Dam construction as an important anthropogenic modification triggers abrupt shifts in microbial community assembly in freshwater lake sediments

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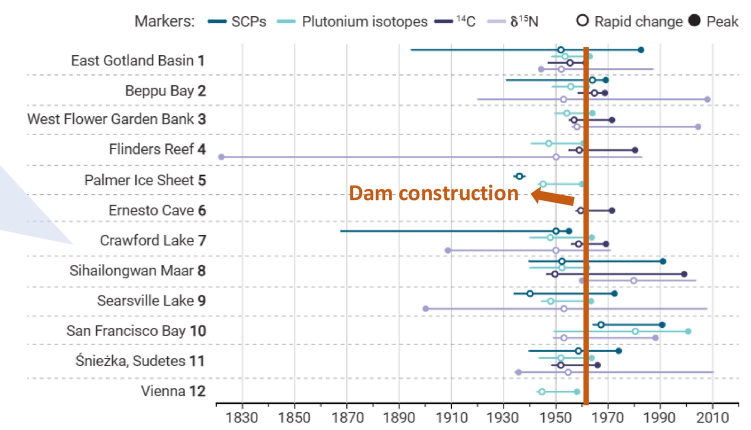
Motivation

- Dam construction **dramatically** increased in the **mid-20th century** and is considered one of the **most far-reaching** anthropogenic modifications of aquatic ecosystems.
- **Little** is known about the human impact on sediment zonation under cover of natural redox niches.

Globally important stratigraphic markers jointly show that the Anthropocene, as a candidate geological epoch, seems appear in the 1950s [1].

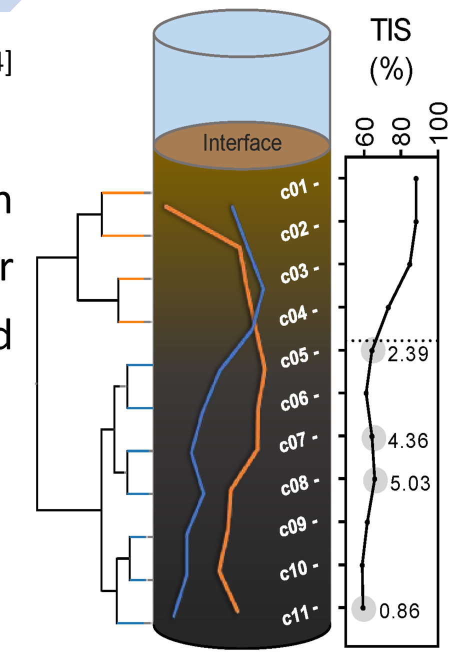


Result 1 Methane sequestration

- CH_4 acts as the main component of sediment gas space [4]
- Gas space as a proxy for ebullitive CH_4 flux
- Gas space volume percent $VP_{(a)}$ is calculated [4] based on measured volumetric ($Moi_{(v)}$) and mass ($Moi_{(m)}$) water contents, and pore water density $\rho_{(w)}$ and mixed sediment density $\rho_{(w\&s)}$:

