplankton biomass. Dissolved O_2 concentration ($\mu\text{mol L}^{-1}$, **a**) and O_2 saturation level (% O_2 in %, **b**) versus Chlorophyll-a concentration (Chl-a in $\mu\text{g L}^{-1}$) in surface waters of 79 African lakes (Fig. 1) located within (CCC) ($n=92$) or outside (non-CCC) ($n=407$) the Cuvette Centrale Congolaise. Solid lines show significant linear regressions (Table S5).

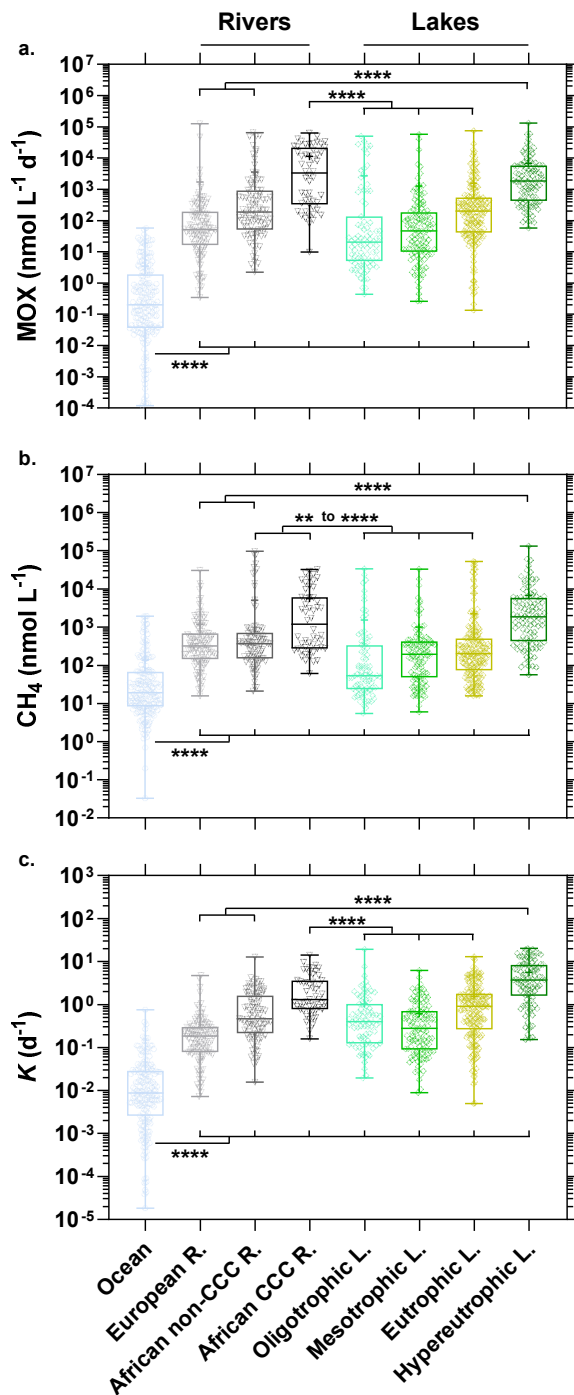


Figure S15 Comparison of methane concentration and methane oxidation in lakes, rivers, and ocean. Methane oxidation (MOX in $\text{nmol L}^{-1} \text{d}^{-1}$, **a**), dissolved CH_4 concentration (nmol L^{-1} , **b**) MOX rate constant (K in d^{-1} , **c**) in surface waters of 79 African lakes (L.) (Fig. 1) ($n=503$) grouped by trophic state, European ($n=114$) and African ($n=148$) rivers (R.) separated into those draining or not the Cuvette Centrale Congolaise (CCC) (**3**), and in the ocean ($n=495$) based on the compilation of (**4**) with additional data (**5,6**). Results of the statistical comparison of means are summarized at the top of the figures and detailed in Table S6.

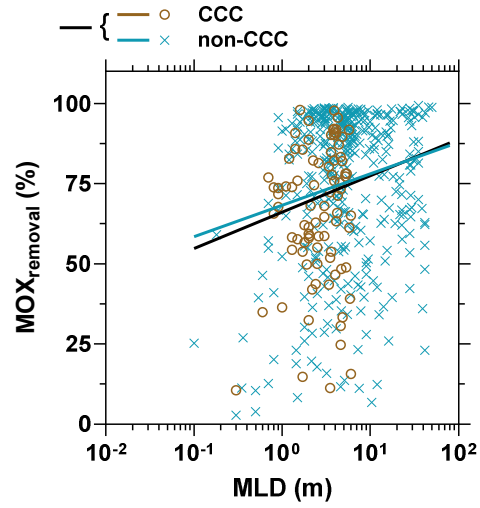


Figure S16 Contribution of methane oxidation (MOX) to total dissolved CH₄ methane removal including degassing to the atmosphere (MOX_{removal}) in African lakes. Contribution of methane oxidation (MOX) to total dissolved CH₄ methane removal including degassing to the atmosphere (MOX_{removal} in %) versus mixed layer depth (MLD in m) in surface waters of 79 African lakes (Fig. 1) located within (CCC) (n=87) or outside (non-CCC) (n=396) the Cuvette Centrale Congolaise. Solid lines show significant linear regressions (Table S5).

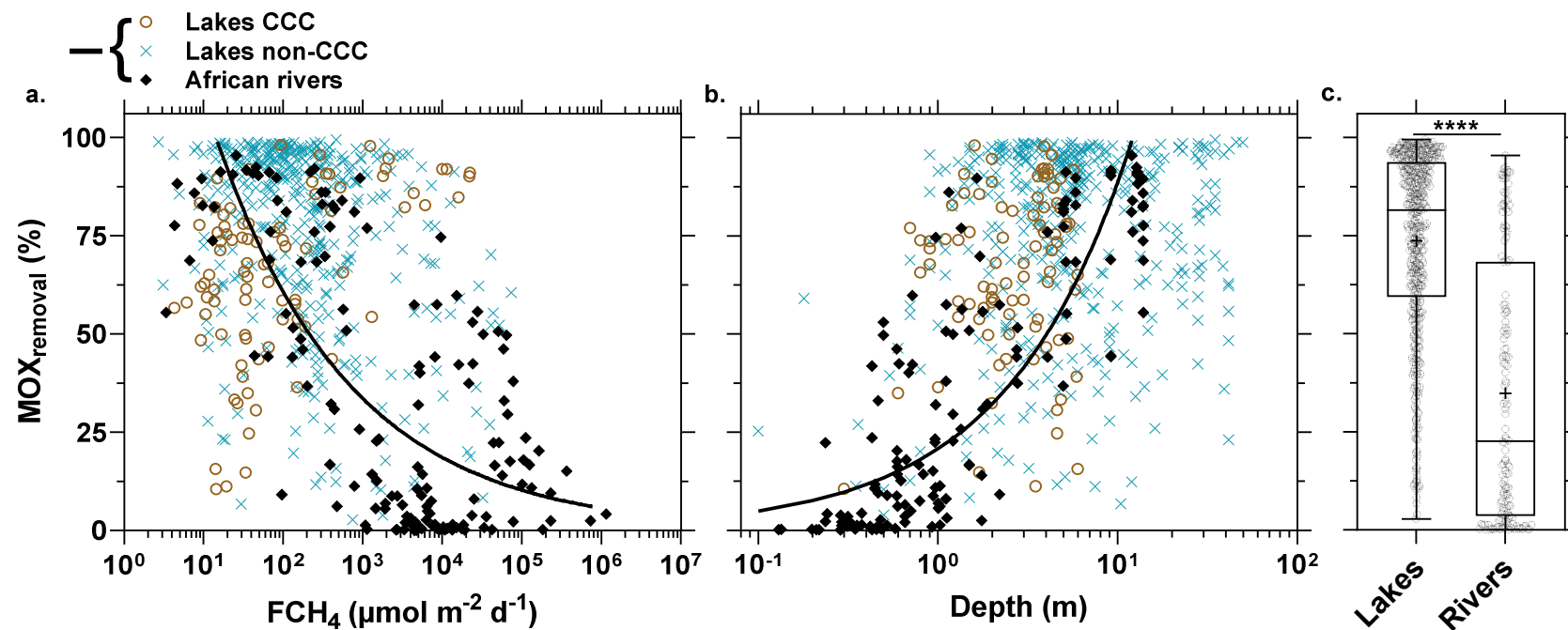


Figure S17 Comparison of the contribution of methane oxidation (MOX) to total dissolved CH₄ methane removal including degassing to the atmosphere (MOX_{removal}) in African lakes and rivers. Contribution of methane oxidation (MOX) to total dissolved CH₄ methane removal including degassing to the atmosphere (MOX_{removal} in %) versus diffusive CH₄ emission to the atmosphere (FCH₄ in μmol m⁻² d⁻¹, **a**) and depth (m, **c**) in surface waters of 79 African lakes (Fig. 1) located within (CCC) (n=87) or outside (non-CCC) (n=396) the Cuvette Centrale Congolaise and African rivers (n=148) (**3**). Solid lines show significant linear regressions (Table S5). Result of the statistical comparison of means is summarized at the top of the figure (**c**) and detailed in Table S4. Depth in plot **b** corresponds to the mixed layer depth in lakes, and total depth (distance from surface water to river bed) in rivers.

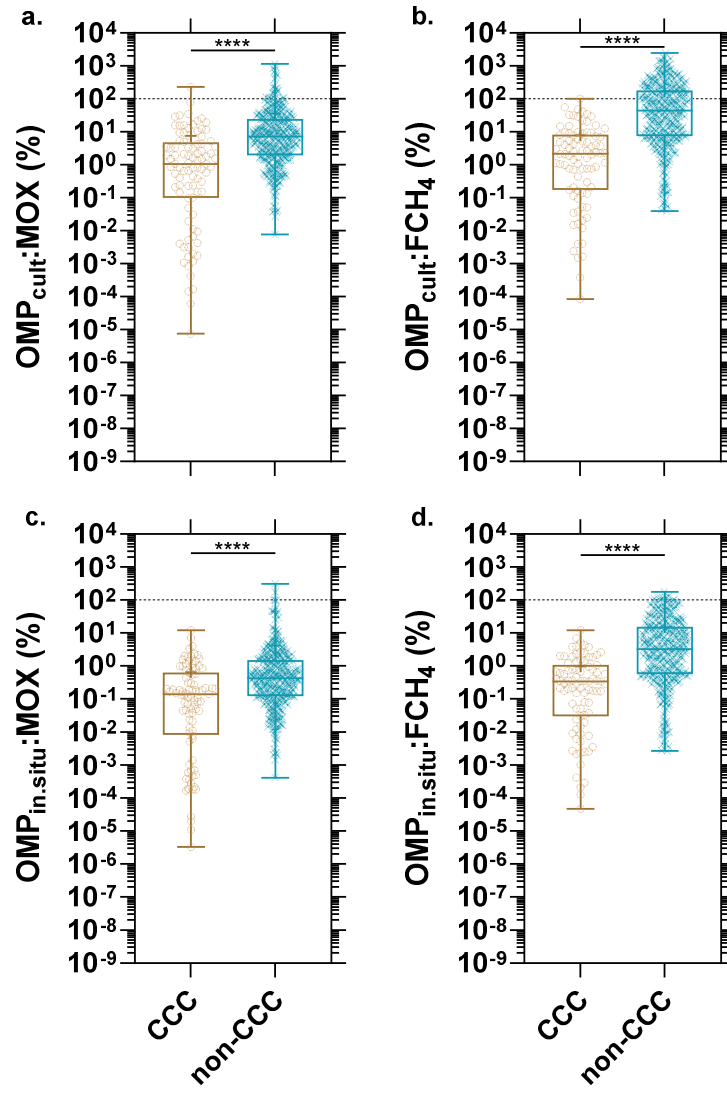


Figure S18 Comparison of oxic methane production (OMP_i) to methane oxidation (MOX) and to diffusive CH₄ emissions to the atmosphere (FCH₄) in lakes within and outside the Cuvette Centrale Congolaise. Ratio (%) of oxic methane production (OMP_{cult} and OMP_{in.situ}) to methane oxidation (MOX **a,c**) (n=503) and to diffusive CH₄ emissions to the atmosphere (FCH₄ converted into volumetric units using the mixed layer depth **b,d**) (n=483) in surface waters of 79 African lakes (Fig. 1) located within (CCC) or outside (non-CCC) the Cuvette Centrale Congolaise. OMP_{cult} and OMP_{in.situ} were computed from measured Chl-a concentrations and OMP ratios to Chl-a reported in literature from either pure cultures of cyanobacteria and diatoms or from incubations of lake water in five African lakes, respectively (Table S3). Results of the statistical comparison of means are summarized at the top of the figures and detailed in Table S4. Dotted horizontal line indicates 100% meaning that OMP is quantitatively equivalent to MOX or FCH₄.

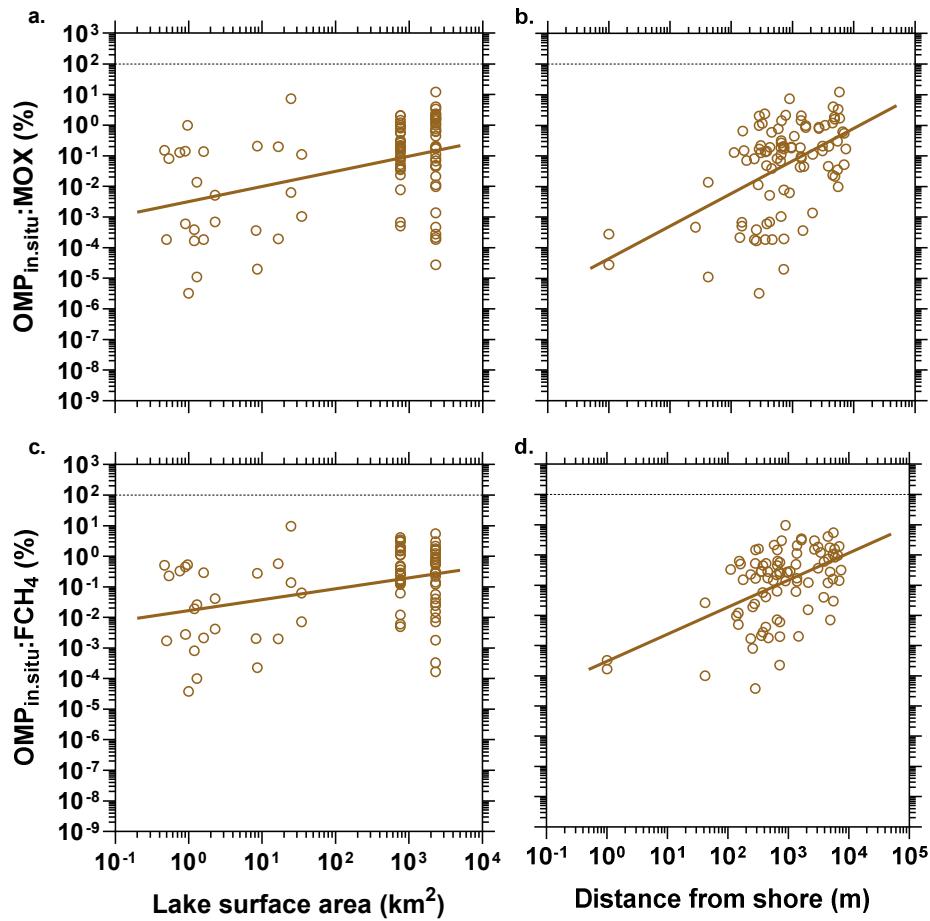


Figure S19 Relative importance of oxic methane production (OMP) and methane oxidation (MOX) and diffusive CH_4 emissions to the atmosphere (FCH_4) driven by inputs of flooded forests. Ratio (%) of oxic methane production ($OMP_{in.situ}$) to methane oxidation (MOX **a,b**) and to diffusive CH_4 emissions to the atmosphere (FCH_4 converted into volumetric units using the mixed layer depth **c,d**) versus lake surface area (km^2 **a,c**) and distance from shore (m **b,d**) in surface waters of 16 African lakes (Fig. 1) located within the Cuvette Centrale Congolaise (Lakes Mai Ndombe and Tumba plus 14 smaller adjacent lakes). $OMP_{in.situ}$ was computed from measured Chl-a concentrations and OMP ratios to Chl-a reported in literature from incubations of lake water in five African lakes (Table S3). Dotted horizontal line indicates 100% meaning that OMP is quantitatively equivalent to MOX or FCH_4 . Solid lines show the linear regressions (Table S5).

