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Three decades of changing nutrient stoichiometry from source to sea on the Swedish west coast

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European ecosystems have been subject to extensive shifts in anthropogenic disturbance, primarily through atmospheric deposition, climate change, and land management. These changes have altered the macronutrient composition of aquatic systems, with widespread increases in organic carbon (C), and declines in nitrogen (N) and phosphorus (P). Less well known is how these disturbances have affected nutrient stoichiometry, which may be a more useful metric to evaluate the health of aquatic ecosystems than individual nutrient concentrations. The Swedish west coast has historically experienced moderate to high levels of atmospheric deposition of sulfate and N, and eutrophication. In addition, coastal waters have been darkening with damaging effects on marine flora and fauna. Here, we present three decades of macronutrient data from seven watercourses (plus additional lakes) along the Swedish west coast, including headwaters and river mouths, across a range of land covers, and with catchments ranging 0.037 – 40000 km^2.

We find a high degree of consistency between these diverse sites, with widespread increasing trends in organic C, and declines in inorganic N and total P. These trends in individual macronutrients translate into large stoichiometric changes, with a doubling in C:P, and increases in C:N and N:P by 50% and 30%, showing that freshwaters are moving further away from the Redfield Ratio, and becoming even more C rich, and depleted in N and P. These changes were not restricted to headwaters but were also evident in larger rivers and at river mouths. Although recovery from atmospheric deposition is linked to some of these changes, land cover also appears to have an effect; lakes buffer against C increases, and decreases in inorganic N have been greatest under arable land cover. Taken together, our findings show that freshwater macronutrient concentrations and stoichiometry have undergone substantial shifts during the last three decades, and these shifts can potentially explain some of the detrimental changes that adjacent coastal ecosystems are undergoing. Our findings are relevant for all European and North American waters that have experienced historically high levels of atmospheric sulphate and N deposition, and provide a starting point for understanding and mitigating against the trajectories of long-term change in aquatic systems.