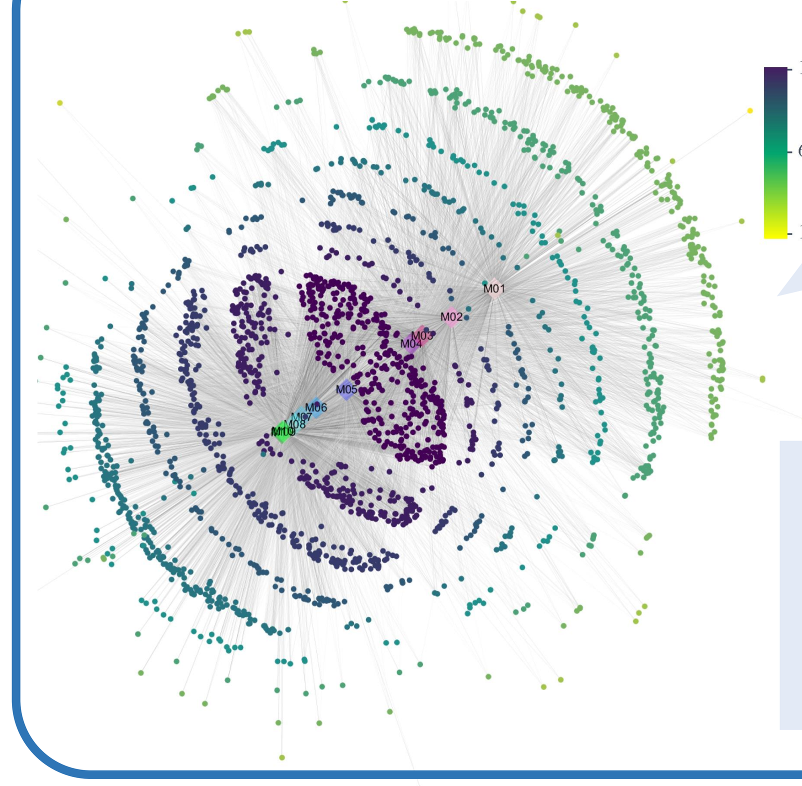
$$\begin{cases} TIS = Moi_{(v)} + VP_{(a)} \\ VP_{(a)} = 1 - \frac{Moi_{(v)} \cdot \rho_{(w)}}{Moi_{(m)} \cdot \rho_{(w\&s)}} \end{cases}$$

✓ Gaseous methane accumulation occurred **only** below the damming horizon.

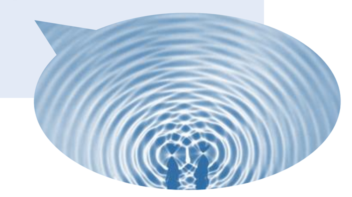


TIS: total interstitial space volume percent
Grey circles: methane bubbles with gas volume (%)
Dotted line: the damming horizon

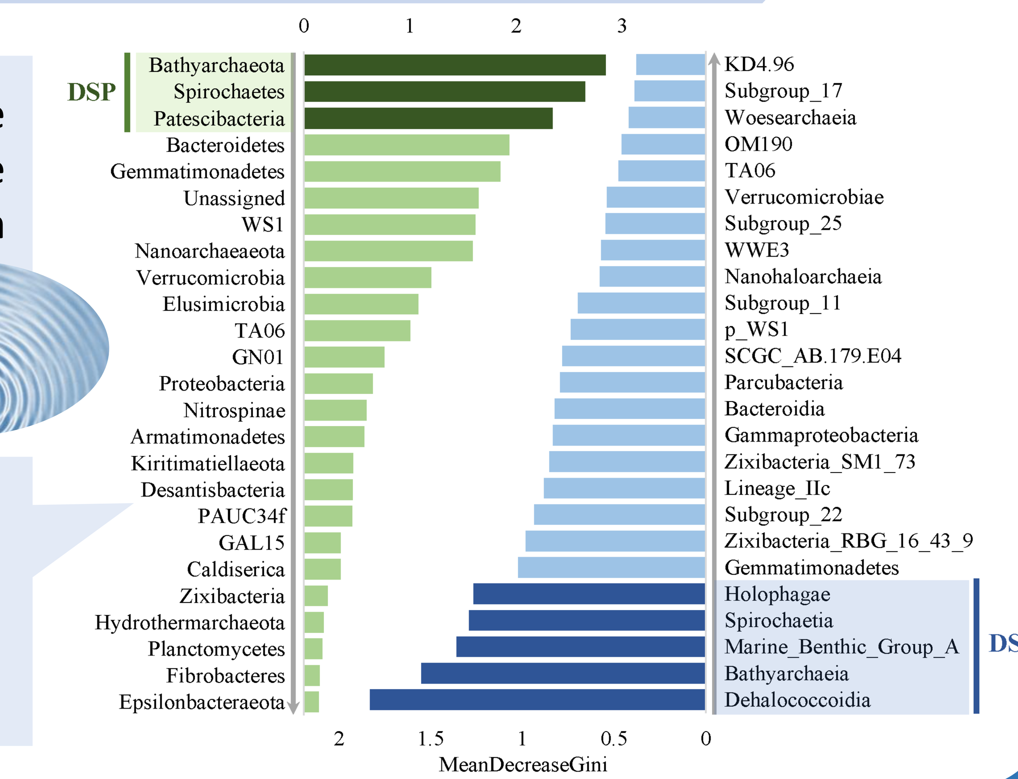
Result 2 Microbial community stratification and damming sensitive taxa



The "two-wave-interference" like topological network exhibits the microbial **community polarization** induced by damming.