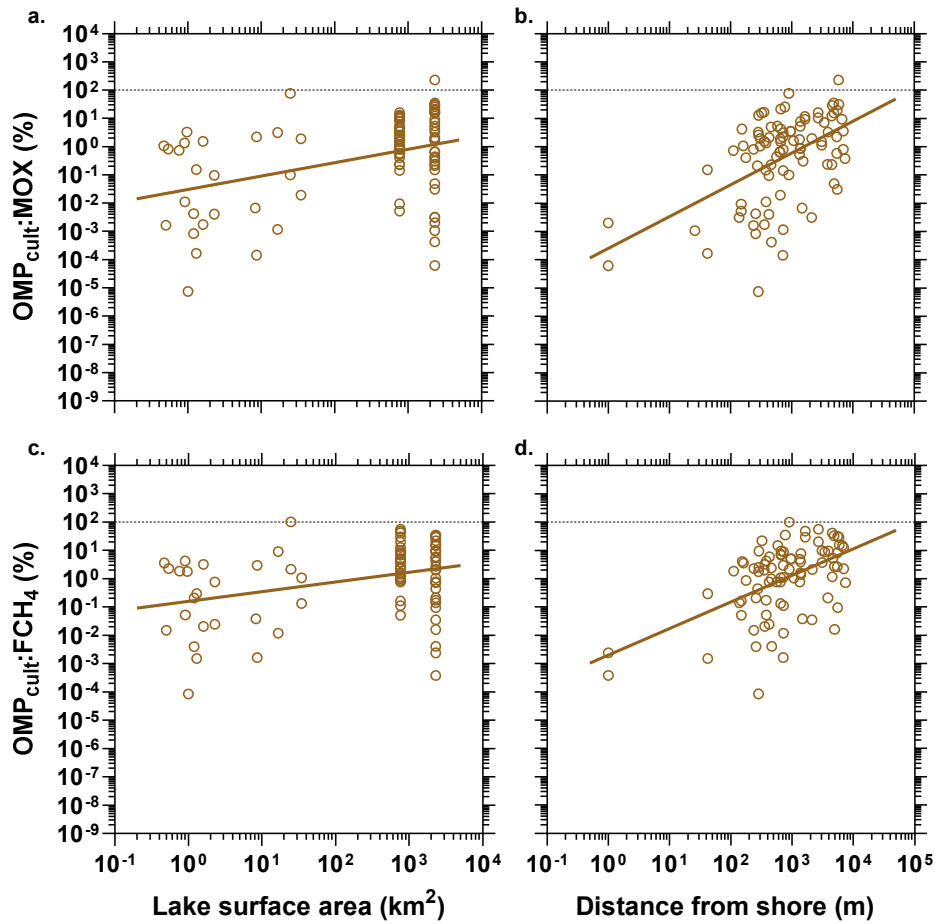


Figure S20 Relative importance of oxic methane production (OMP) and methane oxidation (MOX) and diffusive CH_4 emissions to the atmosphere (FCH_4) driven by inputs of flooded forests. Ratio (%) of oxic methane production (OMP_{cult}) to methane oxidation (MOX **a,b**) and to diffusive CH_4 emissions to the atmosphere (FCH_4 converted into volumetric units using the mixed layer depth **c,d**) versus lake surface area (km^2 **a,c**) and distance from shore (m **b,d**) in surface waters of 16 African lakes (Fig. 1) located within the Cuvette Centrale Congolaise (Lakes Mai Ndombe and Tumba plus 14 smaller adjacent lakes) ($n=92$). OMP_{cult} was computed from measured Chl-a concentrations and OMP ratios to Chl-a reported in literature from pure cultures of cyanobacteria and diatoms (Table S3). Dotted horizontal line indicates 100% meaning that OMP is quantitatively equivalent to MOX or FCH_4 . Solid lines show the linear regressions (Table S5).

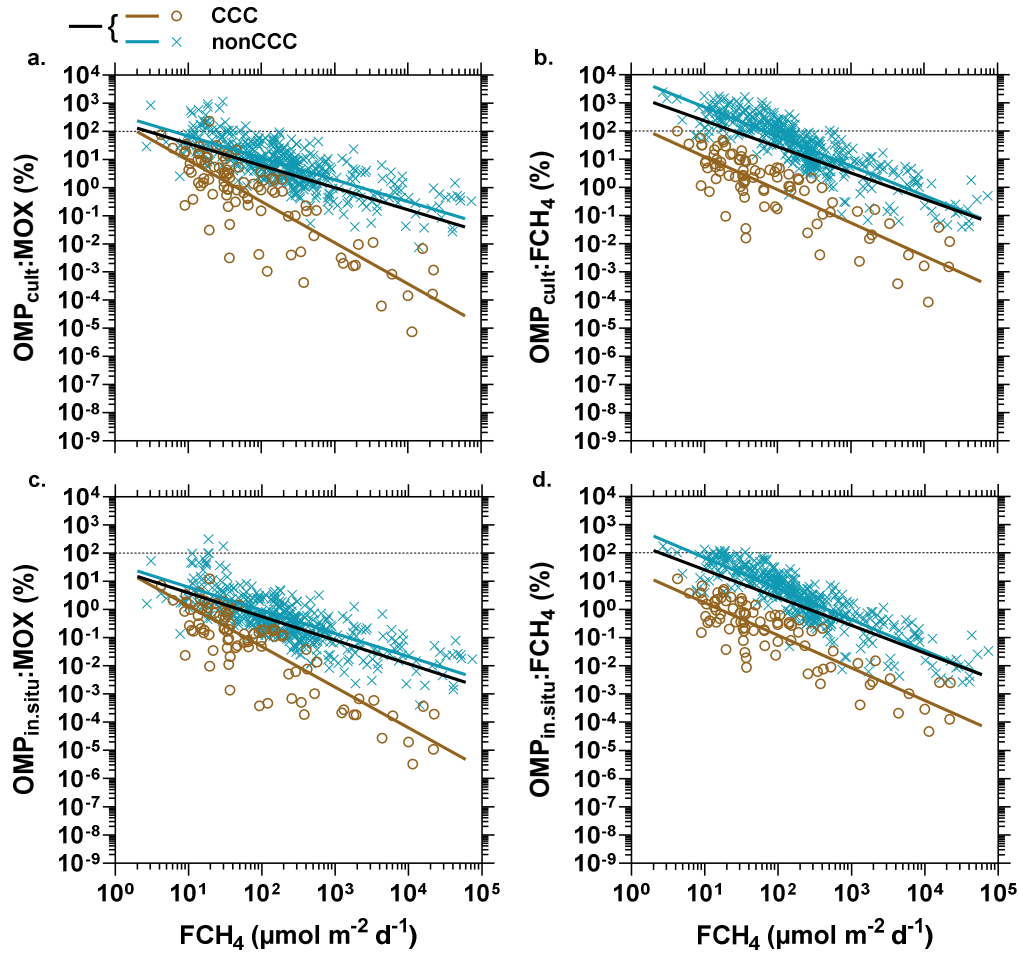


Figure S21. Relative importance of oxic methane production ($OMP_{in.situ}$) to methane oxidation (MOX) and to diffusive CH₄ emissions to the atmosphere (FCH₄) decreases with lake methane diffusive emissions. Ratio (%) of oxic methane production (OMP_{cult} and $OMP_{in.situ}$) to methane oxidation (MOX **a,c**) ($n=503$) and to diffusive CH₄ emissions to the atmosphere (FCH₄ converted into volumetric units using the mixed layer depth **b,d**) ($n=483$) versus FCH₄ (areal in $\mu\text{mol m}^{-2} \text{d}^{-1}$) in surface waters of 79 African lakes (Fig. 1) located within (CCC) or outside (non-CCC) the Cuvette Centrale Congolaise. OMP_{cult} and $OMP_{in.situ}$ were computed from measured Chl-a concentrations and OMP ratios to Chl-a reported in literature from either pure cultures of cyanobacteria and diatoms or from incubations of lake water in five African lakes, respectively (Table S3). Dotted horizontal line indicates 100% meaning that OMP is quantitatively equivalent to MOX or FCH₄. Solid lines show the linear regressions (Table S5).

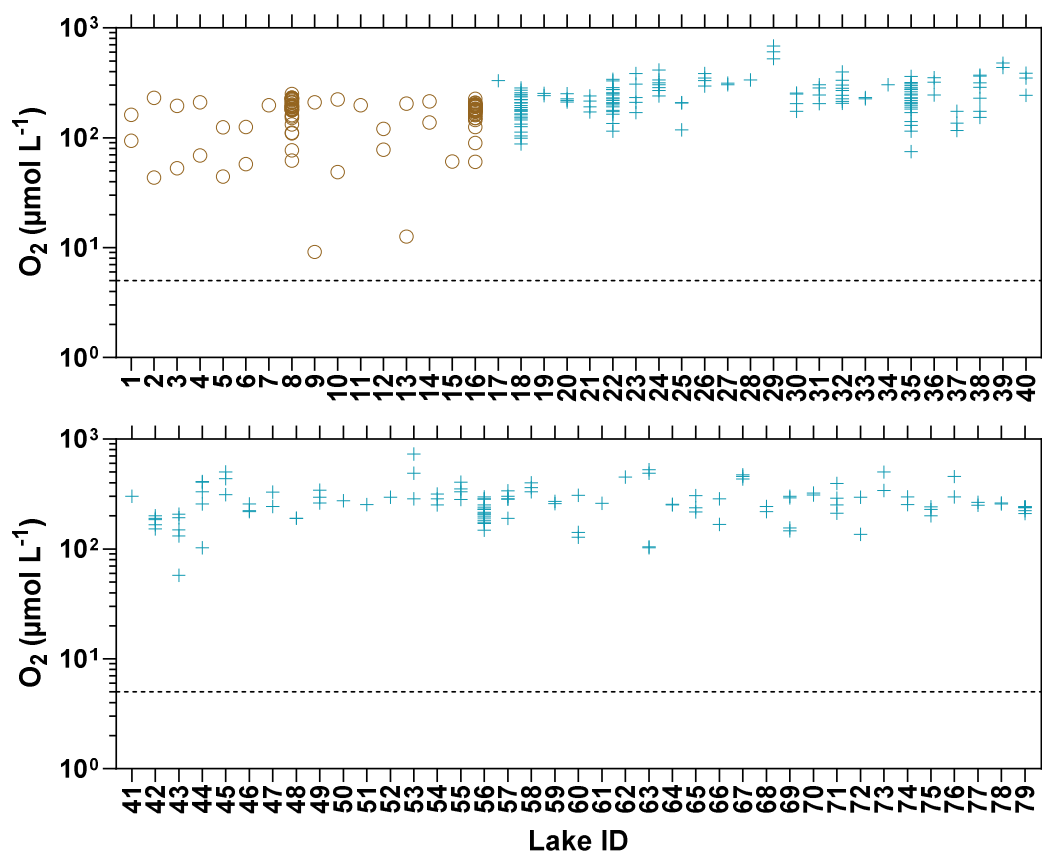


Figure S22 Methane oxidation incubations remained oxic. O₂ concentration (μmol L⁻¹) at the end of the methane oxidation incubations calculated from the initial O₂ concentration (at the moment of sampling), the duration of the incubation (d), and community respiration (CR in μmol L⁻¹ d⁻¹) in surface waters of 79 African lakes (Fig. 1) located within (CCC) (n=92) or outside (non-CCC) (n=92) the Cuvette Centrale Congolaise. Lakes are labelled by numbers given in Table S1 and Figure 1. CR was computed with a parametrization as a function of chlorophyll-a and dissolved organic carbon concentrations, established from O₂ decrease during incubations of 24h obtained in 21 African lakes (n=188). The horizontal dotted line indicates the threshold O₂ concentration (5 μmol L⁻¹) below which MOX is inhibited (7).

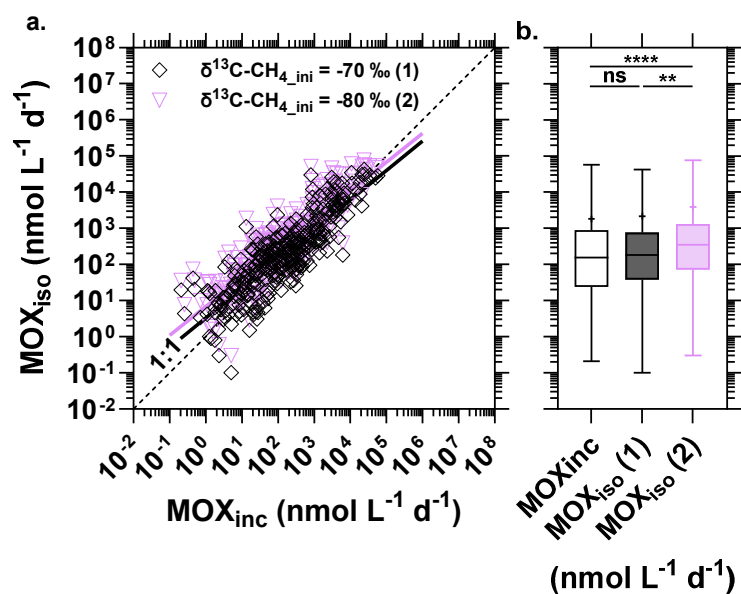


Figure S23 Isotopic fractionation models provide higher methane oxidation rate estimates. Methane oxidation (MOX in $\text{nmol L}^{-1} \text{d}^{-1}$) from incubations (MOX_{inc}) versus MOX from Rayleigh fractionation model (MOX_{iso}) ($n=381$) using two values for initial $^{13}\text{C}/^{12}\text{C}$ ratio of CH_4 ($\delta^{13}\text{C-CH}_4$) of -80 and -70‰ (a), and corresponding box-plots (b). In plot (a), solid lines show the linear regressions (Table S5) and dotted line the 1:1 line. In plot (b), the box represents the first and third quartile, horizontal line corresponds to the median, cross to the mean, error bars to the maximum and minimum. Results of the statistical comparison of means are summarized on top of the figures and detailed in Table S6.

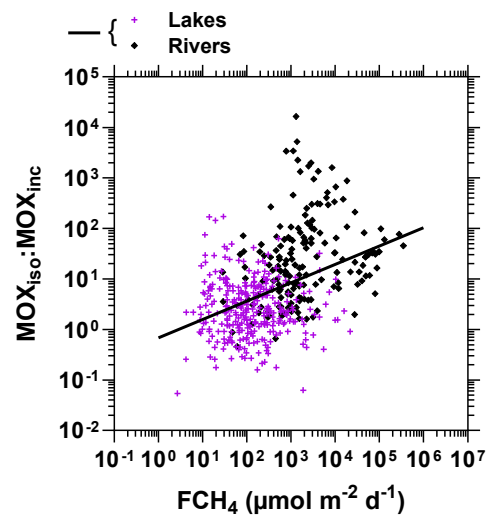


Figure S24 Impact of methane diffusive emission estimates on the calculation of methane oxidation rates with isotopic fractionation models. Ratio of methane oxidation (MOX in $nmol L^{-1} d^{-1}$) obtained from Rayleigh fractionation model using an initial $^{13}C/^{12}C$ ratio of CH_4 ($\delta^{13}C-CH_4$) of -80‰ and from incubations ($MOX_{iso}:MOX_{inc}$) versus the diffusive CH_4 emission to the atmosphere (FCH_4 in $\mu mol m^{-2} d^{-1}$) in African lakes (present study) ($n=381$) and African rivers (3) ($n=171$).

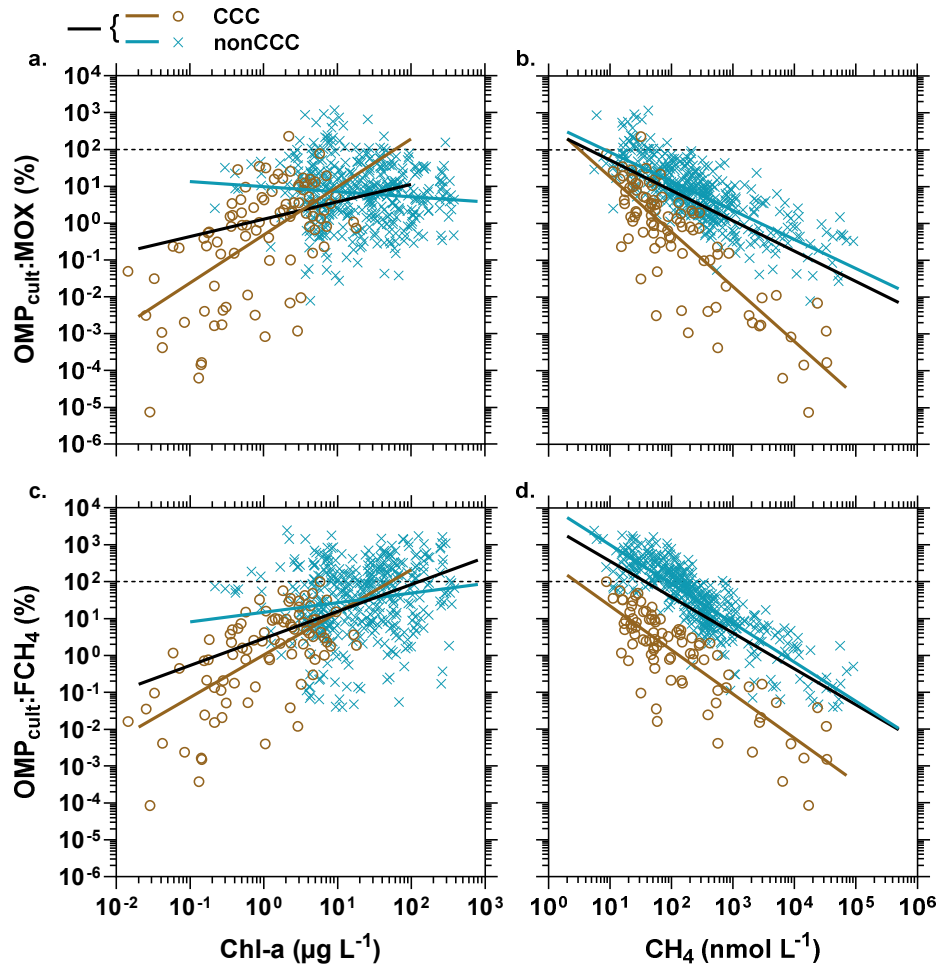


Figure S25 Relative importance of oxic methane production (OMP_{in.situ}) to methane oxidation (MOX) and to diffusive CH₄ emissions to the atmosphere (FCH₄) decreases with lake productivity and methane concentrations. Ratio (%) of oxic methane production (OMP_{cult}) to methane oxidation (MOX) (n=503) and to diffusive CH₄ emissions to the atmosphere (FCH₄ converted into volumetric units using the mixed layer depth) (n=483) versus chlorophyll-a (Chl-a, **a,c**) and CH₄ (**b,d**) concentrations in surface waters of 79 African lakes (Fig. 1) located within (CCC) or outside (non-CCC) the Cuvette Centrale Congolaise. Solid lines show the linear regressions (Table S5). OMP_{cult} was computed from measured Chl-a concentrations and OMP ratios to Chl-a reported in literature from pure cultures of cyanobacteria and diatoms (Table S3). Solid lines show significant linear regressions (Table S5).

