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Nitrogen and Phosphorus Controls of the Carbon Cycle

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Two current questions of global environmental and climate change bear on the controlling roles of N and P in the biogeochemical carbon cycle: (1) How much of new primary production on land is attributable to nutrient recycling from decomposition of organic matter in soils and addition of chemical fertilisers? (2) How much of new primary production in the coastal oceanic zone is supportable by nutrients transported from land and by coastal upwelling from the deeper ocean?

Our estimates of the N and P fluxes, and their effects on primary production, were de-rived from model analysis (TOTEM) that begins in the year 1700, taken as the initial quasi-steady state of the environment in pre-industrial time. From 1700 to 1995, terrestrial uptake of atmospheric CO_2 increased from about 0.6 to 2.1 Gt C/year (1 gigaton C = 83.3 $x10^{12}$ moles C). This number represents uptake of carbon by land biota, less biota and soil respiration. The incremental increase of 1.5 Gt C/year or 125 $x10^{12}$ mol C/year constitutes new biomass with an average Redfield ratio for land plants of C:N:P = 510:4:1. Thus this biomass also took equivalent amounts of N and P: 0.98 $x10^{12}$ mol N and 0.25 $x10^{12}$ mol P. These amounts of C, N and P are small fractions, approximately 2%, of the amounts cycled through bioproduction, respiration and humus decomposition. Soil humus, of Redfield ratio C:N:P = 140:6.6:1, releases most of the nitrogen and phosphorus needed for primary production, with additional smaller amounts from dissolution and leaching of soil minerals (in the mid-1990s, 42 $x10^{12}$ mol N/year and 9 $x10^{12}$ mol P/year). In comparison to these fluxes, the amounts of chemical fertilisers added globally to croplands in 1995 were considerably smaller: 5 $x10^{12}$ mol N/year and 1.1_10^{12} mol P/year. There are indications (TOTEM) that only about 45% of N and 30% of P from fertilisers are utilised by crops, and the residuals variably stored in soils and groundwaters, and removed to the atmosphere (denitrification) and rivers.

The main external inputs of nutrients N and P to the oceanic coastal zone are by coastal upwelling and by riverine flow from land, and from atmospheric deposition of N. During the past 300 years, the N and P inputs by coastal upwelling remained at 10.8 $x10^{12}$ mol N/year and 0.46_10^{12} mol P/year in our model analysis. The flux of dissolved carbon associated with the upwelling is much greater than Redfield ratio C:P = 106:1 in marine primary production, and the N:P ratio of 23 in the upwelling fluxes is also greater than Redfield ratio N:P = 16:1. Thus in the nutrient upwelling, phosphorus controls net ecosystem bio-productivity as the least available element, and an excess of nitrogen and carbon is created in the coastal zone.

In contrast to the nutrient inputs from coastal upwelling, the riverine inputs of N and P have increased owing to land-use activities in the past 300 years, and atmospheric deposition of N in the coastal ocean has also increased from fossil fuel burning:

Nutrient flux	Year 1700	Year 1995
N from rivers (DIN + TON) and atmospheric deposition	3.45	5.60
P from rivers (DIP + TOP)	0.29	0.45

Table 1. Fluxes of N and P into coastal ocean zone (units of 10^{12} mol/year).

P from rivers (DIP + TOP) 0.29 0.45 The fact that the N:P ratios of about 12:1 in the inputs to the coastal zone (Table 1) are smaller than Redfield ratio N:P = 16:1 in marine plankton does not indicate nitrogen deficiency in the coastal zone. It shows that some of the particulate organic phosphorus is not available for biological production and is stored in sediments and exported to the open ocean. Total organic matter brought by rivers to the coastal zone is characterised by Redfield ratio C:N:P is approximately equal to 121:8:1, reflecting the higher values of C:P in land plants and probably faster oxidation of C in humus and riverine particulate organic matter. Increased input of P to the coastal zone by riverine flow above the pre-industrial level, (0.45 - 0.29) $x10^{12}$ = 0.16 $x10^{12}$ mol P/year (Table 1) can support, at the upper limit, new production of about 17 $x10^{12}$ mol C/year or 0.2 Gt C/year.