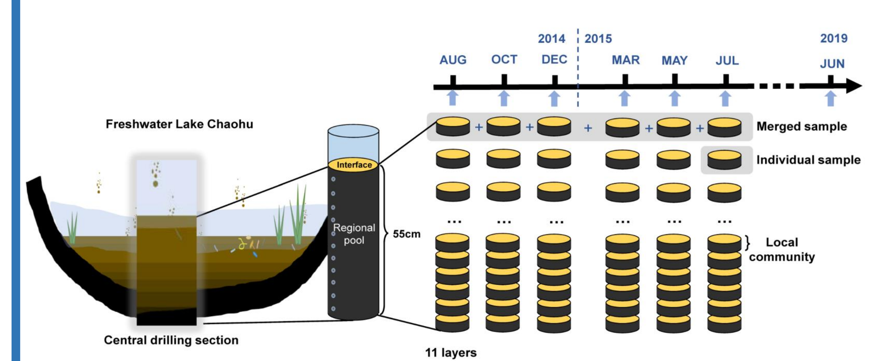


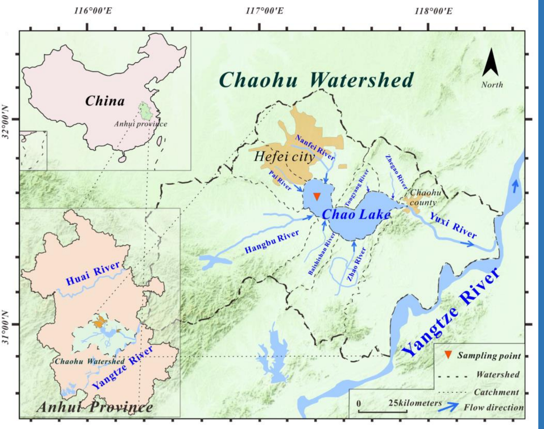
The supervised random forest classifier identifies three damming-sensitive phyla (DSPs) and five damming-sensitive classes (DSCs).



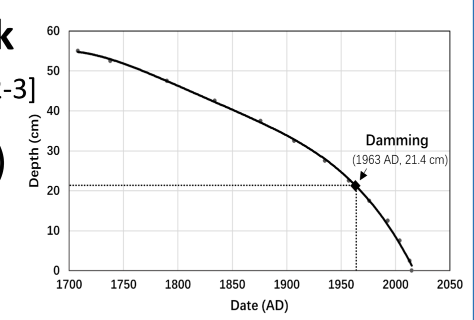
Sampling & Methodology

- **Spatiotemporal** sampling strategy





- Sediment dating using ^{210}Pb and ^{137}Cs [2]
- **1962 damming event** labelled by the **^{137}Cs peak**
- Diatom-inferred eutrophication history (past) [2-3]
- *In-situ* physiochemical measurements (present)