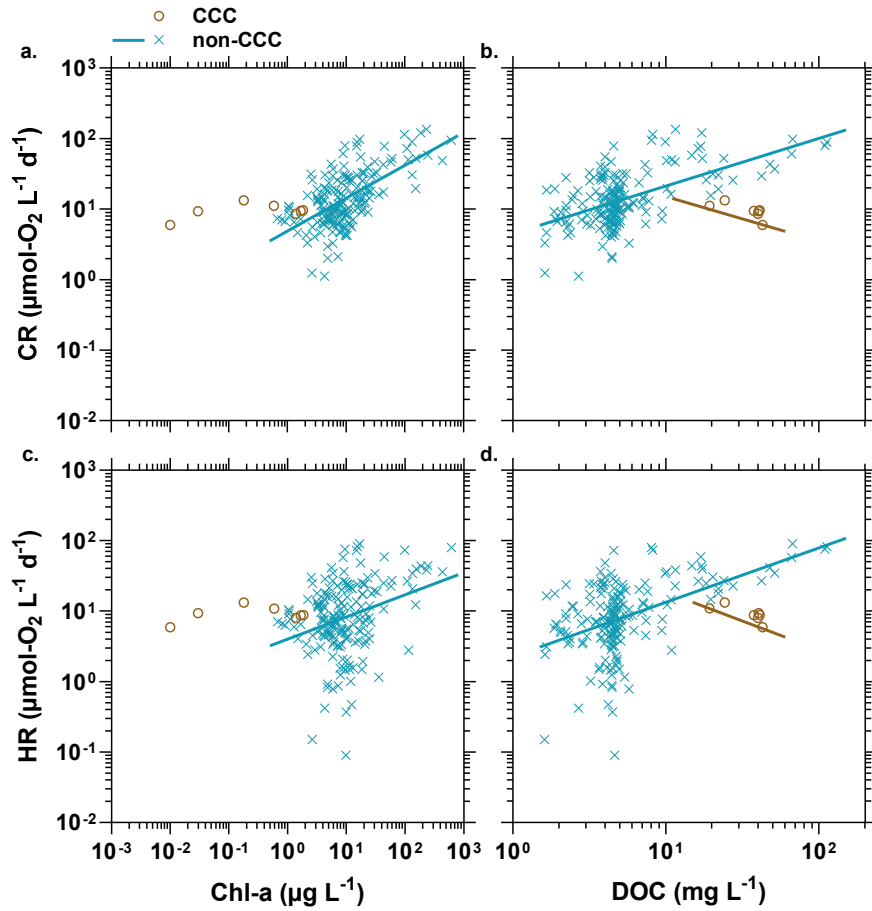


Figure S26 Respiration is driven by phytoplankton biomass and dissolved organic matter. Community (CR) and heterotrophic (HR) respiration versus chlorophyll-a (Chl-a in $\mu\text{g L}^{-1}$) (a,c) and dissolved organic carbon (DOC in mg L^{-1}) (b,d) in 21 African lakes (n=188) located within (CCC) or outside (non-CCC) the Cuvette Centrale Congolaise. CR was measured from the decrease of O_2 concentration during 24h in incubations. HR was computed from CR and autotrophic respiration (AR) estimated from a carbon specific respiration rate for phytoplankton of 0.1 d^{-1} (8) and phytoplankton carbon content estimated from Chl-a and a C:Chl-a ratio of 50.

Table S1 Name, latitude (°N), longitude (°E), lake surface area (SA in km²), maximum (max.) depth (m), elevation above sea level (Elev. in m), location within (CCC) or outside (non-CCC) the Cuvette Centrale Congolaise, mixing regime (polymictic, meromictic), trophic state (oligotrophic (oligo), mesotrophic (meso), eutrophic (eu), hypereutrophic), date of sampling, number of methane oxidation measurements (n), mean ± standard deviation (std) of chlorophyll-a (Chl-a) concentration (µg L⁻¹), percent Chl-a per phytoplankton group (Chlorophytes (Chloroph), Chrysophytes (Chrysoph), Cryptophytes (Cryptoph), Cyanobacteria (Cyanob), Diatoms (Diat), Dinoflagellates (Dinofl), Euglenophytes (Euglenoph), and Raphidophytes (Raphidoph)), mean ± std of specific conductivity (Sp Cond in µS cm⁻¹), pH, dissolved organic carbon (DOC in mg L⁻¹), and CH₄ dissolved concentration in surface waters of 79 African lakes (Fig. 1).

Name	Latitude °N	Longitude °E	SA km ²	Max. depth m	Elev. m	Region	Mixing	Trophic state	Date (MM YY)	n	Chl-a µg L ⁻¹	Chloroph	Chrysoph	Cryptoph	Cyanob	Diat	Dinofl	Euglenoph	Raphidoph	Sp Cond µS cm ⁻¹	pH	DOC mg L ⁻¹	CH ₄ nmol L ⁻¹
Besako	-1.52822	18.56587	34.5	4.4	288	CCC	polymictic	Oligotrophic	Aug 22; Mar 23	2	1.3 ± 1.5	41.7	2.9	33.1	0.0	4.4	2.4	0.0	15.5	62 ± 7	3.77 ± 0.05	50.6 ± 0.4	503 ± 389
Empoko	-1.66644	18.50992	0.54	3.6	288	CCC	polymictic	Oligo - Mesotrophic	Aug 22; Mar 23	2	3.7 ± 4.9	17.1	11.4	5.4	0.3	51.4	0.0	0.0	14.5	43 ± 9	3.91 ± 0.09	31.0 ± 11.0	1,433 ± 1,814
Epete	-1.52997	18.64645	8.6	4.1	286	CCC	polymictic	Oligo - Mesotrophic	Aug 22; Mar 23	2	3.4 ± 4.6	29.3	0.0	15.2	1.1	54.4	0.0	0.0	0.0	62 ± 8	3.79 ± 0.05	50.1 ± 3.3	7,301 ± 10,022
Ibeke Ya Ibenga	-1.70591	18.50052	1.6	3.9	289	CCC	polymictic	Oligo - Mesotrophic	Mar 23; Aug 22	2	2.5 ± 3.1	37.1	1.3	1.4	0.0	46.5	0.0	0.0	13.7	46 ± 4	3.87 ± 0.06	34.4 ± 7.0	1,460 ± 1,940
Ikaba	-1.65265	17.98633	1.3	3.9	289	CCC	polymictic	Oligo - Mesotrophic	Aug 22; Mar 23	2	2.4 ± 3.2	47.6	7.8	4.0	0.0	30.9	0.1	0.0	9.6	54 ± 36	3.94 ± 0.31	44.7 ± 25.7	17,333 ± 23,305
Itabanga	-0.80930	17.87143	1.2	1.6	291	CCC	polymictic	Oligotrophic	Apr 23; Aug 23	2	0.7 ± 0.5	1.6	4.2	14.6	1.6	59.9	0.1	0.0	18.0	54 ± 7	3.85 ± 0.04	42.2 ± 5.8	4,483 ± 6,133
Kesekenda	-2.57504	17.74300	0.76	0.9	290	CCC	polymictic	Eutrophic	Aug 22	1	18.0	4.9	14.4	0.4	0.0	72.4	0.0	0.0	7.9	26	4.18	25.0	282
Mai Ndombe	-2.07023	18.30997	2,305	6.2	288	CCC	polymictic	Oligotrophic	Aug 22; Apr 23	34	1.5 ± 2.1	17.5	2.8	4.9	1.3	54.6	5.8	0.0	12.9	51 ± 4	3.86 ± 0.07	40.1 ± 3.9	379 ± 1,165
Moliba Mpé	-2.70194	17.75146	0.97	3.8	287	CCC	polymictic	Oligo - Eutrophic	Aug 22; Aug 23	2	4.0 ± 5.7	7.8	1.3	0.8	1.7	88.4	0.0	0.0	0.0	21 ± 1	4.28 ± 0.02	20.7 ± 0.2	8,551 ± 12,011
Mpakotchi	-1.68358	18.54062	0.91	3.9	288	CCC	polymictic	Oligo - Mesotrophic	Aug 22; Aug 23	2	3.3 ± 3.8	25.3	31.1	4.2	0.0	25.7	3.3	0.0	10.2	43 ± 8	3.89 ± 0.08	30.5 ± 11.4	2,619 ± 3,532
Mukolombu	-2.62363	17.72462	0.47	0.7	289	CCC	polymictic	Eutrophic	Aug 22	1	16.6	6.6	16.7	0.7	0.0	64.3	0.0	0.0	11.7	17	4.53	17.8	140
Ngoie	-0.88240	17.95411	2.3	2.0	291	CCC	polymictic	Oligotrophic	Aug 22; Aug 23	2	0.7 ± 0.7	0.1	7.4	7.1	0.6	35.7	39.1	0.0	9.9	54 ± 7	3.84 ± 0.01	43.0 ± 3.0	365 ± 39
Nkenge	-1.53143	18.02357	16.7	3.9	288	CCC	polymictic	Mesotrophic	Aug 22; Aug 23	2	3.8 ± 1.3	16.1	27.3	12.4	1.9	42.3	0.0	0.0	0.0	68 ± 14	3.75 ± 0.06	57.4 ± 6.9	16,545 ± 23,323
Nikolo Etulu	-1.55153	18.72644	24.8	4.3	290	CCC	polymictic	Oligo - Mesotrophic	Aug 22; Aug 23	2	4.0 ± 2.4	19.8	14.2	2.2	0.2	30.6	28.7	0.0	4.3	62 ± 2	3.77 ± 0.03	51.1 ± 7.2	216 ± 293
Poso Mabindi	-1.45986	18.67903	8.3	3.6	287	CCC	polymictic	Oligotrophic	Mar 23	1	2.3	0.0	0.0	26.2	0.0	0.0	32.3	0.0	41.5	50	3.83	41.7	23,775
Tumba	-0.76313	18.03345	765	5.4	290	CCC	polymictic	Oligo - Mesotrophic	Apr 23; Aug 23	33	2.0 ± 1.7	36.5	8.7	2.8	1.0	44.2	2.9	0.0	3.9	29 ± 9	4.17 ± 0.22	23.8 ± 7.1	185 ± 521
Adais	1.32939	33.56558	157	3.0	1033	non-CCC	polymictic	Eutrophic	Jun 22	1	47.8	0.0	0.0	0.0	100.0	0.0	0.0	0.0	260	9.38	5.6	1,548	
Albert	1.62855	30.88074	5,402	58.0	614	non-CCC	polymictic	Meso - Eutrophic	Jun 19; Nov 21; May 22; Apr 24; Jun 24	77	7.0 ± 3.4	2.9	0.8	3.0	52.9	38.1	0.1	2.2	0.0	557 ± 79	8.93 ± 0.21	4.5 ± 0.5	451 ± 1,539
Bisina	1.62376	33.95044	168	3.4	1040	non-CCC	polymictic	Mesotrophic	Dec 21	2	6.0 ± 1.4	2.0	0.0	0.0	96.1	0.0	0.0	1.9	0.0	247 ± 0	8.81 ± 0.02	3.2 ± 0.2	430 ± 15
Bunyonyi	-1.29442	29.91904	53.7	39.4	1944	non-CCC	polymictic	Eutrophic	Mar 25; Jun 25	4	15.2 ± 1.6	1.2	0.2	19.2	49.7	21.1	2.7	5.9	0.0	244 ± 2	7.93 ± 0.29	5.6 ± 0.1	328 ± 319
Chahafi	-1.34598	29.77290	0.63	5.2	1890	non-CCC	polymictic	Eutrophic	Mar 25; Jun 25	4	46.0 ± 6.0	4.9	0.0	0.1	94.7	0.1	0.1	0.1	0.0	252 ± 1	8.00 ± 0.59	6.3 ± 0.4	760 ± 1,034
Edward	-0.37106	29.56531	2,253	117.0	911	non-CCC	polymictic	Meso - Eutrophic	Oct 16; Mar 17; Jan 18; Mar 19	32	13.7 ± 17.4	1.3	5.9	0.8	74.8	14.4	0.2	2.6	0.0	827 ± 70	8.95 ± 0.20	5.1 ± 1.4	356 ± 454
George	-0.00103	30.21876	273	3.0	912	non-CCC	polymictic	Hypereutrophic	Jan 18; Mar 19	5	119.1 ± 74.2	0.9	4.7	0.2	93.0	0.8	0.1	0.3	0.0	237 ± 11	9.33 ± 1.85	12.9 ± 2.4	318 ± 151
Kacheera	-0.58047	31.11921	47.2	3.8	1228	non-CCC	polymictic	Hypereutrophic	Apr 24; Jun 24	9	199.4 ± 58.9	4.7	0.0	0.5	87.3	6.2	0.0	1.3	0.0	518 ± 111	9.00 ± 0.26	17.5 ± 1.8	293 ± 247
Kanyabutete	0.41542	30.28828	0.012	3.6	1189	non-CCC	polymictic	Mesotrophic	Mar 25; Jun 25	3	4.3 ± 0.2	16.1	1.9	22.8	51.3	0.0	1.0	6.9	0.0	542 ± 7	8.03 ± 0.19	2.8 ± 0.1	7,738 ± 9,175
Karengye	-0.90700	30.12918	3.6	3.2	1366	non-CCC	polymictic	Hypereutrophic	Mar 25; Jun 25	4	217.3 ± 79.6	0.2	0.3	1.2	97.7	0.2	0.4	0.0	0.0	504 ± 21	8.99 ± 0.09	9.3 ± 0.3	166 ± 161
Karunga	-0.72200	31.16679	1.4	2.0	1225	non-CCC	polymictic	Hypereutrophic	Apr 24	2	104.1 ± 1.9	11.2	0.0	2.8	54.8	27.5	0.5	3.3	0.0	539 ± 1	8.56 ± 0.04	15.9 ± 5.2	1,324 ± 305
Katinda	-0.22110	30.10605	0.44	21.0	1039	non-CCC	polymictic	Hypereutrophic	Apr 17	1	133.5	0.0	0.6	0.2	98.0	0.0	0.1	1.1	0.0	749	9.62	9.9	915
Kawi	1.20510	33.62582	11.2	2.2	1033	non-CCC	polymictic	Hypereutrophic	Dec 21; Jun 22	3	124.7 ± 42.6	0.0	1.3	0.2	98.1	0.0	0.1	0.3	0.0	370 ± 10	9.83 ± 0.09	14.8 ± 1.3	3,385 ± 2,061
Kayumba	-1.33885	29.78896	1.5	5.2	1891	non-CCC	polymictic	Eutrophic	Mar 25; Jun 25	4	38.5 ± 3.1	48.4	0.0	9.2	11.1	24.2	0.4	6.7	0.0	173 ± 5	8.22 ± 0.83	5.9 ± 0.4	349 ± 297
Kifuruka	0.48967	30.28679	0.15	4.7	1400	non-CCC	polymictic	Eu - Hypereutrophic	Mar 25; Jun 25	4	65.4 ± 19.2	0.0	0.0	0.0	99.6	0.0	0.0	0.4	0.0	311 ± 4	8.77 ± 0.19	11.1 ± 1.7	19,411 ± 13,260
Kijanebaloba	-0.71850	31.32567	46.0	4.9	1221	non-CCC	polymictic	Hypereutrophic	Apr 24; Jun 24	11	119.1 ± 39.9	10.1	0.4	2.4	59.7	24.8	0.5	2.1	0.0	323 ± 22	8.54 ± 0.50	14.7 ± 1.1	749 ± 2,039
Kiribwato	0.43088	30.32378	0.12	10.6	1228	non-CCC	polymictic	Meso - Eutrophic	Mar 25; Jun 25	3	5.7 ± 1.9	9.6	1.5	19.7	69.2	0.0	0.0	0.0	0.0	362 ± 2	8.36 ± 0.28	3.2 ± 0.0	716 ± 175
Kyamwinda	-0.18694	30.14541	3.1	43.0	1021	non-CCC	polymictic	Eutrophic	Apr 17	1	17.5	0.0	0.8	0.2	96.5	0.0	0.1	2.4	0.0	411	9.19	4.0	485
Kyoga	1.46714	32.95412	4,828	9.4	1031	non-CCC	polymictic	Eu - Hypereutrophic	Nov 21; Jun 22; Apr 24; Jun 24	76	35.0 ± 12.8	4.3	0.3	0.8	82.6	8.9	0.0	3.0	0.0	189 ± 57	8.74 ± 0.45	6.2 ± 2.7	460 ± 1,092
Lemwa	1.12292	33.67943	21.8	2.3	1041	non-CCC	polymictic	Hypereutrophic	Dec 21; Jun 22	3	109.5 ± 7.2	10.5	0.3	4.6	65.2	4.7	0.3	14.3	0.0	252 ± 5	8.69 ± 0.60	10.8 ± 1.1	130 ± 16
Mbajo	0.44884	30.27454	0.16	0.8	1263	non-CCC	polymictic	Eutrophic	Mar 25; Jun 25	3	18.7 ± 2.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	494 ± 9	8.26 ± 0.41	4.0 ± 0.9	33,025 ± 8,333
Mbuuro	-0.66416	30.93079	14.5	3.2	1248	non-CCC	polymictic	Hypereutrophic	Jul 24; Jun 25	7	179.4 ± 74.0	2.6	0.0	1.2	94.0	0.1	0.1	1.9	0.0	145 ± 3	8.66 ± 0.77	11.8 ± 0.6	552 ± 1,175
Michu	0.44642	30.27011	0.096	34.3	1273	non-CCC	polymictic	Hypereutrophic	Jun 25	2	224.8 ± 140.8	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	362 ± 0	9.30 ± 0.03	4.6 ± 0.1	57,043 ± 2,310
Mishera	-0.73442	30.97835	2.5	2.2	1240	non-CCC	polymictic	Hypereutrophic	Apr 24	3	346.4 ± 11.0	0.4	0.0	0.0	99.6	0.0	0.0	0.0	0.0	275 ± 0	9.38 ± 0.22	20.1 ± 0.7	969 ± 425
Mrambi	-0.22968	30.10563	0.56	20.0	1082	non-CCC	polymictic	Eutrophic	Apr 17	1	25.0	6.3	0.0	1.9	89.2	2.3	0.5	0.0	0.0	669	9.34	6.4	727
Mulehe	-1.21796	29.72226	2.7	5.6	1791	non-CCC	polymictic	Hypereutrophic	Mar 25; Jun 25	6	84.6 ± 7.8	6.4	1.0	6.3	71.6	11.8	0.3	2.5	0.0	225 ± 1	8.02 ± 0.39	5.3 ± 0.6	97 ± 150
Mutanda	-1.21664	29.67370	23.3	63.0	1877	non-CCC	polymictic	Eutrophic	Mar 25; Jun 25	6	11.6 ± 3.4	6.6	2.6	19.1	35.9	25.0	3.8	7.1	0.0	232 ± 4	7.56 ± 0.38	6.3 ± 0.1	79 ± 69
Nakivale	-0.78039	30.88927	35.9	2.0	1245	non-CCC	polymictic	Hypereutrophic	Apr 24; Jun 24	6	307.0 ± 45.5	1.8	0.0	0.0	98.2	0.0	0.0	0.0	0.0	690 ± 14	9.70 ± 0.28	25.8 ± 2.8	965 ± 148
Nakuwa	1.22712	33.46427	224	2.8	1032	non-CCC	polymictic	Hypereutrophic	Dec 21; Jun 22	3	73.7 ± 12.1	5.5	0.4	17.1	66.0	4.3	0.0	6.6	0.0	240 ± 26	8.83 ± 0.16	14.4 ± 4.8	91 ± 3
Nanyanchu	0.43402	30.32380	0.015	2.2	1243	non-CCC	polymictic	Mesotrophic	Mar 25; Jun 25	4	4.9 ± 0.8	14.4	6.1	37.3	23.0	11.1	1.6	6.5	0.0	504 ± 14	8.29 ± 0.25	4.2 ± 0.1	4,301 ± 1,633

