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An Earth system view on boundaries for human perturbation of the N and P cycles

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The appropriation and transformation of land, water, and living resources can alter Earth system functioning, and potentially undermine the basis for the sustainability of our societies. Human activities have greatly increased the flows of reactive forms of nitrogen (N) and phosphorus (P) in the Earth system. These non-substitutable nutrient elements play a fundamental role in the human food system. Furthermore, the current mode of social and economic globalization, and its effect on the present-day energy system, also has large effects including large NO_x-N emissions through combustion. Until now, this perturbation of N and P cycles has been treated largely as a local/regional issue, and managed in terms of direct impacts (water, land or air pollution). However, anthropogenic N and P cycle changes affect physical Earth system feedbacks (through greenhouse gas and aerosol changes) and biogeochemical feedbacks (via ecosystem changes, links to the carbon cycle, and altered nutrient limitation) with impacts that can be far removed from the direct sources.

While some form of N and P management at the global level seems likely to be needed for continued societal development, the current local-level and sectorial management is often problematically simplistic, as seen in the tensions between divergent N management needs for climate change mitigation, air pollution control, food production, and ecosystem conservation. We require a step change in understanding complex biogeochemical, physical and socio-economic interactions in order to analyse these effects together, and inform policy trade-offs to minimize emergent systemic risks.

Planetary boundaries for N and P cycle perturbation have recently been proposed. We discuss the current status of these precautionary boundaries and how we may improve on these preliminary assessments. We present an overview of the human perturbation of the global biogeochemical cycles of N and P and its interaction with the functioning of the Earth system. There are various N and P impacts, which vary in space and time and are associated with multiple human drivers. There are multiple possible constraints that need to be considered; for P there is an issue with absolute availability, but not for N. The societal benefits (e.g. food production) and environmental impacts (e.g. eutrophication) are linked through stoichiometry, which differs in terrestrial and aquatic systems, presenting challenges for any global optimization approach. By setting out these features, we can better assess how to apply and improve our current analytic frameworks, models, and data for safer navigation of the biogeochemical complexities of global sustainability.