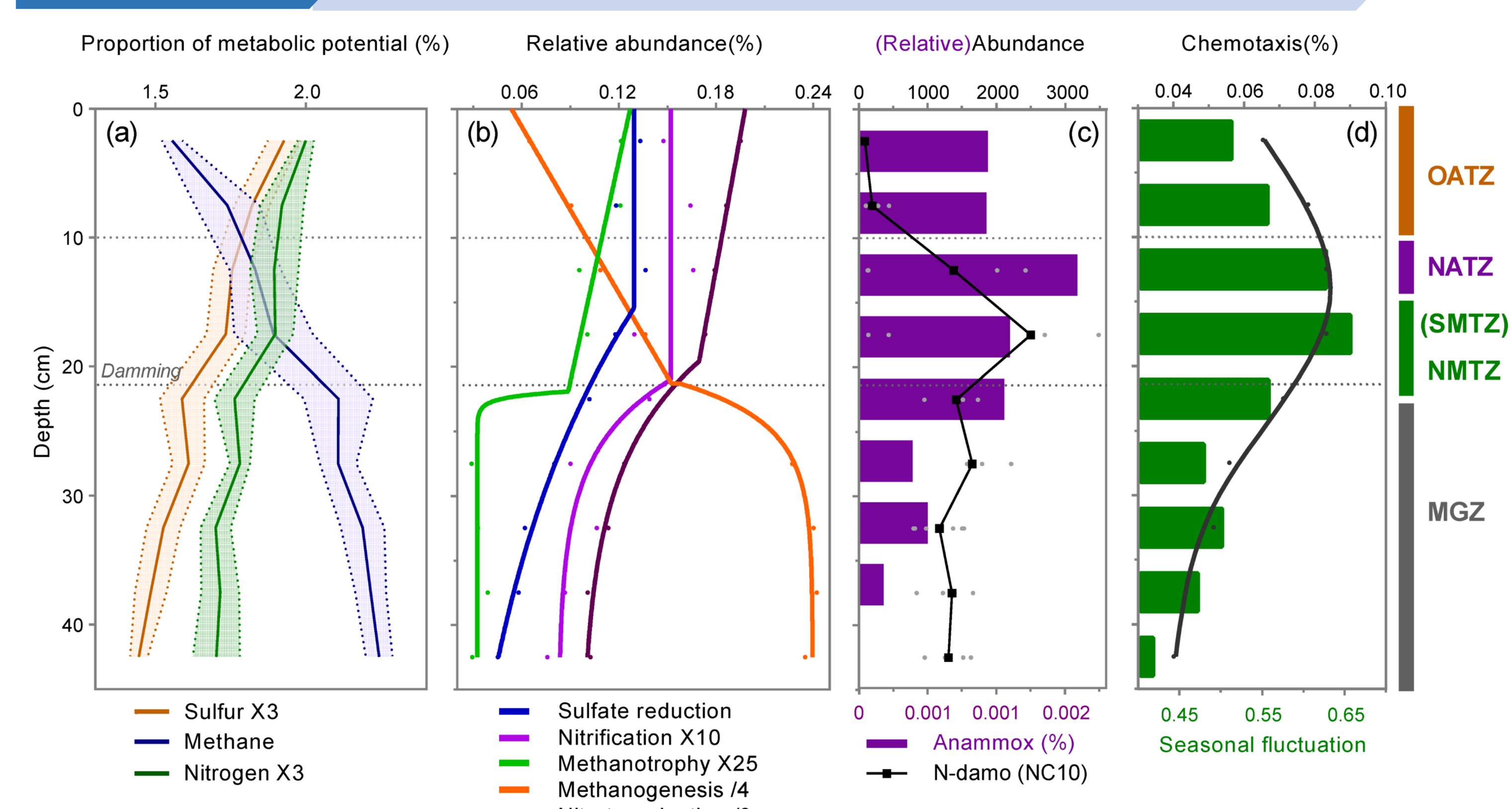


- **Shotgun metagenomics & amplicon sequencing** → microbial taxonomic & metabolic information

Statistics

- Novel **Gas-space-based** method → ***in-situ*** methane accumulation
- Bipartite network & UPGMA → community layering
- Random forest algorithm → damming-sensitive taxa
- **Phylogenetic null model** → community assembly processes

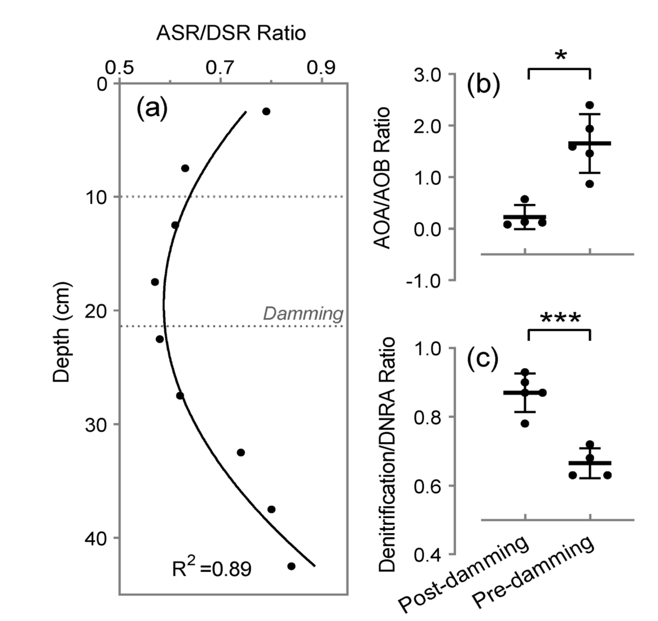
Result 3 Modification of geochemical zonation



Vertical biogeochemical zonation identified according to the energy metabolism potential predicted by metagenomic data annotated with KEGG and NCycDB.