Table S1 (continued)

Nyaguo	1.34233	33.71742	36.8	3.8	1032	non-CCC	polymictic	Eutrophic	Dec 21; Jun 22	2	17.5 ± 0.5	5.5	0.2	1.9	80.7	0.0	0.0	11.7	0.0	149 ± 9	8.37 ± 0.40	8.3 ± 2.0	75 ± 60
Nyamusingire	-0.28757	30.03013	4.0	3.8	981	non-CCC	polymictic	Hypereutrophic	Mar 19	2	61.1 ± 1.7	0.6	4.1	0.0	95.3	0.0	0.0	0.0	0.0	787 ± 0	5.51 ± 0.00	23.9	4,237 ± 971
Nyasala	1.31189	33.62630	21.0	3.6	1031	non-CCC	polymictic	Hypereutrophic	Dec 21; Jun 22	3	49.0 ± 19.0	0.2	0.0	0.0	90.7	0.0	0.0	9.1	0.0	228 ± 11	8.92 ± 0.39	7.9 ± 0.8	355 ± 446
Odapakol	1.38588	33.40060	29.7	3.1	1032	non-CCC	polymictic	Eutrophic	Jun 22	1	23.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	290	8.37	6.9	1,162
Opeta	1.64422	34.14797	64.5	2.0	1041	non-CCC	polymictic	Eutrophic	Dec 21	1	7.8	2.6	0.0	1.2	92.4	0.0	0.0	3.8	0.0	228	8.55	11.7	213
Pingiri	1.36179	33.38301	28.9	3.1	1032	non-CCC	polymictic	Eutrophic	Jun 22	1	27.9	0.3	0.0	6.2	90.1	2.0	1.3	0.0	0.0	268	8.12	15.6	56
Rwankenzi	0.41675	30.27100	0.033	12.0	1174	non-CCC	polymictic	Hypereutrophic	Mar 25; Jun 25	3	299.2 ± 68.9	0.3	0.1	0.1	99.4	0.1	0.1	0.0	0.0	1036 ± 45	9.61 ± 0.08	18.7 ± 3.4	63,330 ± 7,029
Rwebikere	0.68762	30.23384	0.078	7.5	1576	non-CCC	polymictic	Eutrophic	Mar 25; Jun 25	3	9.4 ± 0.3	5.8	2.0	0.9	88.1	0.5	1.7	0.9	0.0	177 ± 6	8.62 ± 0.10	6.4 ± 0.3	2,303 ± 110
Saaka	0.69185	30.24294	0.57	3.9	1562	non-CCC	polymictic	Hypereutrophic	Mar 25; Jun 25	4	102.7 ± 10.9	2.9	0.0	1.0	87.7	5.8	1.7	0.9	0.0	639 ± 22	7.42 ± 0.39	7.6 ± 0.1	9,225 ± 1,251
Victoria	-1.07739	32.83910	67.075	79.0	1131	non-CCC	polymictic	Oligo - Eutrophic	Mar 18; Oct 18; Jun 19	36	9.4 ± 7.4	3.9	13.4	4.6	62.4	12.1	0.1	3.6	0.0	98 ± 4	8.39 ± 0.46	2.5 ± 0.5	167 ± 132
Wamala	0.33286	31.89033	179	5.2	1159	non-CCC	polymictic	Hypereutrophic	May 24	6	61.3 ± 5.7	4.2	0.0	0.5	67.0	19.8	0.0	8.4	0.0	208 ± 7	8.85 ± 0.46	12.5 ± 0.8	306 ± 394
Kanyamukali	0.40633	30.23622	0.023	13.5	1157	non-CCC	meromictic	Hypereutrophic	Mar 25; Jun 25	3	58.0 ± 5.1	7.5	0.0	6.8	79.9	1.1	0.7	3.9	0.0	957 ± 32	8.98 ± 0.08	8.4 ± 0.7	417 ± 38
Kanyongo	0.68092	30.23526	0.12	95.0	1556	non-CCC	meromictic	Mesotrophic	Mar 25; Jun 25	2	3.6 ± 0.9	6.1	1.1	1.0	73.7	4.0	9.5	4.6	0.0	238 ± 5	8.67 ± 0.02	3.4 ± 0.6	477 ± 193
Kasenda	0.43190	30.29035	0.072	16.8	1256	non-CCC	meromictic	Eutrophic	Jun 25	3	54.4 ± 12.4	1.0	0.1	32.4	65.6	0.1	0.2	0.7	0.0	270 ± 24	8.52 ± 0.66	5.5 ± 0.1	15,457 ± 6,458
Katanda	0.48071	30.26295	0.40	146.0	1341	non-CCC	meromictic	Oligotrophic	Mar 25; Jun 25	2	1.2	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	412	8.61	3.7	417 ± 136
Kyanga	0.40069	30.23392	0.12	54.7	1157	non-CCC	meromictic	Eutrophic	Mar 25	1	12.5	0.6	0.0	0.0	99.4	0.0	0.0	0.0	0.0	1084	9.67	8.7	1,077
Lugembe	0.44939	30.28111	0.087	19.0	1268	non-CCC	meromictic	Eutrophic	Mar 25; Jun 25	4	34.1 ± 29.1	0.1	0.0	11.7	86.3	0.1	0.4	1.5	0.0	323 ± 29	10.50 ± 1.54	10.8 ± 0.6	31,765 ± 23,210
Lyantonde	0.48890	30.27986	0.14	180.0	1434	non-CCC	meromictic	Meso - Eutrophic	Mar 25; Jun 25	2	6.1 ± 1.6	4.7	0.0	4.6	88.5	0.8	0.2	1.1	0.0	474 ± 9	8.80 ± 0.29	2.6 ± 0.0	269 ± 26
Mugamir	0.42039	30.28671	0.28	55.2	1198	non-CCC	meromictic	Eutrophic	Mar 25; Jun 25	3	29.7 ± 23.3	0.2	0.7	2.6	91.1	0.1	3.8	1.4	0.0	392 ± 6	9.21 ± 0.14	5.9 ± 0.2	5,023 ± 4,115
Murusi	0.42692	30.29259	0.23	56.8	1223	non-CCC	meromictic	Eu - Hypereutrophic	Mar 25; Jun 25	2	66.7 ± 19.5	13.7	0.5	0.4	82.4	0.0	0.3	2.7	0.0	236 ± 17	10.02 ± 0.53	5.8 ± 0.4	54,750 ± 51,679
Mwamba	0.46174	30.27404	0.42	32.0	1301	non-CCC	meromictic	Eutrophic	Mar 25; Jun 25	3	32.8 ± 10.2	1.7	1.0	0.1	97.1	0.0	0.1	0.0	0.0	338 ± 34	9.44 ± 0.19	3.6 ± 0.2	678 ± 290
Mwegenyi	0.48944	30.26168	0.37	140.0	1397	non-CCC	meromictic	oligotrophic	Mar 25; Jun 25	2	1.5 ± 0.3	3.2	0.0	0.0	96.8	0.0	0.0	0.0	0.0	356 ± 6	8.58 ± 0.28	1.9 ± 0.0	688 ± 61
Nkuruba	0.51732	30.30254	0.027	36.5	1511	non-CCC	meromictic	Eutrophic	Mar 25; Jun 25	4	17.6 ± 12.2	12.3	0.6	2.7	84.2	0.0	0.1	0.0	0.0	314 ± 3	8.44 ± 0.60	4.2 ± 1.1	1,244 ± 422
Ntambi	0.40929	30.23046	0.32	106.0	1166	non-CCC	meromictic	Hypereutrophic	Mar 25; Jun 25	2	91.1 ± 40.9	1.8	0.0	0.7	96.0	0.7	0.8	0.0	0.0	5642 ± 27	9.52 ± 0.10	14.7 ± 0.6	2,216 ± 304
Nyabikere	0.49705	30.32845	0.44	40.1	1379	non-CCC	meromictic	Eu - Hypereutrophic	Mar 25; Jun 25	4	57.6 ± 29.7	40.0	2.5	9.6	47.1	0.0	0.0	0.8	0.0	251 ± 9	8.30 ± 0.20	5.0 ± 0.5	724 ± 824
Nyaharia	0.49896	30.28656	0.030	81.0	1447	non-CCC	meromictic	Eutrophic	Mar 25; Jun 25	2	12.5 ± 1.2	0.0	0.0	5.0	91.7	2.4	0.0	1.0	0.0	364 ± 37	8.90 ± 0.78	6.3 ± 0.2	29,422 ± 18,270
Nyamiteza	0.43558	30.22558	0.30	103.0	1259	non-CCC	meromictic	Eutrophic	Mar 25; Jun 25	2	18.1 ± 13.4	0.0	0.5	0.0	98.9	0.0	0.0	0.6	0.0	924 ± 15	9.94 ± 0.35	8.3 ± 0.4	1,578 ± 1,944
Nyamusogani	0.42408	30.22943	0.104	37.6	1224	non-CCC	meromictic	Meso - Eutrophic	Mar 25; Jun 25	2	7.6 ± 5.3	8.2	1.3	8.8	75.2	0.0	4.0	2.6	0.0	881 ± 30	8.94 ± 0.15	4.0 ± 0.5	427 ± 112
Nyanswiga	0.50648	30.28748	0.033	34.0	1469	non-CCC	meromictic	Meso - Eutrophic	Mar 25; Jun 25	3	6.1 ± 1.8	1.2	0.0	3.0	95.8	0.0	0.0	0.0	0.0	293 ± 12	8.74 ± 0.61	3.7 ± 0.2	925 ± 257
Nyarayabana	0.42913	30.24902	0.11	40.0	1190	non-CCC	meromictic	Eu - Hypereutrophic	Mar 25; Jun 25	2	90.4 ± 77.4	2.2	2.1	5.3	36.3	3.7	46.0	4.4	0.0	557 ± 16	9.64 ± 0.16	7.2 ± 1.5	1,879 ± 2,194
Nyinabulitwa	0.51085	30.32419	0.38	61.7	1423	non-CCC	meromictic	Oligo - Mesotrophic	Mar 25; Jun 25	2	3.1 ± 1.6	9.5	0.0	0.1	88.6	0.1	0.2	1.4	0.0	248 ± 4	8.60 ± 0.31	1.7 ± 0.0	230 ± 12
Rwenjuba	0.44150	30.26671	0.22	149.0	1251	non-CCC	meromictic	Mesotrophic	Mar 25; Jun 25	2	3.1 ± 0.2	2.4	0.5	1.8	95.2	0.0	0.1	0.0	0.0	568 ± 6	8.81 ± 0.25	1.3 ± 0.1	427 ± 63
Tanganyika	-6.48404	29.48482	32.821	1470.0	766	non-CCC	meromictic	Oligotrophic	Oct 19; May 21	8	0.5 ± 0.3	33.2	1.1	0.9	63.1	1.7	0.0	0.0	0.0	652 ± 10	9.00 ± 0.01	1.6 ± 0.9	25 ± 26

Table S2 Presence/absence (Y/N) and genus of colonial and/or filamentous forms of cyanobacteria observed by microscopy, chlorophyll-a concentration (Chl-a in $\mu\text{g L}^{-1}$) in 181 samples in 50 African lakes within (CCC) or outside (non-CCC) the Cuvette Centrale Congolaise (Fig. 1). A qualitative evaluation of abundance is given, YYY indicating a majority of cells present as colonies/filaments compared to single cells and Y indicating a majority of cells present as single cells with presence of some colonies/filaments.

Name	Region	date	Latitude °N	Longitude °E	Chl-a $\mu\text{g L}^{-1}$	Colonies	Filaments	Cyanobacteria colony	Cyanobacteria filament
Besako	CCC	18/08/2022	-1.5363	18.5548	2.4	N	N		
Besako	CCC	27/03/2023	-1.5254	18.5675	0.2	N	N		
Empoko	CCC	16/08/2022	-1.6678	18.5104	7.2	N	N		
Empoko	CCC	27/03/2023	-1.6670	18.5104	0.2	N	N		
Epete	CCC	17/08/2022	-1.5300	18.6465	6.6	N	N		
Epete	CCC	27/03/2023	-1.5287	18.6459	0.1	N	N		
Ibeke Ibenga	CCC	26/03/2023	-1.7059	18.5005	0.3	N	N		
Ibeke Ibenga	CCC	16/08/2022	-1.7064	18.4992	4.7	N	N		
Ikaba	CCC	20/08/2022	-1.6527	17.9863	4.6	N	N		
Ikaba	CCC	29/03/2023	-1.6533	17.9865	0.1	N	N		
Itabanga	CCC	07/04/2023	-0.8093	17.8714	0.3	N	N		
Itabanga	CCC	21/08/2022	-0.8092	17.8711	1.0	N	N		
Kesekenda	CCC	23/08/2022	-2.5750	17.7430	18.0	N	N		
Mai Ndombe	CCC	13/08/2022	-2.6397	18.2598	1.7	N	N		
Mai Ndombe	CCC	13/08/2022	-2.4492	18.2655	1.3	N	N		
Mai Ndombe	CCC	13/08/2022	-2.4433	18.2379	3.4	N	N		
Mai Ndombe	CCC	14/08/2022	-2.1211	18.3480	2.2	N	N		
Mai Ndombe	CCC	15/08/2022	-1.9307	18.2278	1.4	N	N		
Mai Ndombe	CCC	15/08/2022	-1.8861	18.2246	2.0	N	N		
Mai Ndombe	CCC	15/08/2022	-1.8540	18.2671	2.3	N	N		
Mai Ndombe	CCC	18/08/2022	-1.6503	18.4054	7.1	N	N		
Mai Ndombe	CCC	18/08/2022	-1.6251	18.3131	2.4	N	N		
Mai Ndombe	CCC	20/08/2022	-1.7100	18.0385	4.3	N	N		
Mai Ndombe	CCC	21/08/2022	-2.0238	18.1952	9.5	N	N		
Mai Ndombe	CCC	21/08/2022	-2.6672	18.2327	4.9	N	N		
Mai Ndombe	CCC	24/03/2023	-2.6660	18.2335	0.8	N	N		
Mai Ndombe	CCC	24/03/2023	-2.4425	18.2374	0.1	N	N		
Mai Ndombe	CCC	24/03/2023	-2.3392	18.3484	0.4	N	N		
Mai Ndombe	CCC	24/03/2023	-2.2049	18.4778	0.2	N	N		
Mai Ndombe	CCC	25/03/2023	-2.1690	18.3833	1.0	N	N		
Mai Ndombe	CCC	25/03/2023	-2.1211	18.3484	1.1	N	N		
Mai Ndombe	CCC	25/03/2023	-2.0069	18.2616	0.2	N	N		
Mai Ndombe	CCC	25/03/2023	-2.0241	18.1942	0.0	N	N		
Mai Ndombe	CCC	25/03/2023	-2.0229	18.1887	0.0	N	N		
Mai Ndombe	CCC	25/03/2023	-1.8548	18.2686	1.6	N	N		
Mai Ndombe	CCC	26/03/2023	-1.7316	18.3351	0.4	N	N		
Mai Ndombe	CCC	28/03/2023	-1.6506	18.4059	0.0	N	N		
Mai Ndombe	CCC	28/03/2023	-1.6248	18.3131	0.4	N	N		
Mai Ndombe	CCC	28/03/2023	-1.6248	18.2355	0.9	N	N		
Mai Ndombe	CCC	28/03/2023	-1.6089	18.1775	0.6	N	N		
Mai Ndombe	CCC	28/03/2023	-1.7064	18.0972	0.6	N	N		
Mai Ndombe	CCC	29/03/2023	-1.7098	18.0369	0.8	N	N		
Mai Ndombe	CCC	29/03/2023	-1.7091	18.0355	0.1	N	N		
Mai Ndombe	CCC	30/03/2023	-1.7551	18.2173	0.2	N	N		
Mai Ndombe	CCC	31/03/2023	-1.9307	18.2278	0.0	N	N		
Mai Ndombe	CCC	31/03/2023	-2.0245	18.1868	0.1	N	N		
Mai Ndombe	CCC	01/04/2023	-2.6400	18.2598	0.0	N	N		
Moliba Mpé	CCC	23/08/2022	-2.7019	17.7515	8.0	N	N		
Moliba Mpé	CCC	02/04/2023	-2.7021	17.7518	0.0	N	N		
Mpakotchi	CCC	26/03/2023	-1.6836	18.5406	0.6	N	N		
Mpakotshi	CCC	16/08/2022	-1.6842	18.5403	6.0	N	N		

