



## Challenges and opportunities in atmospheric methane mitigation from freshwater and marine environments

Lu Shen<sup>1</sup>, Minghao Zhuang<sup>2</sup>, Shushi Peng<sup>3</sup>, Vincent Gauci<sup>4</sup>, Wei Wei<sup>5</sup>, Lidong Wu<sup>6</sup>, and Michael MacLeod<sup>7</sup>

<sup>1</sup>Peking University, China (lshen@pku.edu.cn)

<sup>2</sup>College of Resources and Environmental Sciences, China Agricultural University, Beijing, 100193, China

<sup>3</sup>College of Urban and Environmental Sciences, Peking University, Beijing100871, China

<sup>4</sup>School of Geography, Earth and Environmental Sciences, The University of Birmingham, Edgbaston, Birmingham B15 2TT, UK

<sup>5</sup>Key Laboratory of the Three Gorges Reservoir Region's Eco-Environment, Ministry of Education, Chongqing University, Chongqing, China

<sup>6</sup>Chinese Academy of Fishery Sciences, Beijing 100141, China

<sup>7</sup>Department of Rural Economy, Environment and Society, Scotland's Rural College (SRUC), Edinburgh, UK

Methane emissions from the aquatic environment exhibit distinct characteristics: while oceans, covering 70% of Earth's surface, emit 9 Tg of methane annually, freshwater wetlands, which occupy only 2% of Earth's surface, emit 150-200 Tg per year. This significant contrast raises important questions about the underlying mechanisms and potential strategies to mitigate methane emissions in these water systems. In this work, we explore the challenges and opportunities of methane mitigation in both freshwater and marine environments.

For freshwater wetlands, existing projections of future methane emissions usually neglect feedbacks associated with global biogeochemical cycles. Here, we employ data-driven approaches to estimate both current and future wetland emissions, considering the effects of changing meteorology and biogeochemical feedbacks arising from atmospheric sulfate deposition and CO<sub>2</sub> fertilization. We show that, under low-CO<sub>2</sub> scenarios (1.5 and 2°C warming pathways), the suppressive effect of sulfate deposition on wetland methane emissions largely diminishes by 2100 due to clean air policies, resulting in an additional emission increase of  $7 \pm 2$  Tg a<sup>-1</sup>. This increase account for 35% and 22% of total wetland emission changes under 1.5 and 2°C warming pathways, a factor not yet considered by current Integrated Assessment Models.

For marine waters, we assess the methane emissions from mariculture's aquatic environment at 10-km resolution globally, using measurements from research cruises and satellite-observed net primary productivity. Mariculture's aquatic emission intensity is estimated to be 1–6 gCH<sub>4</sub> per kg of carcass weight (CW), >95% lower than freshwater systems, due to suppressed microbial production in marine waters and inefficient ventilation to the atmosphere. The life-cycle assessment shows that mariculture's carbon footprints are ~40% lower than those of freshwater aquaculture, suggesting considerable climate benefits of mariculture expansion to meet future

protein needs.