OATZ, oxic-anoxic transition zone **SMTZ**, sulfate-methane transition zone
NATZ, nitrate-ammonium transition zone **MGZ**, methanogenetic zone
NMTZ, nitrate/nitrite-methane transition zone

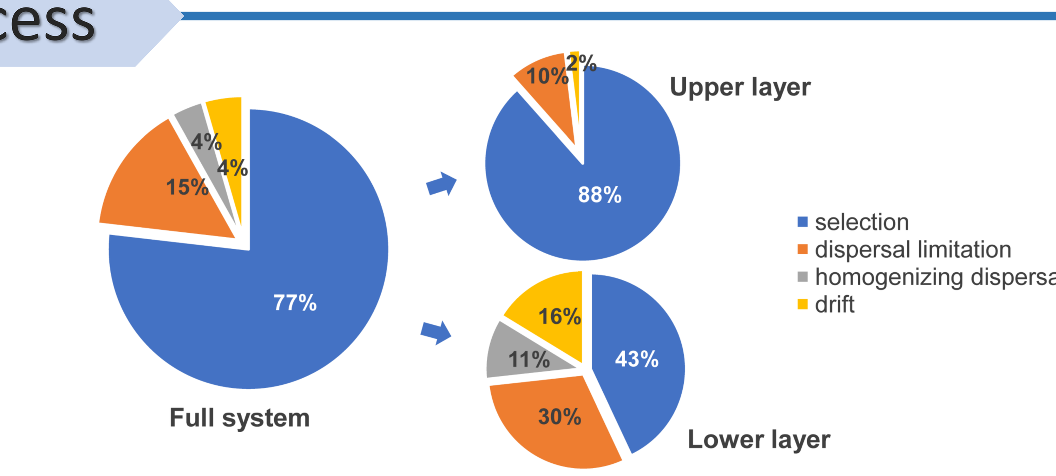
- ✓ Damming modifies sediment redox cascades.
- ✓ Dam-induced initial energy differentiation is **amplified** by microbial nitrogen and methane metabolism, forming an abrupt **nitrate-methane** transition and thus controls the depth of methane sequestration.
- ✓ Damming motivates cell chemotaxis



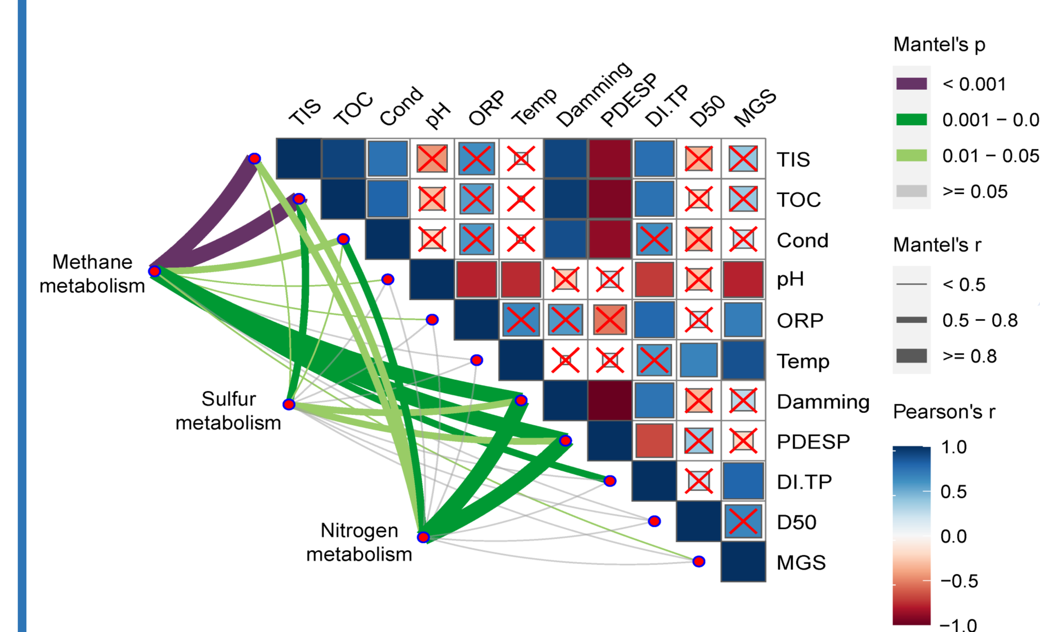
ASR/DSR, ratio of assimilatory/dissimilatory sulfate reduction
AOA/AOB, ratio of ammonia-oxidizing archaea and bacteria reflected by archaeal/bacterial amoABC genes
Denitrification/DNRA, ratio of denitrification and dissimilatory nitrate reduction to ammonium