Table S2 continued

Mukolombu	CCC	23/08/2022	-2.6236	17.7246	16.6	N	N		
Ngoie	CCC	07/04/2023	-0.8824	17.9541	0.2	N	N		
Ngoie	CCC	22/08/2023	-0.8825	17.9540	1.2	N	N		
Nkenge	CCC	19/08/2022	-1.5314	18.0236	4.7	N	N		
Nkenge	CCC	28/03/2023	-1.5311	18.0235	2.9	N	N		
Nkolo Etulu	CCC	17/08/2022	-1.5301	18.7099	5.8	N	N		
Nkolo Etulu	CCC	27/03/2023	-1.5473	18.7268	2.3	N	N		
Poso Mabindi	CCC	27/03/2023	-1.4599	18.6790	2.3	N	N		
Tumba	CCC	06/04/2023	-0.6809	17.9025	4.6	N	N		
Tumba	CCC	06/04/2023	-0.6758	17.9734	0.3	N	N		
Tumba	CCC	06/04/2023	-0.7337	17.9972	0.1	N	N		
Tumba	CCC	07/04/2023	-0.8702	18.0655	1.8	N	N		
Tumba	CCC	07/04/2023	-0.9326	18.0648	0.4	N	N		
Tumba	CCC	08/04/2023	-0.9594	18.0502	0.3	N	N		
Tumba	CCC	08/04/2023	-0.9261	18.1132	0.5	N	N		
Tumba	CCC	08/04/2023	-0.9855	18.1546	0.3	N	N		
Tumba	CCC	09/04/2023	-0.8115	18.1203	0.2	N	N		
Tumba	CCC	09/04/2023	-0.8126	18.0363	0.2	N	N		
Tumba	CCC	09/04/2023	-0.6986	18.0673	0.4	N	N		
Tumba	CCC	09/04/2023	-0.6672	18.1260	0.5	N	N		
Tumba	CCC	09/04/2023	-0.6309	18.0584	0.7	N	N		
Tumba	CCC	10/04/2023	-0.6008	18.0145	1.0	N	N		
Tumba	CCC	10/04/2023	-0.6314	17.9511	0.6	N	N		
Tumba	CCC	10/04/2023	-0.6162	17.8223	0.5	N	N		
Tumba	CCC	21/08/2023	-0.6807	17.9032	3.0	N	N		
Tumba	CCC	21/08/2023	-0.6755	17.9739	1.4	N	N		
Tumba	CCC	21/08/2023	-0.7333	17.9974	3.6	N	N		
Tumba	CCC	22/08/2023	-0.8230	17.9387	1.2	N	N		
Tumba	CCC	22/08/2023	-0.8703	18.0657	3.0	Y		Snowella	
Tumba	CCC	22/08/2023	-0.9331	18.0649	2.6	Y		Snowella	
Tumba	CCC	22/08/2023	-0.9594	18.0500	3.2	N	N		
Tumba	CCC	22/08/2023	-0.9255	18.1136	2.3	Y		Snowella	
Tumba	CCC	23/08/2023	-0.9859	18.1544	4.2	N	N		
Tumba	CCC	23/08/2023	-0.8115	18.1207	3.8	N	N		
Tumba	CCC	24/08/2023	-0.8125	18.0358	1.9	N	N		
Tumba	CCC	24/08/2023	-0.6985	18.0675	3.0	N	N		
Tumba	CCC	24/08/2023	-0.6672	18.1264	4.1	N	N		
Tumba	CCC	24/08/2023	-0.6305	18.0584	5.1	N	N		
Tumba	CCC	24/08/2023	-0.6006	18.0146	6.6	N	N		
Tumba	CCC	25/08/2023	-0.6314	17.9510	3.5	N	N		
Tumba	CCC	25/08/2023	-0.6157	17.8225	0.9	N	N		
Adais	non-CCC	14/06/2022	1.3507	33.5503	47.8	Y	Y	Aphanocapsa, Coelomoron, Microcystis, Snowella	Anabaenopsis, Limnothrix, Planktolyngbya, Pseudanabaena, Raphidiopsis
Albert	non-CCC	21/11/2021	1.8688	31.1809	7.2	Y	Y	Coelosphaerium, Microcystis	Planktolyngbya
Albert	non-CCC	22/11/2021	2.1135	31.3782	7.3	Y	Y	Chroococcus, Microcystis	Dolichospermum, Planktolyngbya
Albert	non-CCC	24/11/2021	1.4976	30.8592	2.7	Y	Y	Microcystis	Pseudanabaena, Raphidiopsis, Planktolyngbya, Dolichospermum
Albert	non-CCC	28/05/2022	1.4972	30.8590	5.7	Y	Y	Aphanothece, Microcystis	Planktolyngbya, Anabaenopsis
Albert	non-CCC	10/04/2024	2.0470	31.3929	3.2	Y		Snowella	
Albert	non-CCC	12/04/2024	1.8203	31.3443	4.5	Y		Microcystis	
Albert	non-CCC	15/04/2024	1.4975	30.8589	10.8	Y		Aphanocapsa, Microcystis	
Albert	non-CCC	16/04/2024	1.2410	30.7026	6.9	Y		Snowella	
Bisina	non-CCC	05/12/2021	1.6221	33.9253	7.0		Y		Cf Aphanizomenon
Bunyonyi	non-CCC	12/06/2025	-1.2903	29.9154	16.0	Y	YYY	Aphanocapsa	Pseudanabaena, Planktolyngbya, Raphidiopsis, Anabaenopsis
Bunyonyi	non-CCC	12/06/2025	-1.2903	29.9154	16.2	Y	YY	(Microcystis), Chroococcus, Aphanocapsa, Merismopedia	Pseudanabaena, Planktolyngbya, Raphidiopsis, Dolichospermum, Anabaenopsis
Chahafi	non-CCC	18/03/2025	-1.3457	29.7737	40.3	YYY	Y	Microcystis, Aphanocapsa, Chroococcus, Snowella	Planktolyngbya, Raphidiopsis, Dolichospermum
Edward	non-CCC	20/10/2016	-0.1937	29.8380	5.6	Y	Y	Chroococcus	Planktolyngbya
Edward	non-CCC	21/10/2016	-0.2024	29.8314	10.2		Y		Planktolyngbya
Edward	non-CCC	22/10/2016	-0.1819	29.8440	9.0	Y		Chroococcus	
Edward	non-CCC	22/10/2016	-0.1740	29.8419	28.7	Y	Y	Aphanocapsa, Chroococcus, Microcystis	Anabaena, Anabaenopsis, Raphidiopsis, Pseudanabaena, Romeria
Edward	non-CCC	23/10/2016	-0.1999	29.7942	5.9	Y	Y	Aphanocapsa, Chroococcus, Gloeotheca, Microcystis	Glaucoispira, Planktolyngbya, Raphidiopsis, Romeria
Edward	non-CCC	25/10/2016	-0.1934	29.7529	4.8	Y		Synechococcus	
Edward	non-CCC	04/11/2016	-0.2515	29.7999	7.1				
Edward	non-CCC	04/11/2016	-0.3202	29.7854	8.7	Y	Y	Aphanocapsa	Pseudanabaena

Table S2 continued

Edward	non-CCG	04/11/2016	-0.3960	29.7836	6.2	Y	Y	Microcystis	Planktolyngbya, Pseudanabaena, Romeria
Edward	non-CCG	23/03/2017	-0.2054	29.8282	3.8	Y	Y	Aphanothece, Gloeotheca, Merismopedia, Microcystis	Planktolyngbya, Raphidiopsis
Edward	non-CCG	24/03/2017	-0.1940	29.8379	33.1	Y	Y	Aphanothece, Cyanodictyon, Gloeotheca, Merismopedia, Microcystis, Pannus	Planktolyngbya, Raphidiopsis
Edward	non-CCG	24/03/2017	-0.1743	29.8417	98.3	Y	Y	Aphanocapsa, Chroococcidiopsis, Chroococcus, Gloeotheca, Microcystis	Anabaenopsis, Aphanizomenon, Planktolyngbya, Pseudanabaena, Raphidiopsis, Romeria
Edward	non-CCG	25/03/2017	-0.1931	29.7519	4.7	Y	Y	Synechococcus	Romeria
Edward	non-CCG	26/03/2017	-0.2004	29.7934	6.4	Y	Y	Aphanocapsa, Aphanothece, Chroococcus, Coelomorion, Microcystis	Planktolyngbya, Pseudanabaena, Raphidiopsis, Romeria
Edward	non-CCG	26/03/2017	-0.2516	29.8004	3.9	Y	Y	Aphanocapsa, Chroococcus, Gloeotheca, Limnococcus, Microcystis	Planktolyngbya, Raphidiopsis, Romeria
Edward	non-CCG	30/03/2017	-0.3201	29.7857	3.7	Y	Y	Aphanothece, Microcystis	Planktolyngbya
Edward	non-CCG	18/01/2018	-0.1932	29.8376	7.9	Y	Y	Aphanocapsa, Chroococcus, Coelomorion, Coelosphaerium, Merismopedia, Pannus, Snowella	Aphanizomenon, Planktolyngbya, Pseudanabaena, Raphidiopsis
Edward	non-CCG	18/01/2018	-0.2023	29.8317	5.5	Y	Y	Aphanothece, Merismopedia, Microcystis, Pannus	Planktolyngbya, Raphidiopsis
Edward	non-CCG	19/01/2018	-0.1928	29.7521	7.0	Y	Y	Microcystis	Planktolyngbya
Edward	non-CCG	20/01/2018	-0.1996	29.7942	5.7	Y	Y	Microcystis	
Edward	non-CCG	20/01/2018	-0.1818	29.8441	9.8	Y	Y	Aphanocapsa, Chroococcus, Coelomorion, Coelosphaerium, Merismopedia, Microcystis, Synechococcus	Planktolyngbya, Raphidiopsis, Romeria
Edward	non-CCG	21/01/2018	-0.2482	29.8869	26.6	Y	Y	Aphanocapsa, Coelomorion, Merismopedia, Microcystis	Planktolyngbya, Romeria
Edward	non-CCG	21/01/2018	-0.2512	29.8003	10.6	Y	Y	Aphanocapsa, Chroococcus, Cyanodictyon,	Planktolyngbya, Pseudanabaena
Edward	non-CCG	22/01/2018	-0.2911	29.7366	8.2	Y	Y	Aphanocapsa, Microcystis	Planktolyngbya
Edward	non-CCG	24/01/2018	-0.3458	29.8269	18.3	Y	Y	Aphanocapsa, Aphanothece, Chroococcus, Coelomorion, Merismopedia	Anabaenopsis, Planktolyngbya, Raphidiopsis
Edward	non-CCG	24/01/2018	-0.3402	29.8209	17.4	Y	Y	Aphanocapsa, Chroococcus, Cyanodictyon, Merismopedia, Microcystis	Anabaenopsis, Planktolyngbya, Raphidiopsis, Romeria
Edward	non-CCG	26/01/2018	-0.1742	29.8424	29.4		Y	Aphanocapsa, Chroococcus, Coelosphaerium, Merismopedia, Microcystis, Synechocystis	Anabaenopsis, Planktolyngbya, Raphidiopsis, Romeria
George	non-CCG	28/01/2018	-0.1345	30.0388	244.5	Y	Y	Aphanocapsa, Aphanothece, Chroococcus, Coelosphaerium, Epigloeosphaera, Gloeotheca, Merismopedia, Microcystis, Synechococcus	Anabaenopsis, Planktolyngbya, Pseudanabaena, Raphidiopsis
Karengye	non-CCG	21/03/2025	-0.9070	30.1292	148.6	YYY	YYY	Aphanocapsa, Merismopedia, Microcystis, Chroococcus	Planktolyngbya, Raphidiopsis, Pseudanabaena
Kawi	non-CCG	04/12/2021	1.2051	33.6258	172.0	Y	Y	Aphanocapsa, Chroococcus, Coelomorion, Limnococcus, Merismopedia, Microcystis	Anabaenopsis, Limnithrix, Planktolyngbya, Pseudanabaena, Raphidiopsis
Kawi	non-CCG	10/06/2022	1.2047	33.6279	112.5	Y	Y	Aphanocapsa, Merismopedia, Microcystis	Anabaenopsis, cf Cuspidothrix, Glaucospira, Oscillatoria, Planktolyngbya, Pseudanabaena, Raphidiopsis
Kayumba	non-CCG	18/03/2025	-1.3447	29.7852	38.8	Y	Y	Aphanocapsa, Merismopedia, Microcystis, Chroococcus	Raphidiopsis, Planktolyngbya
Kyoga	non-CCG	28/11/2021	1.3624	33.3474	21.5	Y	Y	Aphanocapsa, Coelomorion, Merismopedia	Planktolyngbya, Pseudanabaena
Kyoga	non-CCG	28/11/2021	1.3581	33.2311	27.1	Y	Y	Aphanocapsa, Coelomorion, Merismopedia, Microcystis	Planktolyngbya, Pseudanabaena, Raphidiopsis, Anabaenopsis
Kyoga	non-CCG	30/11/2021	1.5238	32.5385	22.0	Y	Y	Merismopedia, Microcystis	Dolichospermum, Planktolyngbya, Pseudanabaena, Raphidiopsis, ...
Kyoga	non-CCG	04/06/2022	1.6663	33.3487	28.8	Y	Y	Aphanocapsa, Merismopedia, Microcystis	Planktolyngbya, Pseudanabaena, Raphidiopsis
Kyoga	non-CCG	07/06/2022	1.4764	32.8473	51.4	Y	Y	Aphanothece, Merismopedia, Microcystis, Coelomorion	Planktolyngbya, Pseudanabaena, Raphidiopsis
Kyoga	non-CCG	22/04/2024	1.3636	33.3461	29.4	Y	Y	Aphanothece, Merismopedia, Microcystis, Coelomorion	Planktolyngbya, Pseudanabaena, Raphidiopsis, Romeria
Kyoga	non-CCG	22/06/2024	1.6669	33.3487	34.4	Y	Y	Aphanothece, Merismopedia, Microcystis	Planktolyngbya
Kyoga	non-CCG	24/06/2024	1.5243	32.5380	18.5	Y		Aphanocapsa	
Lemwa	non-CCG	08/12/2021	1.1285	33.6783	109.5	Y	Y	Aphanocapsa, Asterocapsa, Chroococcus, Coelomorion, Cyanodictyon, Microcystis, Pannus	Anabaenopsis, Calothrix, Planktolyngbya, Pseudanabaena, Raphidiopsis, Romeria
Lemwa	non-CCG	10/06/2022	1.1284	33.6795	102.3	Y	Y	Aphanocapsa, Asterocapsa, Merismopedia, Microcystis	Anabaenopsis, Limnithrix, Pseudanabaena
Mbajo	non-CCG	21/06/2025	0.4496	30.2719	16.6	Y	YY	Aphanocapsa, Merismopedia, Chroococcus	Planktolyngbya, Raphidiopsis, Pseudanabaena, Dolichospermum
Mburo	non-CCG	26/06/2025	-0.6505	30.9435	125.6	YYY	YY	Microcystis, Chroococcus, Aphanocapsa	Anabaenopsis, Limnithrix, Pseudanabaena
Mdichu	non-CCG	21/06/2025	0.4463	30.2702	324.4	YYY	Y	Microcystis (mostly unicells)	Planktolyngbya, Raphidiopsis, Pseudanabaena
Mulehe	non-CCG	19/03/2025	-1.2179	29.7225	77.2	YY	YY	Microcystis, Merismopedia, Aphanocapsa	Planktolyngbya, Raphidiopsis, Pseudanabaena, Dolichospermum
Mutanda	non-CCG	19/03/2025	-1.2337	29.6688	13.6	Y	YYY	Merismopedia	Planktolyngbya, Raphidiopsis, Dolichospermum, Pseudanabaena
Nyaguo	non-CCG	04/12/2021	1.3423	33.7174	17.1	Y	Y	Aphanocapsa, Asterocapsa, Microcystis	Anabaenopsis, Aphanizomenon, Planktolyngbya, Romeria
Nyaguo	non-CCG	11/06/2022	1.3426	33.7175	17.8	Y	Y	Asterocapsa	Pseudanabaena
Nyasala	non-CCG	07/12/2021	1.3010	33.6184	27.4	Y	Y	Aphanocapsa, Chroococcus, Coelomorion, Coelosphaerium, Merismopedia, Microcystis	Anabaenopsis, Glaucospira, Planktolyngbya, Pseudanabaena, Raphidiopsis, Romeria
Nyasala	non-CCG	11/06/2022	1.3030	33.6185	56.1	Y	Y	Merismopedia	Planktolyngbya, Pseudanabaena, Raphidiopsis, Romeria
Rwankenzi	non-CCG	21/06/2025	0.4166	30.2710	265.7	YYY	YYY	Microcystis!	Planktolyngbya!
Rwebikere	non-CCG	22/03/2025	0.6876	30.2338	9.2	Y	Y	Chroococcus	Limnithrix, Planktolyngbya
Saaka	non-CCG	22/03/2025	0.6897	30.2429	89.8	YYY	YYY	Microcystis, Chroococcus, Aphanocapsa	Dolichospermum, Planktolyngbya, Pseudanabaena, Anabaenopsis
Victoria	non-CCG	01/04/2018	-0.7346	33.4326	3.7	Y	Y	Coelomorion, Microcystis, Snowella	Dolichospermum, Planktolyngbya
Victoria	non-CCG	29/10/2018	0.1641	33.5489	5.7	Y	Y	Aphanocapsa, Coelomorion, Microcystis, Snowella	Dolichospermum, Planktolyngbya
Victoria	non-CCG	03/11/2018	-0.9166	31.8015	3.1	Y	Y	Coelomorion, Microcystis, Snowella	Dolichospermum, Planktolyngbya
Victoria	non-CCG	07/06/2019	0.4018	33.2480	6.1	Y	Y	Microcystis, Snowella	Planktolyngbya
Victoria	non-CCG	07/06/2019	0.4476	33.2571	7.9	Y	Y	Coelomorion, Coelosphaerium, Merismopedia, Microcystis, Snowella	Planktolyngbya, Pseudanabaena, Romeria
Victoria	non-CCG	08/06/2019	0.2673	33.1879	5.0	Y		Snowella	
Victoria	non-CCG	09/06/2019	0.1892	32.4639	11.7	Y	Y	Aphanocapsa, Merismopedia, Microcystis, Snowella	Planktolyngbya
Victoria	non-CCG	09/06/2019	0.1164	32.6172	14.0		Y		Planktolyngbya, Romeria
Victoria	non-CCG	15/06/2019	0.2237	33.9718	26.2	Y	Y	Aphanocapsa, Aphanothece, Microcystis, Snowella	Planktolyngbya, Pseudanabaena
Victoria	non-CCG	16/06/2019	0.2990	33.6965	18.6	Y	Y	Aphanocapsa, Aphanothece, Microcystis, Snowella	Planktolyngbya, Pseudanabaena
Victoria	non-CCG	17/06/2019	0.2707	33.3335	20.5	Y	Y	Microcystis, Pannus	Planktolyngbya, Pseudanabaena

