Methane process rates in lakes and reservoirs: a global analysis

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1. Introduction

Lakes release methane (CH_4), a greenhouse gas
- >34x more potent than CO_2

Lake CH_4 emissions depend on two microbial processes
- Emission = Production – Oxidation
  - **CH_4 production**: Organic matter → CH_4
  - **CH_4 oxidation**: CH_4 → CO_2

Problem: Lake CH_4 emission estimates globally important, but highly variable
- 8-180 Tg C/yr, or 6-16% of global natural CH_4 emissions[1-2]

Why so variable?: Controls on production & oxidation are poorly understood globally
- Relatively few, geographically limited estimates of production and/or oxidation compared to emission

Aim: Synthesize studies of lake methane production & oxidation to better understand global patterns in lake CH_4 processing

2. Research Questions

Q1. From what lakes do we have information on CH_4 production and/or oxidation?
H1: Most observations from Northern temperate, high-nutrient (eutrophic) lakes.

Q2: What lake characteristics are correlated to higher CH_4 production and/or oxidation rates?
H2: Eutrophic and low-latitude lakes will correlate with higher production but lower oxidation rates.

Q3. Do different experimental methodologies bias estimates of CH_4 production and/or oxidation?
H3: Production and oxidation will be higher when measured in slurry sediment incubations compared to intact sediment core incubations.

Fig 1. Example of a sediment slurry incubation (left) and the typical layout for an intact core sediment incubation (right).

3. Meta-Analysis Methods

Compile studies (n=137) that used incubations to measure lake CH_4 production and/or oxidation rates

From each study, extract lake characteristics and experimental methodology

From each study, extract rates of CH_4 production and/or oxidation

Analyze how methodology and lake characteristics correlate with CH_4 production and oxidation rates across all studies in dataset

4. Results

Q1. Studied lake systems

RESULTS:
- 137 studies of 217 lakes (1973-2018) dominated by:
  - Northern temperate/boreal lakes
  - High or low-nutrient lakes (eutrophic and oligotrophic)
- Sediments: more production estimates than oxidation
- Water column: more oxidation estimates than production

SIGNIFICANCE:
- Current understanding of CH_4 production & oxidation based on a geographically limited subset of lakes
- Comparatively few measurements of sediment CH_4 oxidation & water column CH_4 production

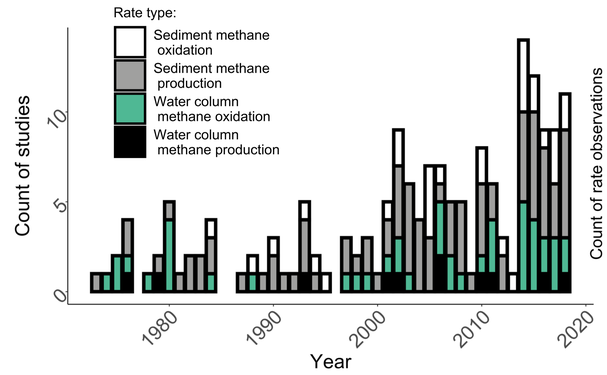

Fig 2. Number of studies published between 1973-2018 that included CH_4 production or oxidation from sediments and water of at least one lake.

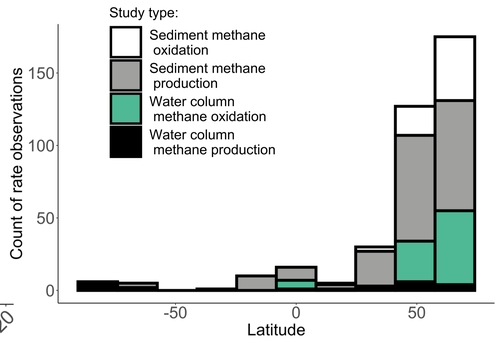

Fig 3. Number of rate observations of CH_4 production or oxidation from sediments and water of lakes included in the meta-analysis.

Q2. Lake characteristics & rates

RESULTS:
- Significant correlation between trophic status and sediment CH_4 production & oxidation rates
- Latitude or temperature not a clear predictor of production or oxidation (graph not shown)

SIGNIFICANCE:
- Future studies needed to clarify potential causal link between trophic status and CH_4 emission, production, and oxidation

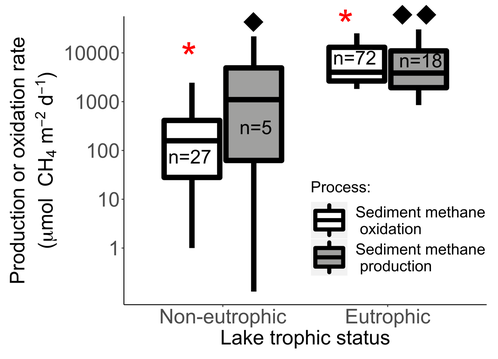

Fig 4. CH_4 oxidation (white) and production (grey) rates in non-eutrophic (left) and eutrophic (right) lakes. Welch's t-test used to determine significant differences (asterisks & diamonds, p< 0.05).

Q3. Methodological bias

RESULTS:
- Production & oxidation rates significantly higher in incubations done with slurries than intact sediment cores

SIGNIFICANCE:
- When comparing rates across multiple methodologies, consider that slurry experiments likely yield potential rates
- Intact core incubations may be more appropriate for whole-system estimates and comparisons of CH_4 processing

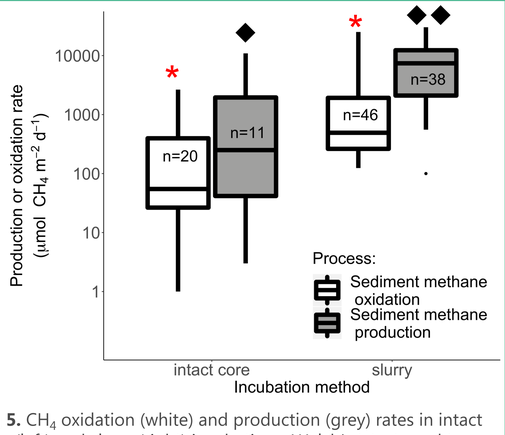

Fig 5. CH_4 oxidation (white) and production (grey) rates in intact core (left) and slurry (right) incubations. Welch's t-test used to determine significant differences (asterisks & diamonds, p< 0.05).

5. Summary

Meta-analysis of CH_4 production and oxidation rates from >200 lakes

1. Majority of published lake CH_4 production & oxidation rates come from northern temperate, boreal, oligotrophic, and eutrophic systems.
- Clear knowledge gap of CH_4 production & oxidation in low-latitude (tropical), mesotrophic, and dystrophic lakes

2. Positive correlation between lake trophic status, CH_4 production rates, and CH_4 oxidation rates.
- Studies into causal link between eutrophication & CH_4 processing needed

3. CH_4 production & oxidation rates significantly higher when measured in slurries vs. intact core incubations.
- Consider methodological bias when comparing rates across different lakes and studies

References
[1] Saunois, M., Bousquet, P., Poulter, B., Peregon, A., Ciais, P., Canadell, J. G., ... & Janssens-Maenhout, G. (2016). The global methane budget 2000–2012. *Earth System Science Data*, *8*(2), 697-751.
[2] Kirschke, S., Bousquet, P., Ciais, P., Saunois, M., Canadell, J. G., Dlugokencky, E. J., ... & Cameron-Smith, P. (2013). Three decades of global methane sources and sinks. *Nature Geoscience*, *6*(10), 813-823.

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