EGU24-4469, updated on 10 Dec 2024
https://doi.org/10.5194/egusphere-egu24-4469
EGU General Assembly 2024

Blind spots hinder understanding of the tropical nitrogen cycle

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Our current understanding of the tropical terrestrial nitrogen (N) cycle has been shaped by decades of field-based research, predominately at a small subset of sites across the globe. These field data inform hypotheses on how N cycling is mediated by biotic and abiotic drivers, and inform the paradigm that tropical wet forests are characterized by high rates of N inputs and outputs compared with other systems, driven by high inorganic N availability. However, recent findings that do not seem to conform to this paradigm call into question how well the bulk of our underlying data represents the diversity of the tropics as a whole. We propose that there may be blind spots in our understanding of N cycling created by a paucity of sampling from areas where environmental factor combinations differ from those often studied. Identifying these blind spots may help to resolve which drivers can be generalized across the tropics as a whole, versus which sustain system heterogeneity. We conducted a pan-tropical synthesis of field sampling sites for N fixation and denitrification (two key processes that influence system N inputs and outputs, as a proxy for general understanding of N cycling) and sampling intensity between 1950 and 2022. As a metric of geographic biases in general understanding, we tallied citations counts for each study over time. We also collated globally gridded data for a range of factors hypothesized to control N cycling rates, including soil and climatic variables, productivity, topography, vegetation type, biogeographic region, and disturbance. With these data, we: 1) mapped major axes of variation in tropical environmental conditions using principal components, 2) determined the distribution of environmental variables within sampled sites versus the tropics as a whole, and 3) identified regions where unique combinations of conditions are under sampled.

Preliminary results show a relative over-representation of evergreen broadleaf forests, and under-representation of grasslands and savannas. This corresponded to a proportional oversampling of sites with higher soil fertility (soil N and P), high net primary productivity, high rainfall, and low rainfall seasonality. To quantify system-level biases we also explored intra-biome sampling variability for factors such as fertility and elevation (e.g., tropical montane versus lowland forests). Denitrification and N fixation tended to follow similar patterns in site characteristics, suggesting that these metrics are a good proxy for overall N cycling understanding.

Overall, our study identifies regions of the global tropics where environmental drivers are similar to those dictating existing knowledge, as well as understudied regions that should be targeted to explore system heterogeneity. Future work can leverage this information to design cross-system comparisons to explicitly test current hypothesized mechanisms to advance our understanding of

the N cycle. Constraining nutrient availability and cycling in tropical ecosystems is especially important in the context of global change, where shifting environmental conditions may alter how forests cycle and retain N and, therefore, how nutrient limitation will constrain productivity responses to rising carbon dioxide.

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