Table S2 continued

Kanyamukali	non-CCC	23/03/2025	0.4063	30.2362	57.5	Y	YYY	<i>Microcystis</i>	<i>Planktolyngbya, Raphidiopsis</i>
Kanyongo	non-CCC	22/03/2025	0.6809	30.2353	4.3	YYY	YY	<i>Microcystis, Merismopedia, Aphanocapsa, Chroococcus</i>	<i>Planktolyngbya, Raphidiopsis, Dolichospermum, Pseudanabaena</i>
Kasenda	non-CCC	20/06/2025	0.4320	30.2904	68.0	YYY	YYY	<i>Microcystis, Merismopedia, Aphanocapsa, Snowella</i>	<i>Planktolyngbya, Limnothrix, Raphidiopsis, Anabaenopsis</i>
Lyantonde	non-CCC	23/06/2025	0.4888	30.2802	7.3		Y		<i>Raphidiopsis, Planktolyngbya</i>
Mugamir	non-CCC	20/06/2025	0.4204	30.2867	12.0	Y	Y	<i>Aphanocapsa, Microcystis (unicells and some colonies)</i>	<i>Planktolyngbya, Pseudanabaena, Raphidiopsis, Limnothrix</i>
Murusi	non-CCC	20/06/2025	0.4268	30.2926	80.5	Y	Y	<i>Aphanocapsa, Microcystis (mostly unicells, some colonies)</i>	<i>Planktolyngbya, Pseudanabaena</i>
Ntambi	non-CCC	23/03/2025	0.4093	30.2305	62.2		YYY		<i>Arthrospira, Planktolyngbya</i>
Nyabikere	non-CCC	23/06/2025	0.4969	30.3285	94.5	Y	YYY	<i>Aphanocapsa</i>	<i>Dolichospermum, Planktolyngbya</i>
Nyaharia	non-CCC	22/06/2025	0.4989	30.2867	11.6	Y		<i>Aphanocapsa</i>	
Nyanswiga	non-CCC	22/06/2025	0.5059	30.2875	7.8	Y		<i>Aphanocapsa</i>	
Nyinabulitwa	non-CCC	23/06/2025	0.5111	30.3233	2.0	Y	Y	<i>Chroococcus</i>	<i>Planktolyngbya</i>

Table S3 Oxic methane production (OMP) hourly rates in freshwater phytoplankton laboratory cultures (OMP_{cult}) of cyanobacteria (**21**) and diatoms (**64**), and OMP based on incubations with ¹³C-HCO₃⁻ additions of in-situ water (OMP_{in.situ}) from Lakes George, Nyamusingere, Edward, Katinda, and Kyamwinga (**14**). Rates originally reported per mass of dry weight (dw) (μmolCH₄ gdw⁻¹ h⁻¹) were converted into OMP rates per Chl-a (nmolCH₄ μgChl-a⁻¹ d⁻¹) assuming a carbon (C) content of 50% of dry weight and C:Chl-a ratio of 50 mg:mg; the integration at daily scale was made by multiplying by 12h corresponding approximately to the photoperiod in the tropics. In the lakes sampled during this study, among diatoms, several species of *Navicula* were frequently observed such as *N. zanonii*, *N. cryptocephala*, and *N. vandamii*, and among cyanobacteria, *Microcystis aeruginosa* was frequently observed and abundant in lakes with high phytoplanktonic biomass, while *Anabaena* sp was occasionally present in some lakes.

	OMP:Chl-a nmolCH ₄ μgChl-a ⁻¹ d ⁻¹	OMP:dw μmolCH ₄ gdw ⁻¹ h ⁻¹
OMP_{cult}		
Cyanobacteria		
<i>Scytonema hofmanni</i> PCC7110	0.1892 ± 0.0604	0.16 ± 0.05
<i>Anabaena borealis</i>	0.5928 ± 0.0052	0.49 ± 0.00
<i>Anabaena</i> sp. PCC7120	0.8949 ± 0.5283	0.75 ± 0.44
<i>Anabaena cylindrica</i> ATCC29414	0.9695 ± 0.6699	0.81 ± 0.56
<i>Microcystis aeruginosa</i> PCC7806	1.0485 ± 0.3704	0.87 ± 0.31
Diatoms		
<i>Navicula</i> sp.	0.0276 ± 0.0055	0.023 ± 0.005
<i>Chrysochromulina</i> sp.	0.0297 ± 0.0148	0.025 ± 0.012
OMP_{in.situ}		
Lake George	0.0720	
Lake Nyamusingere	0.0379	
Lake Edward	0.0400	
Lake Katinda	0.0465	
Lake Kyamwinga	0.0000	

Table S4 Results of unpaired two-tailed t-test with Welch's correction (t-statistic (t), degree of freedom (df), P value and corresponding summary, and sample size of each group (n1,n2)) comparing means in the lakes within the Cuvette Centrale Congolaise (CCC) and those outside (non-CCC) shown in corresponding Figures.

Figure	Variable	Groups		t, df	P value	Summary	n1	n2
2b	log(MOX)	non-CCC	vs CCC	t=2.866, df=128.9	0.0049	**	92	411
2e	log(K)	non-CCC	vs CCC	t=5.677, df=204.8	<0.0001	****	92	199
5b	log(MOXremoval)	non-CCC	vs CCC	t=3.624, df=137.2	0.0004	***	87	396
	Temperature	non-CCC	vs CCC	t=10.66, df=174.7	<0.0001	****	92	411
	Sp Cond	non-CCC	vs CCC	t=17.27, df=410.1	<0.0001	****	92	407
	pH	non-CCC	vs CCC	t=87.91, df=75.31	<0.0001	****	31	407
	O2	non-CCC	vs CCC	t=13.96, df=191.2	<0.0001	****	92	407
	%O2	non-CCC	vs CCC	t=12.81, df=181.9	<0.0001	****	92	407
	log(TSM)	non-CCC	vs CCC	t=9.921, df=498.8	<0.0001	****	92	411
	log(Chl-a)	non-CCC	vs CCC	t=16.87, df=124.2	<0.0001	****	92	411
	log(POC)	non-CCC	vs CCC	t=10.64, df=210.6	<0.0001	****	92	403
	DOC	non-CCC	vs CCC	t=22.33, df=97.81	<0.0001	****	91	399
	a350	non-CCC	vs CCC	t=25.74, df=92.01	<0.0001	****	92	397
	log(DIN)	non-CCC	vs CCC	t=4.145, df=105.3	<0.0001	****	91	396
	log(NH4)	non-CCC	vs CCC	t=3.178, df=103.1	0.002	**	92	403
	log(NO3)	non-CCC	vs CCC	t=5.579, df=107.7	<0.0001	****	91	397
	log(PO4)	non-CCC	vs CCC	t=4.040, df=184.5	<0.0001	****	92	404
	log(%CH4)	non-CCC	vs CCC	t=3.131, df=130.1	0.0022	**	92	411
S2d	log(CH4)	non-CCC	vs CCC	t=4.615, df=151.6	<0.0001	****	92	203
S2e	log(CH4)	non-CCC	vs CCC	t=5.170, df=138.2	<0.0001	****	87	241
S2f	log(CH4)	non-CCC	vs CCC	t=1.541, df=163.6	0.1253	ns	92	199
S13b	log(K:Chla) Temp>25°C	non-CCC	vs CCC	t=3.616, df=91.01	0.0005	***	92	330
S13d	log(K:Chla) O2<260µM	non-CCC	vs CCC	t=11.32, df=133.3	<0.0001	****	92	198
S17c	%MOXremoval	Rivers	vs Lakes	t=13.29, df=194.6	<0.0001	****	483	148
S18a	log(OMPcult:MOX)	non-CCC	vs CCC	t=7.163, df=103.4	<0.0001	****	92	411
S18b	log(OMPcult:FCH4)	non-CCC	vs CCC	t=10.35, df=110.1	<0.0001	****	87	396
S18c	log(OMPIn.situ:MOX)	non-CCC	vs CCC	t=5.798, df=106.2	<0.0001	****	92	411
S18d	log(OMPIn.situ:FCH4)	non-CCC	vs CCC	t=9.041, df=115.3	<0.0001	****	87	396

Table S5 Equations and statistics at 0.05 level of linear regressions given in Figures.

Figure	Y vs X	Equation	b	a	r ²	P value	n
2a	log(MOX) vs log(CH4) CCC	Y=a+bX	1.3160 ± 0.0561	-0.8977 ± 0.1273	0.86	<0.0001	92
2a	log(MOX) vs log(CH4) non-CCC	Y=a+bX	1.0550 ± 0.0452	-0.2911 ± 0.1156	0.57	<0.0001	411
2a	log(MOX) vs log(CH4) all	Y=a+bX	1.1100 ± 0.0380	-0.4307 ± 0.0951	0.63	<0.0001	503
2d	log(K) vs log(Chl-a) CCC	Y=a+bX	0.0314 ± 0.0807	-0.2326 ± 0.0559	0.00	0.6978	92
2d/4a	log(K) vs log(Chl-a) non-CCC	Y=a+bX	0.8025 ± 0.0459	-1.1910 ± 0.0654	0.43	<0.0001	411
2d	log(K) vs log(Chl-a) all	Y=a+bX	0.3999 ± 0.0352	-0.5896 ± 0.0465	0.21	<0.0001	503
3	log(MOX:MOXmodel) vs log(Chl-a) CCC	Y=a+bX	0.1109 ± 0.0183	0.0208 ± 0.0127	0.29	<0.0001	92
3	log(MOX:MOXmodel) vs log(Chl-a) non-CCC	Y=a+bX	0.3911 ± 0.0301	0.0711 ± 0.0430	0.29	<0.0001	411
3	log(MOX:MOXmodel) vs log(Chl-a) all	Y=a+bX	0.3656 ± 0.0193	0.0905 ± 0.0255	0.42	<0.0001	503
5a	MOXremoval vs log(K) CCC	Y=a+bX	33.200 ± 2.2090	73.770 ± 1.3020	0.73	<0.0001	87
5a	MOXremoval vs log(K) non-CCC	Y=a+bX	22.980 ± 1.1010	78.360 ± 0.8436	0.52	<0.0001	397
5a	MOXremoval vs log(K) All	Y=a+bX	24.200 ± 1.0130	77.900 ± 0.7468	0.54	<0.0001	484
6a	log(OMPin.situ:MOX) vs log(Chl-a) CCC	Y=a+bX	1.1990 ± 0.1839	-1.2650 ± 0.1275	0.32	<0.0001	92
6a	log(OMPin.situ:MOX) vs log(Chl-a) non-CCC	Y=a+bX	-0.1899 ± 0.0713	-0.1391 ± 0.1017	0.02	0.0081	411
6a	log(OMPin.situ:MOX) vs log(Chl-a) all	Y=a+bX	0.3533 ± 0.0575	-0.9226 ± 0.0760	0.07	<0.0001	503
6b	log(OMPin.situ:MOX) vs log(CH4) CCC	Y=a+bX	-1.4670 ± 0.0930	1.7700 ± 0.2110	0.73	<0.0001	92
6b	log(OMPin.situ:MOX) vs log(CH4) non-CCC	Y=a+bX	-0.8392 ± 0.0341	1.6500 ± 0.0873	0.60	<0.0001	411
6b	log(OMPin.situ:MOX) vs log(CH4) all	Y=a+bX	-0.8772 ± 0.0426	1.5210 ± 0.1067	0.46	<0.0001	503
6c	log(OMPin.situ:FCH4) vs log(Chl-a) CCC	Y=a+bX	1.0630 ± 0.1461	-0.9265 ± 0.1013	0.38	<0.0001	87
6c	log(OMPin.situ:FCH4) vs log(Chl-a) non-CCC	Y=a+bX	0.2083 ± 0.0842	0.0425 ± 0.1200	0.02	0.0139	396
6c	log(OMPin.situ:FCH4) vs log(Chl-a) all	Y=a+bX	0.6186 ± 0.0598	-0.5664 ± 0.0792	0.18	<0.0001	483
6d	log(OMPin.situ:FCH4) vs log(CH4) CCC	Y=a+bX	-1.1770 ± 0.0736	1.5520 ± 0.1685	0.75	<0.0001	87
6d	log(OMPin.situ:FCH4) vs log(CH4) non-CCC	Y=a+bX	-1.1100 ± 0.0308	2.9860 ± 0.0782	0.77	<0.0001	396
6d	log(OMPin.situ:FCH4) vs log(CH4) all	Y=a+bX	-1.0240 ± 0.0436	2.4990 ± 0.1088	0.53	<0.0001	483
S2a	log(CH4) vs log(depth) CCC	Y=a+bX	-0.1449 ± 0.3342	2.1620 ± 0.1686	0.00	0.6657	92
S2a	log(CH4) vs log(depth) non-CCC	Y=a+bX	-0.3782 ± 0.0648	2.7840 ± 0.0729	0.08	<0.0001	411
S2b	log(CH4) vs log(MLD) CCC	Y=a+bX	-0.0775 ± 0.3509	2.1480 ± 0.1724	0.00	0.8257	87
S2b	log(CH4) vs log(MLD) non-CCC	Y=a+bX	-0.9693 ± 0.0767	3.1090 ± 0.0651	0.29	<0.0001	396
S2c	log(CH4) vs log(Chl-a) CCC	Y=a+bX	-0.2302 ± 0.1281	2.0920 ± 0.0888	0.03	0.0757	92
S2c	log(CH4) vs log(Chl-a) non-CCC	Y=a+bX	0.3874 ± 0.0634	1.9240 ± 0.0903	0.08	<0.0001	411
S3a	log(Chl-a) vs log(depth) CCC	Y=a+bX	-1.1680 ± 0.2408	0.4605 ± 0.1215	0.21	<0.0001	92
S3a	log(Chl-a) vs log(depth) non-CCC	Y=a+bX	-0.6040 ± 0.0405	1.8640 ± 0.0456	0.35	<0.0001	411
S3b	log(Chl-a) vs log(MLD) CCC	Y=a+bX	-1.2000 ± 0.2455	0.4808 ± 0.1206	0.22	<0.0001	87
S3b	log(Chl-a) vs log(MLD) non-CCC	Y=a+bX	-0.7990 ± 0.0553	1.8650 ± 0.0469	0.35	<0.0001	396
S4	log(CH4) vs log(salinity) CCC	Y=a+bX	1.4060 ± 0.9395	4.3260 ± 1.4900	0.02	0.1381	92
S4	log(CH4) vs log(salinity) non-CCC	Y=a+bX	0.4074 ± 0.1336	2.7530 ± 0.1152	0.02	0.0024	411
S4	log(CH4) vs log(salinity) all	Y=a+bX	0.4226 ± 0.0899	2.7660 ± 0.0929	0.04	<0.0001	503
S5	log(MOX) vs log(CH4) CCC	Y=a+bX	-0.1988 ± 0.1839	1.8590 ± 0.1275	0.01	0.2827	92
S5	log(MOX) vs log(CH4) non-CCC	Y=a+bX	1.1900 ± 0.0713	0.7331 ± 0.1017	0.40	<0.0001	411
S5	log(MOX) vs log(CH4) all	Y=a+bX	0.6467 ± 0.0575	1.5170 ± 0.0760	0.20	<0.0001	503
S6c	log(O2 consumption MOX:CR) vs log(Chl-a) CCC	Y=a+bX	-0.0651 ± 0.1446	-0.1759 ± 0.0994	0.00	0.6539	81
S6c	log(O2 consumption MOX:CR) vs log(Chl-a) non-CCC	Y=a+bX	0.6163 ± 0.0674	-0.5661 ± 0.0952	0.18	<0.0001	395
S6c	log(O2 consumption MOX:CR) vs log(Chl-a) all	Y=a+bX	0.4139 ± 0.0495	-0.2861 ± 0.0651	0.13	<0.0001	476
S6d	log(O2 consumption MOX:HR) vs log(Chl-a) CCC	Y=a+bX	-0.0117 ± 0.1462	-0.1384 ± 0.1005	0.00	0.9367	81
S6d	log(O2 consumption MOX:HR) vs log(Chl-a) non-CCC	Y=a+bX	0.6959 ± 0.0648	-0.4521 ± 0.0907	0.23	<0.0001	378
S6d	log(O2 consumption MOX:HR) vs log(Chl-a) all	Y=a+bX	0.5090 ± 0.0482	-0.2032 ± 0.0629	0.20	<0.0001	459
S6e	log(O2 consumption MOX:CR) vs log(CH4) CCC	Y=a+bX	1.4040 ± 0.0948	-2.7770 ± 0.1829	0.74	<0.0001	81
S6e	log(O2 consumption MOX:CR) vs log(CH4) non-CCC	Y=a+bX	0.9233 ± 0.0405	-1.9460 ± 0.0994	0.57	<0.0001	395
S6e	log(O2 consumption MOX:CR) vs log(CH4) all	Y=a+bX	0.9610 ± 0.0364	-2.0210 ± 0.0865	0.59	<0.0001	476
S6f	log(O2 consumption MOX:HR) vs log(CH4) CCC	Y=a+bX	1.4110 ± 0.0971	-2.7520 ± 0.1873	0.73	<0.0001	81
S6f	log(O2 consumption MOX:HR) vs log(CH4) non-CCC	Y=a+bX	0.9208 ± 0.0473	-1.6770 ± 0.1127	0.50	<0.0001	378
S6f	log(O2 consumption MOX:HR) vs log(CH4) all	Y=a+bX	1.0000 ± 0.0421	-1.8820 ± 0.0972	0.55	<0.0001	459
S7	log(MOX) vs log(MOXoriginal_model) all	Y=a+bX	0.9813 ± 0.0288	0.5082 ± 0.0582	0.70	<0.0001	503
S7	log(MOX) vs log(MOXupdated_model) all	Y=a+bX	1.0290 ± 0.0206	-0.0697 ± 0.0510	0.83	<0.0001	503
S8a	log(K) vs log(surface area) CCC	Y=a+bX	-0.2306 ± 0.0377	0.3201 ± 0.1020	0.29	<0.0001	92
S8b	log(K) vs log(distance from shore) CCC	Y=a+bX	-0.3750 ± 0.0697	0.8393 ± 0.2052	0.24	<0.0001	92
S10a	log(K) vs log(TSM) CCC	Y=a+bX	-0.0307 ± 0.1015	-0.2261 ± 0.0614	0.00	0.7631	92
S10a/4c	log(K) vs log(TSM) non-CCC	Y=a+bX	0.9155 ± 0.0538	-0.9702 ± 0.0555	0.41	<0.0001	411
S10a	log(K) vs log(TSM) all	Y=a+bX	0.6208 ± 0.0469	-0.6501 ± 0.0454	0.26	<0.0001	503
S10b	log(K) vs log(POC) CCC	Y=a+bX	0.0370 ± 0.1717	-0.2362 ± 0.0571	0.00	0.8300	92
S10/4b	log(K) vs log(POC) non-CCC	Y=a+bX	0.9560 ± 0.0538	-0.6449 ± 0.0396	0.44	<0.0001	403
S10b	log(K) vs log(POC) all	Y=a+bX	0.8009 ± 0.0501	-0.5124 ± 0.0341	0.34	<0.0001	495
S10c	log(Chl-a) vs log(TSM) CCC	Y=a+bX	0.7639 ± 0.1053	-0.2280 ± 0.0636	0.37	<0.0001	92
S10c	log(Chl-a) vs log(TSM) non-CCC	Y=a+bX	1.0660 ± 0.0225	0.3421 ± 0.0232	0.85	<0.0001	411
S10c	log(Chl-a) vs log(TSM) all	Y=a+bX	1.1970 ± 0.0309	0.1231 ± 0.0299	0.75	<0.0001	503
S10d	log(Chl-a) vs log(POC) CCC	Y=a+bX	1.2770 ± 0.1793	-0.1227 ± 0.0596	0.36	<0.0001	92
S10d	log(Chl-a) vs log(POC) non-CCC	Y=a+bX	1.0270 ± 0.0214	0.7782 ± 0.0158	0.85	<0.0001	403
S10d	log(Chl-a) vs log(POC) all	Y=a+bX	1.2700 ± 0.0388	0.5075 ± 0.0264	0.69	<0.0001	495
S11	log(K:Chl-a) vs log(bottom depth) CCC	Y=a+bX	0.4851 ± 0.3300	-0.4031 ± 0.1665	0.02	0.1450	92
S11	log(K:Chl-a) vs log(bottom depth) non-CCC	Y=a+bX	-0.0092 ± 0.0478	-1.4370 ± 0.0538	0.00	0.8470	411
S11	log(K:Chl-a) vs log(bottom depth) all	Y=a+bX	-0.2721 ± 0.0594	-0.9840 ± 0.0618	0.04	<0.0001	503

