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Microfluidic analysis of N2O cycling in karst aquatic systems: Linking hydrological, geochemical and microbiological processes

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Karst landscapes, comprising ~20% of the Earth's ice-free land surface, are geological terrains characterized by topographical features resulting from the dissolution of soluble rocks, primarily carbonates. These dissolution features, such as sinkholes and conduits, facilitate the interaction between surface water and groundwater, making the hydrological and biogeochemical characteristics of karst landscapes a crucial component of the global nitrogen (N) cycle. Specifically, karst landscapes and aquifers have recently been identified as hotspots for the production of nitrous oxide (N2O), the third most important greenhouse gas with a 100-year global warming potential ~300 times that of carbon dioxide. However, the mechanisms by which N2O is produced and consumed across karst aquatic landscapes remain poorly understood due to a variety of heterogeneous, yet often coupled, hydrologic, chemical, and microbiological processes that influence N2O cycling. Thus, a holistic approach that considers the interplay between these processes is necessary to quantitatively predict N2O production and consumption rates within, as well as emissions from, karst aquatic environments. Such advances are essential for developing predictive models of future global warming, for which N2O production is likely to have a major impact because (1) reactive nitrogen species, such as nitrate (NO3−) and ammonium (NH4+), which microbes convert to N2O, have more than doubled in aquatic environments over the past few decades due to anthropogenic activities (e.g., fertilizer use, fossil fuel burning), and (2) karst landscapes are globally widespread. We present a microfluidic study where we (1) develop microfluidic chips that replicate karst aquifers to simulate various hydrologic conditions, (2) use the microfluidic chips to experimentally produce and measure N2O production and consumption by inoculating and culturing denitrifying bacteria under various hydrologic conditions, (3) measure functional gene activity to identify dominant microbial processes responsible for N2O cycling, and (4) link lab experimental findings to field measurements including nitrogen species concentrations, microbial activity, and hydrological conditions to evaluate natural N2O production and consumption mechanisms. The results show that (1) surface water-groundwater interactions create conditions favorable for N2O production through incomplete denitrification and (2) the magnitude and duration of such interactions controls both N2O production and consumption rates and therefore, atmospheric emissions from karst aquatic ecosystems.

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References

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