Result 4 Shifts of community assembly process

✓ Phylogenetic null model analysis reveals a **pronounced shift** in microbial community assembly process at the damming horizon, from a **selection-oriented deterministic** community assembly down to a **more stochastic, dispersal-limited** one.

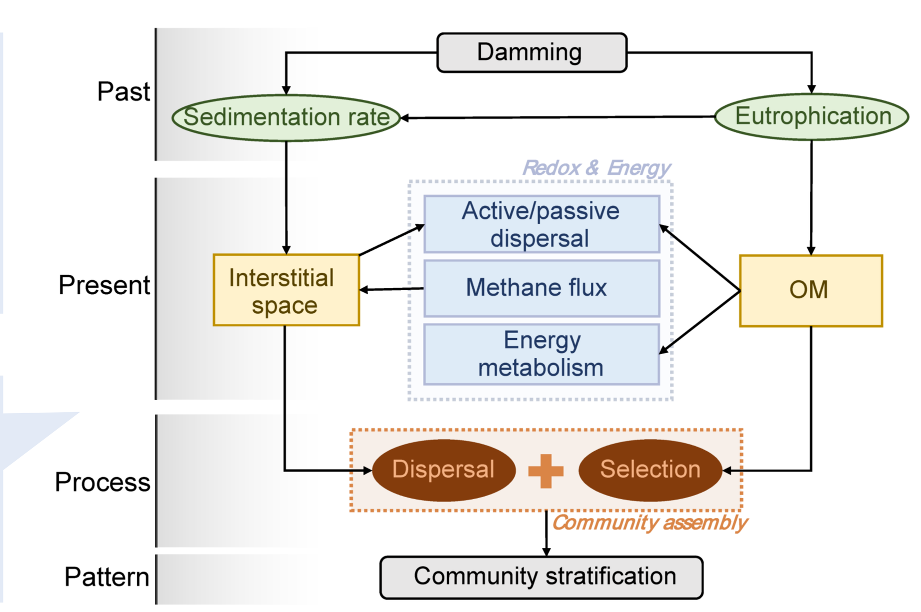


Result 5 Causality between anthropogenic activities and sediment stratification



✓ Methane and nitrogen metabolism are mainly driven by damming and eutrophication.

✓ Causal effect between dam construction and sediment microbial stratification



Highlights

- ✓ The construction of dam has altered sediment **redox hierarchy** and **biogeochemical zonation** by modifying microbial **metabolic activities** involved in **methane** and **nitrogen** cycling.
- ✓ Damming significantly impacts the **community structure** and **assembly processes** of sediment microbes.
- ✓ Dam building has the potential to **affect greenhouse gas emissions** by influencing sediment **methane sequestration**.
- ✓ Overall, the response of microbial communities in lake sediments to dam construction reflects a critical **tipping point** of the Anthropocene in **subsurface biogeochemical cycles**.

REFERENCES

[1] Colin N. Waters Simon D. Turner. (2022). *Science*. 378, 706-708.
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[5] Zhou X et al. (2023). PREPRINT. https://doi.org/10.21203/rs.3.rs-2524837/v1

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See the Abstract!