Table S5 (continued)

S12a	log(K:Chl-a) vs log(PO4) CCC	Y=a+bX	0.1633 ± 0.1721	-0.0879 ± 0.1452	0.01	0.3451	92
S12a	log(K:Chl-a) vs log(PO4) non-CCC	Y=a+bX	0.1150 ± 0.0387	-1.3430 ± 0.0461	0.02	0.0032	404
S12a	log(K:Chl-a) vs log(PO4) all	Y=a+bX	0.2166 ± 0.0499	-1.0270 ± 0.0565	0.04	<0.0001	496
S12b	log(K:Chl-a) vs log(NH4) CCC	Y=a+bX	0.0473 ± 0.1069	-0.1733 ± 0.1040	0.00	0.6595	92
S12b	log(K:Chl-a) vs log(NH4) non-CCC	Y=a+bX	0.0292 ± 0.0643	-1.4470 ± 0.0317	0.00	0.6500	403
S12b	log(K:Chl-a) vs log(NH4) all	Y=a+bX	-0.1418 ± 0.0649	-1.2550 ± 0.0397	0.01	0.0292	495
S12c	log(K:Chl-a) vs log(DIN) CCC	Y=a+bX	-0.4544 ± 0.1236	-0.0356 ± 0.0947	0.13	0.0004	91
S12c	log(K:Chl-a) vs log(DIN) non-CCC	Y=a+bX	0.1043 ± 0.0709	-1.4590 ± 0.0294	0.01	0.1423	396
S12c	log(K:Chl-a) vs log(DIN) all	Y=a+bX	0.1428 ± 0.0747	-1.2320 ± 0.0373	0.01	0.0563	487
S13a	log(K:Chl-a) vs log(temperature) CCC	Y=a+bX	-0.0282 ± 0.0592	0.6099 ± 1.6930	0.00	0.6345	92
S13a	log(K:Chl-a) vs log(temperature) non-CCC	Y=a+bX	-0.0342 ± 0.0137	-0.5376 ± 0.3650	0.02	0.0130	411
S13a	log(K:Chl-a) vs log(temperature) all	Y=a+bX	0.0540 ± 0.0166	-2.6710 ± 0.4485	0.02	0.0012	503
S13c	log(K:Chl-a) vs log(O2) CCC	Y=a+bX	-2.3340 ± 0.3498	4.9590 ± 0.7760	0.33	<0.0001	92
S13c	log(K:Chl-a) vs log(O2) non-CCC	Y=a+bX	-1.2680 ± 0.2217	1.6320 ± 0.5382	0.07	<0.0001	407
S13c	log(K:Chl-a) vs log(O2) all	Y=a+bX	-2.7090 ± 0.1772	5.2500 ± 0.4237	0.32	<0.0001	499
S14a	O2 vs log(Chl-a) CCC	Y=a+bX	14.4800 ± 3.2100	73.5600 ± 2.2260	0.18	<0.0001	92
S14a	O2 vs log(Chl-a) non-CCC	Y=a+bX	23.7300 ± 2.4100	79.9600 ± 3.4480	0.19	<0.0001	407
S14a	O2 vs log(Chl-a) All	Y=a+bX	24.3300 ± 1.5710	78.2200 ± 2.0830	0.33	<0.0001	499
S14b	%O2 vs log(Chl-a) CCC	Y=a+bX	35.8900 ± 7.7050	177.5000 ± 5.3420	0.19	<0.0001	92
S14b	%O2 vs log(Chl-a) non-CCC	Y=a+bX	64.3100 ± 5.9320	193.9000 ± 8.4860	0.23	<0.0001	407
S14b	%O2 vs log(Chl-a) All	Y=a+bX	65.1700 ± 3.8680	190.2000 ± 5.1290	0.36	<0.0001	499
S16	MOXremoval vs log (MLD) CCC	Y=a+bX	11.180 ± 8.3650	61.450 ± 4.1090	0.02	0.1851	87
S16	MOXremoval vs log (MLD) non-CCC	Y=a+bX	9.7640 ± 2.6160	68.290 ± 2.2200	0.03	0.0002	396
S16	MOXremoval vs log (MLD) All	Y=a+bX	11.360 ± 2.3900	66.100 ± 1.9030	0.04	<0.0001	483
S17a	log(MOXremoval) vs log(FCH4) CCC	Y=a+bX	-0.2567 ± 0.0178	2.2970 ± 0.0483	0.25	<0.0001	631
S17b	log(MOXremoval) vs log(depth) CCC	Y=a+bX	0.6289 ± 0.0334	1.3180 ± 0.0250	0.36	<0.0001	631
S19a	log(OMPin.situ:MOX) vs log(lake surface area) CCC	Y=a+bX	0.4958 ± 0.1124	-2.5010 ± 0.3042	0.18	<0.0001	92
S19b	log(OMPin.situ:MOX) vs log(distance from shore) CCC	Y=a+bX	1.0640 ± 0.1908	-4.3550 ± 0.5621	0.26	<0.0001	92
S19c	log(OMPin.situ:FCH4) vs log(lake surface area) CCC	Y=a+bX	0.3593 ± 0.0941	-1.7860 ± 0.2519	0.15	0.0003	87
S19d	log(OMPin.situ:FCH4) vs log(distance from shore) CCC	Y=a+bX	0.8951 ± 0.1575	-3.5200 ± 0.4674	0.28	<0.0001	87
S20a	log(OMPcult:MOX) vs log(lake surface area) CCC	Y=a+bX	0.4743 ± 0.1197	-1.5150 ± 0.3238	0.15	0.0001	92
S20b	log(OMPcult:MOX) vs log(distance from shore) CCC	Y=a+bX	1.1240 ± 0.1990	-3.5920 ± 0.5861	0.26	<0.0001	92
S20c	log(OMPcult:FCH4) vs log(lake surface area) CCC	Y=a+bX	0.3417 ± 0.1018	-0.8031 ± 0.2725	0.12	0.0012	87
S20d	log(OMPcult:FCH4) vs log(distance from shore) CCC	Y=a+bX	0.9392 ± 0.1684	-2.7060 ± 0.4996	0.27	<0.0001	87
S21a	log(OMPcult:MOX) vs log (FCH4_m2) CCC	Y=a+bX	-1.4600 ± 0.1044	2.4220 ± 0.2196	0.69	<0.0001	92
S21a	log(OMPcult:MOX) vs log (FCH4_m2) non-CCC	Y=a+bX	-0.7752 ± 0.0324	2.6020 ± 0.0795	0.58	<0.0001	411
S21a	log(OMPcult:MOX) vs log (FCH4_m2) all	Y=a+bX	-0.7852 ± 0.0463	2.3510 ± 0.1107	0.36	<0.0001	503
S21b	log(OMPcult:FCH4) vs log (FCH4_m2) CCC	Y=a+bX	-1.1740 ± 0.0873	2.2690 ± 0.1855	0.68	<0.0001	87
S21b	log(OMPcult:FCH4) vs log (FCH4_m2) non-CCC	Y=a+bX	-1.0460 ± 0.0309	3.9030 ± 0.0752	0.74	<0.0001	396
S21b	log(OMPcult:FCH4) vs log (FCH4_m2) all	Y=a+bX	-0.9299 ± 0.0488	3.3060 ± 0.1162	0.43	<0.0001	483
S21c	log(OMPin.situ:MOX) vs log (FCH4_m2) CCC	Y=a+bX	-1.4410 ± 0.0924	1.5560 ± 0.1944	0.73	<0.0001	92
S21c	log(OMPin.situ:MOX) vs log (FCH4_m2) non-CCC	Y=a+bX	-0.8246 ± 0.0339	1.6240 ± 0.0830	0.59	<0.0001	411
S21c	log(OMPin.situ:MOX) vs log (FCH4_m2) all	Y=a+bX	-0.8412 ± 0.0426	1.4330 ± 0.1018	0.44	<0.0001	503
S21d	log(OMPin.situ:FCH4) vs log (FCH4_m2) CCC	Y=a+bX	-1.1560 ± 0.0731	1.3980 ± 0.1554	0.75	<0.0001	87
S21d	log(OMPin.situ:FCH4) vs log (FCH4_m2) non-CCC	Y=a+bX	-1.0950 ± 0.0303	2.9270 ± 0.0738	0.77	<0.0001	396
S21d	log(OMPin.situ:FCH4) vs log (FCH4_m2) all	Y=a+bX	-0.9839 ± 0.0438	2.3820 ± 0.1043	0.51	<0.0001	483
S23	log(MOXiso δ13CH4_ini = -70‰) vs log(MOXinc)	Y=a+bX	0.8150 ± 0.0273	0.5217 ± 0.0659	0.74	<0.0001	318
S23	log(MOXiso δ13CH4_ini = -80‰) vs log(MOXinc)	Y=a+bX	0.7994 ± 0.0264	0.8329 ± 0.0638	0.74	<0.0001	318
S24	log(MOXiso:MOXinc) vs log(FCH4)	Y=a+bX	0.3627 ± 0.0361	-0.1644 ± 0.0969	0.17	<0.0001	489
S25a	log(OMPcult:MOX) vs log(Chl-a) CCC	Y=a+bX	1.3030 ± 0.1888	-0.3273 ± 0.1309	0.35	<0.0001	92
S25a	log(OMPcult:MOX) vs log(Chl-a) non-CCC	Y=a+bX	-0.1386 ± 0.0678	0.9914 ± 0.0966	0.01	0.0416	411
S25a	log(OMPcult:MOX) vs log(Chl-a) all	Y=a+bX	0.4706 ± 0.0572	0.1033 ± 0.0757	0.12	<0.0001	503
S25b	log(OMPcult:MOX) vs log(CH4) CCC	Y=a+bX	-1.4870 ± 0.1052	2.7470 ± 0.2385	0.69	<0.0001	92
S25b	log(OMPcult:MOX) vs log(CH4) non-CCC	Y=a+bX	-0.7894 ± 0.0326	2.7260 ± 0.0834	0.59	<0.0001	411
S25b	log(OMPcult:MOX) vs log(CH4) all	Y=a+bX	-0.8238 ± 0.0463	2.5430 ± 0.1161	0.39	<0.0001	503
S25c	log(OMPcult:FCH4) vs log(Chl-a) CCC	Y=a+bX	1.1530 ± 0.1533	0.0157 ± 0.1063	0.40	<0.0001	87
S25c	log(OMPcult:FCH4) vs log(Chl-a) non-CCC	Y=a+bX	0.2600 ± 0.0813	1.1710 ± 0.1158	0.03	0.0015	396
S25c	log(OMPcult:FCH4) vs log(Chl-a) all	Y=a+bX	0.7317 ± 0.0595	0.4636 ± 0.0787	0.24	<0.0001	483
S25d	log(OMPcult:FCH4) vs log(CH4) CCC	Y=a+bX	-1.1950 ± 0.0880	2.5320 ± 0.2015	0.68	<0.0001	87
S25d	log(OMPcult:FCH4) vs log(CH4) non-CCC	Y=a+bX	-1.0600 ± 0.0313	4.0590 ± 0.0796	0.74	<0.0001	396
S25d	log(OMPcult:FCH4) vs log(CH4) all	Y=a+bX	-0.9723 ± 0.0487	3.5270 ± 0.1216	0.45	<0.0001	483
S26a	CR vs Chl-a CCC	Y=a+bX	-0.0823 ± 1.2670	9.6840 ± 1.3960	0.00	0.9507	7
S26a	log(CR) vs log(Chl-a) non-CCC	Y=a+bX	0.4656 ± 0.0456	0.6854 ± 0.0500	0.37	<0.0001	181
S26a	log(CR) vs log(Chl-a) all	Y=a+bX	0.3517 ± 0.0393	0.8101 ± 0.0429	0.30	<0.0001	188
S26b	CR vs DOC CCC	Y=a+bX	-0.1924 ± 0.0661	16.360 ± 2.3880	0.63	0.0334	7
S26b	log(CR) vs log(DOC) non-CCC	Y=a+bX	0.6773 ± 0.0736	0.6509 ± 0.0581	0.32	<0.0001	181
S26b	log(CR) vs log(DOC) all	Y=a+bX	0.5031 ± 0.0699	0.7553 ± 0.0579	0.22	<0.0001	188
S26c	HR vs Chl-a CCC	Y=a+bX	-0.4963 ± 1.2670	9.6810 ± 1.3950	0.03	0.7113	7
S26c	log(HR) vs log(Chl-a) non-CCC	Y=a+bX	0.3151 ± 0.0728	0.6028 ± 0.0798	0.09	<0.0001	181
S26c	log(HR) vs log(Chl-a) all	Y=a+bX	0.2131 ± 0.0605	0.7161 ± 0.0660	0.06	0.0005	188
S26d	HR vs DOC CCC	Y=a+bX	-0.2010 ± 0.0636	16.320 ± 2.2960	0.67	0.0251	7
S26d	log(HR) vs log(DOC) non-CCC	Y=a+bX	0.7697 ± 0.1042	0.3549 ± 0.0823	0.23	<0.0001	181
S26d	log(HR) vs log(DOC) all	Y=a+bX	0.6275 ± 0.0943	0.4403 ± 0.0782	0.19	<0.0001	188

Table S6 Results of one-way analysis of variance (ANOVA) and Tukey's multiple comparisons test (F value, degree of freedom (DF) of treatment (between columns) (DFn) and of residual (within columns) (DFd), mean 1 and 2, mean and standard error (SE) of difference of means (diff.), n1, n2 Adjusted P value and corresponding summary as shown in figures).

