A unifying framework for the multi-nutrient ocean

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Biological cycling controls the overall concentrations and distributions of multiple nutrient elements in the oceans, while oceanic productivity is reciprocally dependent on the availability of multiple nutrients. The complexities of stoichiometric plasticity in biological nutrient uptake have complicated the development of generalised models for this multi-nutrient ocean. Explicitly considering such plasticity we demonstrate how maximum uptake capacities for different nutrients are a crucial control on their coupled cycles. Using this insight we develop a framework which, when applied within both idealised and realistic ocean circulation models, can reconcile the overall oceanic inventories and residence times of multiple nutrient elements, the limitation potentials of these nutrients and many aspects of their differential distributions, as for example revealed through the international GEOTRACES programme. In addition to making testable predictions from regional to whole-ocean scales, the proposed framework can be used to interpret multi-nutrient distributions and biogeochemical responses to altered forcing.