Figure	Variable tested	F (DFn, DFd)	P value	Tukey's multiple comparisons test	Mean 1	Mean 2	Mean±SE of diff.	n1	n2	Summary	Adj. P Value
2c	log(MOX)	F (3, 499) = 56.16	P<0.0001	Oligotrophic vs. Mesotrophic	1.62	1.675	-0.055 ± 0.1445	83	119	ns	0.9813
				Oligotrophic vs. Eutrophic	-0.583	2.203	-0.5831 ± 0.1321	83	199	****	<0.0001
				Oligotrophic vs. Hypereutrophic	-1.625	3.245	-1.625 ± 0.1494	83	102	****	<0.0001
				Mesotrophic vs. Eutrophic	-0.528	2.203	-0.5282 ± 0.1171	119	199	****	<0.0001
				Mesotrophic vs. Hypereutrophic	-1.57	3.245	-1.57 ± 0.1364	119	102	****	<0.0001
				Eutrophic vs. Hypereutrophic	-1.042	3.245	-1.042 ± 0.1231	199	102	****	<0.0001
2f	log(K)	F (3, 499) = 62.48	P<0.0001	oligotrophic vs. mesotrophic	-0.402	-0.573	0.1716 ± 0.08736	83	119	ns	0.203
				oligotrophic vs. eutrophic	-0.221	-0.18	-0.2213 ± 0.07982	83	199	*	0.0294
				oligotrophic vs. hypereutrophic	-0.904	0.5024	-0.9041 ± 0.0903	83	102	****	<0.0001
				mesotrophic vs. eutrophic	-0.393	-0.18	-0.3929 ± 0.07079	119	199	****	<0.0001
				mesotrophic vs. hypereutrophic	-1.076	0.5024	-1.076 ± 0.08243	119	102	****	<0.0001
				eutrophic vs. hypereutrophic	-0.683	0.5024	-0.6828 ± 0.07439	199	102	****	<0.0001
5c	%MOXremoval	F (3, 557) = 56.21	P<0.0001	Oligotrophic vs. Mesotrophic	69.05	42.37	26.68 ± 3.893	78	180	****	<0.0001
				Oligotrophic vs. Eutrophic	-1.571	70.62	-1.571 ± 3.82	78	205	ns	0.9765
				Oligotrophic vs. Hypereutrophic	-16.1	85.15	-16.1 ± 4.357	78	98	**	0.0014
				Mesotrophic vs. Eutrophic	-28.25	70.62	-28.25 ± 2.933	180	205	****	<0.0001
				Mesotrophic vs. Hypereutrophic	-42.78	85.15	-42.78 ± 3.605	180	98	****	<0.0001
				Eutrophic vs. Hypereutrophic	-14.53	85.15	-14.53 ± 3.526	205	98	***	0.0003
S6a	log(O2 consumption MOX:CR)	F (4, 471) = 17.90	P<0.0001	CCC vs. non-CCC Oligotrophic	-0.176	-0.406	0.23 ± 0.2108	81	20	ns	0.6495
				CCC vs. non-CCC Mesotrophic	-0.176	-0.105	-0.0713 ± 0.129	81	91	ns	0.9504
				CCC vs. non-CCC Eutrophic	-0.176	0.1978	-0.3742 ± 0.112	81	190	**	0.0034
				CCC vs. non-CCC Hypereutrophic	-0.176	0.7137	-0.8901 ± 0.128	81	94	****	<0.0001
	log(O2 consumption MOX:CR)	F (3, 391) = 19.36	P<0.0001	non-CCC Oligotrophic vs. non-CCC Mesotrophic	-0.406	-0.105	-0.3013 ± 0.2061	20	91	ns	0.6085
				non-CCC Oligotrophic vs. non-CCC Eutrophic	-0.604	0.1978	-0.6042 ± 0.1962	20	190	*	0.0133
				non-CCC Oligotrophic vs. non-CCC Hypereutrophic	-1.12	0.7137	-1.12 ± 0.2056	20	94	****	<0.0001
				non-CCC Mesotrophic vs. non-CCC Eutrophic	-0.303	0.1978	-0.3029 ± 0.1064	91	190	*	0.0276
				non-CCC Mesotrophic vs. non-CCC Hypereutrophic	-0.819	0.7137	-0.8188 ± 0.1228	91	94	****	<0.0001
				non-CCC Eutrophic vs. non-CCC Hypereutrophic	-0.516	0.7137	-0.5159 ± 0.1053	190	94	****	<0.0001
S6b	log(O2 consumption MOX:HR)	F (4, 454) = 26.33	P<0.0001	CCC vs. non-CCC Oligotrophic	-0.139	-0.272	0.1333 ± 0.204	81	20	ns	0.9153
				CCC vs. non-CCC Mesotrophic	-0.139	0.0751	-0.2136 ± 0.1251	81	90	ns	0.2626
				CCC vs. non-CCC Eutrophic	-0.139	0.4043	-0.5428 ± 0.1092	81	181	****	<0.0001
				CCC vs. non-CCC Hypereutrophic	-0.139	0.9948	-1.133 ± 0.1262	81	87	****	<0.0001
	log(O2 consumption MOX:HR)	F (3, 374) = 25.65	P<0.0001	non-CCC Oligotrophic vs. non-CCC Mesotrophic	-0.272	0.0751	-0.3469 ± 0.1974	20	90	ns	0.3925
				non-CCC Oligotrophic vs. non-CCC Eutrophic	-0.676	0.4043	-0.6761 ± 0.1882	20	181	**	0.0022
				non-CCC Oligotrophic vs. non-CCC Hypereutrophic	-1.267	0.9948	-1.267 ± 0.198	20	87	****	<0.0001
				non-CCC Mesotrophic vs. non-CCC Eutrophic	-0.329	0.4043	-0.3292 ± 0.103	90	181	**	0.009
				non-CCC Mesotrophic vs. non-CCC Hypereutrophic	-0.92	0.9948	-0.9198 ± 0.1201	90	87	****	<0.0001
				non-CCC Eutrophic vs. non-CCC Hypereutrophic	-0.591	0.9948	-0.5906 ± 0.1042	181	87	****	<0.0001

Table S6 (continued)

S9a	log(K)	F (2, 500) = 9.444 P<0.0001	Cyano>50% vs. Cyano<50% (non-CCC)	-0.087	-0.466	0.3788 ± 0.08927	335	76	****	<0.0001
			Cyano>50% vs. Cyano<50% (CCC)	-0.087	-0.234	0.1464 ± 0.0827	335	92	ns	0.1808
			Cyano<50% (non-CCC) vs. Cyano<50% (CCC)	-0.466	-0.234	-0.2324 ± 0.1089	76	92	ns	0.0842
S9b	log(K:Chl-a)	F (2, 500) = 144.0 P<0.0001	Cyano>50% vs. Cyano<50% (non-CCC)	-1.431	-1.509	0.07721 ± 0.08121	335	76	ns	0.6084
			Cyano>50% vs. Cyano<50% (CCC)	-1.431	-0.196	-1.235 ± 0.07524	335	92	****	<0.0001
			Cyano<50% (non-CCC) vs. Cyano<50% (CCC)	-1.509	-0.196	-1.312 ± 0.09908	76	92	****	<0.0001
S9c	log(Chl-a)	F (2, 500) = 180.2 P<0.0001	Cyano>50% vs. Cyano<50% (non-CCC)	1.344	1.042	0.3015 ± 0.07856	335	76	***	0.0004
			Cyano>50% vs. Cyano<50% (CCC)	1.344	-0.037	1.381 ± 0.07278	335	92	****	<0.0001
			Cyano<50% (non-CCC) vs. Cyano<50% (CCC)	1.042	-0.037	1.08 ± 0.09584	76	92	****	<0.0001
S15a	log(MOX)	F (7, 943) = 195.9 P<0.0001	Ocean vs. European R.	-0.668	1.734	-2.401 ± 0.1256	186	114	****	<0.0001
			Ocean vs. African non-CCC R.	-0.668	2.393	-3.06 ± 0.1327	186	96	****	<0.0001
			Ocean vs. African CCC R.	-0.668	3.377	-4.045 ± 0.1656	186	52	****	<0.0001
			Ocean vs. Oligotrophic L.	-0.668	1.62	-2.287 ± 0.1393	186	83	****	<0.0001
			Ocean vs. Mesotrophic L.	-0.668	1.675	-2.342 ± 0.1239	186	119	****	<0.0001
			Ocean vs. Eutrophic L.	-0.668	2.203	-2.87 ± 0.1077	186	199	****	<0.0001
			Ocean vs. Hypereutrophic L.	-0.668	3.245	-3.912 ± 0.1301	186	102	****	<0.0001
			European R. vs. African non-CCC R.	1.734	2.393	-0.6591 ± 0.1462	114	96	***	0.0002
			European R. vs. African CCC R.	1.734	3.377	-1.644 ± 0.1767	114	52	****	<0.0001
			European R. vs. Oligotrophic L.	1.734	1.62	0.1141 ± 0.1523	114	83	ns	0.9954
			European R. vs. Mesotrophic L.	1.734	1.675	0.05912 ± 0.1383	114	119	ns	0.9999
			European R. vs. Eutrophic L.	1.734	2.203	-0.4691 ± 0.124	114	199	**	0.0041
			European R. vs. Hypereutrophic L.	1.734	3.245	-1.511 ± 0.1439	114	102	****	<0.0001
			African non-CCC R. vs. African CCC R.	2.393	3.377	-0.9846 ± 0.1818	96	52	****	<0.0001
			African non-CCC R. vs. Oligotrophic L.	2.393	1.62	0.7732 ± 0.1582	96	83	****	<0.0001
			African non-CCC R. vs. Mesotrophic L.	2.393	1.675	0.7182 ± 0.1448	96	119	****	<0.0001
			African non-CCC R. vs. Eutrophic L.	2.393	2.203	0.1901 ± 0.1312	96	199	ns	0.8341
			African non-CCC R. vs. Hypereutrophic L.	2.393	3.245	-0.852 ± 0.1501	96	102	****	<0.0001
			African CCC R. vs. Oligotrophic L.	3.377	1.62	1.758 ± 0.1867	52	83	****	<0.0001
			African CCC R. vs. Mesotrophic L.	3.377	1.675	1.703 ± 0.1755	52	119	****	<0.0001
			African CCC R. vs. Eutrophic L.	3.377	2.203	1.175 ± 0.1644	52	199	****	<0.0001
			African CCC R. vs. Hypereutrophic L.	3.377	3.245	0.1326 ± 0.1799	52	102	ns	0.9958
			Oligotrophic L. vs. Mesotrophic L.	1.62	1.675	-0.055 ± 0.151	83	119	ns	>0.9999
			Oligotrophic L. vs. Eutrophic L.	1.62	2.203	-0.5831 ± 0.1379	83	199	***	0.0007
			Oligotrophic L. vs. Hypereutrophic L.	1.62	3.245	-1.625 ± 0.156	83	102	****	<0.0001
			Mesotrophic L. vs. Eutrophic L.	1.675	2.203	-0.5282 ± 0.1223	119	199	***	0.0005
			Mesotrophic L. vs. Hypereutrophic L.	1.675	3.245	-1.57 ± 0.1424	119	102	****	<0.0001
			Eutrophic L. vs. Hypereutrophic L.	2.203	3.245	-1.042 ± 0.1286	199	102	****	<0.0001

Table S6 (continued)

S15b	log(CH ₄)	F (7, 1248) = 86.55 P<0.0001	Ocean vs. European R.	1.402	2.547	-1.145 ± 0.09537	187	114	****	<0.0001
			Ocean vs. African non-CCC R.	1.402	2.666	-1.264 ± 0.1008	187	96	****	<0.0001
			Ocean vs. African CCC R.	1.402	3.155	-1.753 ± 0.1258	187	52	****	<0.0001
			Ocean vs. Oligotrophic L.	1.402	2.021	-0.6194 ± 0.1059	187	83	****	<0.0001
			Ocean vs. Mesotrophic L.	1.402	2.222	-0.8198 ± 0.09341	187	122	****	<0.0001
			Ocean vs. Eutrophic L.	1.402	2.293	-0.8911 ± 0.07116	187	398	****	<0.0001
			Ocean vs. Hypereutrophic L.	1.402	3.245	-1.843 ± 0.08126	187	204	****	<0.0001
			European R. vs. African non-CCC R.	2.547	2.666	-0.1189 ± 0.1112	114	96	ns	0.9631
			European R. vs. African CCC R.	2.547	3.155	-0.6085 ± 0.1343	114	52	***	0.0002
			European R. vs. Oligotrophic L.	2.547	2.021	0.5254 ± 0.1158	114	83	***	0.0002
			European R. vs. Mesotrophic L.	2.547	2.222	0.325 ± 0.1046	114	122	*	0.0403
			European R. vs. Eutrophic L.	2.547	2.293	0.2537 ± 0.08526	114	398	ns	0.0594
			European R. vs. Hypereutrophic L.	2.547	3.245	-0.6981 ± 0.09385	114	204	****	<0.0001
			African non-CCC R. vs. African CCC R.	2.666	3.155	-0.4897 ± 0.1382	96	52	**	0.0097
			African non-CCC R. vs. Oligotrophic L.	2.666	2.021	0.6442 ± 0.1203	96	83	****	<0.0001
			African non-CCC R. vs. Mesotrophic L.	2.666	2.222	0.4439 ± 0.1095	96	122	**	0.0014
			African non-CCC R. vs. Eutrophic L.	2.666	2.293	0.3726 ± 0.09126	96	398	**	0.0012
			African non-CCC R. vs. Hypereutrophic L.	2.666	3.245	-0.5793 ± 0.09934	96	204	****	<0.0001
			African CCC R. vs. Oligotrophic L.	3.155	2.021	1.134 ± 0.1419	52	83	****	<0.0001
			African CCC R. vs. Mesotrophic L.	3.155	2.222	0.9335 ± 0.1329	52	122	****	<0.0001
			African CCC R. vs. Eutrophic L.	3.155	2.293	0.8622 ± 0.1183	52	398	****	<0.0001
			African CCC R. vs. Hypereutrophic L.	3.155	3.245	-0.0896 ± 0.1247	52	204	ns	0.9965
			Oligotrophic L. vs. Mesotrophic L.	2.021	2.222	-0.2004 ± 0.1142	83	122	ns	0.6511
			Oligotrophic L. vs. Eutrophic L.	2.021	2.293	-0.2717 ± 0.09685	83	398	ns	0.0946
			Oligotrophic L. vs. Hypereutrophic L.	2.021	3.245	-1.224 ± 0.1045	83	204	****	<0.0001
			Mesotrophic L. vs. Eutrophic L.	2.222	2.293	-0.0713 ± 0.08306	122	398	ns	0.9895
			Mesotrophic L. vs. Hypereutrophic L.	2.222	3.245	-1.023 ± 0.09186	122	204	****	<0.0001
			Eutrophic L. vs. Hypereutrophic L.	2.293	3.245	-0.9518 ± 0.06911	398	204	****	<0.0001

Table S6 (continued)

S15c	log(K)	F (7, 944) = 220.8 P<0.0001	Ocean vs. European R.	-2.099	-0.813	-1.286 ± 0.07604	187	114	****	<0.0001
			Ocean vs. African non-CCC R.	-2.099	-0.273	-1.826 ± 0.08035	187	96	****	<0.0001
			Ocean vs. African CCC R.	-2.099	0.2222	-2.321 ± 0.1003	187	52	****	<0.0001
			Ocean vs. Oligotrophic L.	-2.099	-0.402	-1.697 ± 0.08441	187	83	****	<0.0001
			Ocean vs. Mesotrophic L.	-2.099	-0.573	-1.526 ± 0.07504	187	119	****	<0.0001
			Ocean vs. Eutrophic L.	-2.099	-0.18	-1.919 ± 0.06518	187	199	****	<0.0001
			Ocean vs. Hypereutrophic L.	-2.099	0.5024	-2.602 ± 0.07877	187	102	****	<0.0001
			European R. vs. African non-CCC R.	-0.813	-0.273	-0.5401 ± 0.08865	114	96	****	<0.0001
			European R. vs. African CCC R.	-0.813	0.2222	-1.035 ± 0.1071	114	52	****	<0.0001
			European R. vs. Oligotrophic L.	-0.813	-0.402	-0.4113 ± 0.09234	114	83	***	0.0003
			European R. vs. Mesotrophic L.	-0.813	-0.573	-0.2397 ± 0.08387	114	119	ns	0.0825
			European R. vs. Eutrophic L.	-0.813	-0.18	-0.6326 ± 0.07517	114	199	****	<0.0001
			European R. vs. Hypereutrophic L.	-0.813	0.5024	-1.315 ± 0.08722	114	102	****	<0.0001
			African non-CCC R. vs. African CCC R.	-0.273	0.2222	-0.4951 ± 0.1102	96	52	***	0.0002
			African non-CCC R. vs. Oligotrophic L.	-0.273	-0.402	0.1288 ± 0.09592	96	83	ns	0.8824
			African non-CCC R. vs. Mesotrophic L.	-0.273	-0.573	0.3003 ± 0.08779	96	119	*	0.015
			African non-CCC R. vs. Eutrophic L.	-0.273	-0.18	-0.0925 ± 0.07952	96	199	ns	0.942
			African non-CCC R. vs. Hypereutrophic L.	-0.273	0.5024	-0.7753 ± 0.091	96	102	****	<0.0001
			African CCC R. vs. Oligotrophic L.	0.2222	-0.402	0.6239 ± 0.1132	52	83	****	<0.0001
			African CCC R. vs. Mesotrophic L.	0.2222	-0.573	0.7955 ± 0.1064	52	119	****	<0.0001
			African CCC R. vs. Eutrophic L.	0.2222	-0.18	0.4026 ± 0.09967	52	199	**	0.0015
			African CCC R. vs. Hypereutrophic L.	0.2222	0.5024	-0.2802 ± 0.109	52	102	ns	0.1684
			Oligotrophic L. vs. Mesotrophic L.	-0.402	-0.573	0.1716 ± 0.09152	83	119	ns	0.5686
			Oligotrophic L. vs. Eutrophic L.	-0.402	-0.18	-0.2213 ± 0.08362	83	199	ns	0.141
			Oligotrophic L. vs. Hypereutrophic L.	-0.402	0.5024	-0.9041 ± 0.0946	83	102	****	<0.0001
			Mesotrophic L. vs. Eutrophic L.	-0.573	-0.18	-0.3929 ± 0.07416	119	199	****	<0.0001
			Mesotrophic L. vs. Hypereutrophic L.	-0.573	0.5024	-1.076 ± 0.08635	119	102	****	<0.0001
			Eutrophic L. vs. Hypereutrophic L.	-0.18	0.5024	-0.6828 ± 0.07793	199	102	****	<0.0001
S23b	log(MOX)	F (2, 951) = 12.08 P<0.0001	MOXinc vs. MOXiso (1)	2.152	2.275	-0.1236 ± 0.08364	318	318	ns	0.3021
			MOXinc vs. MOXiso (2)	2.152	2.553	-0.4013 ± 0.08364	318	318	****	<0.0001
			MOXiso(1) vs. MOXiso (2)	2.275	2.553	-0.2778 ± 0.08364	318	318	**	0.0027

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