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Resilience of phosphorus cycling

A new approach to analysing resilience reveals changes in China's phosphorus system and suggests ways to improve it.

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Phosphorus (P) is intensively recycled in natural ecosystems but ultimately flows to the sea. There it also cycles, contributing to surface growth before settling into the depths. Some returns to fertilize the surface again at upwelling zones, famous for their productive fisheries. Phosphorus then enters the sedimentary cycle, not to return to the biosphere for tens or hundreds of millions of years. Since P is a non-renewable resource at human timescales, population growth and the increasing P demand for agricultural production put pressure on P resources. This is compounded by limited P recycling in urban areas, which results in a 'broken' P cycle[1]; recycle loops are short-circuited and P enters a mainly unidirectional flow, from mine to farm to food to waste — with significant losses along the way[2].

Writing in *Nature Food*, Liang and colleagues propose a new method to examine the resilience of P cycling and apply it to China[3]. To do that, they generate a 149-node P cycling network, and run calculations for each year during 1600–2012. The method augments previous approaches such as life-cycle analysis and substance-flow analysis, and advances the comprehensive vulnerability assessment conducted a few years earlier[4] through the addition of ecological network analysis. Ecological network analysis is derived from thermodynamics, information theory and systems ecology, and starts with measures of efficiency (X) and redundancy (ψ) determined by flows between nodes. The ratio of X to the sum of X and ψ is termed α, a key index that reflects the trade-off between redundancy and efficiency. Too high a value for α indicates a system with greater specialization that is subject to disruption. Lower α indicates more redundancy, conferring stability by providing alternative flow possibilities in the event of disturbances, but at the cost of stagnation. Network resilience (R) has previously been defined[5] in terms of α as $R = -\alpha \times \ln(\alpha)$. This function has an optimum at $\alpha = 1/e = 0.3679$, shown by empirical studies to be the value natural ecosystems tend to. In their analysis of the P cycling network in China, Liang and colleagues adopt this same optimal value to analyse possible system shifts towards greater resilience or redundancy, and take R not as an absolute measure but as a parameter to measure such changes.

Liang and colleagues found that, at the beginning of the twentieth century, China was already 'overly efficient', with α and R at about 0.52 and 0.34, respectively. Since then, its P system has become even more efficient and less redundant, with α increasing to about 0.65 and R dropping to 0.27. The study also revealed that the main drivers behind these values differed across time periods, with changes in food patterns becoming major determinants of recent P cycling network resilience (that is, 2000–2012).

Phosphorus use in China has global implications given the country's market power and pivotal spot in the global P supply chain. China's decision to introduce export tariffs on P products during the 2008 financial crisis contributed to a jump in global P prices, adding pressure on food supplies around the world. Besides, China is a distant second in identified reserves of phosphate rock (with only 4.6% of the total, versus Morocco's 72%)[6], but it is the world leader in P production (45.7%), followed by Morocco (15%) and the US (9.6%).

Looking at the ratio of reserves to consumption (r/c), we can compute the 'lifetime' of reserves for China and the US as 29 and 43 years, respectively (while the global r/c ratio is almost three centuries). This could lead to a competition between the two countries for Morocco's reserves, or even disturbances to food trade given that the US exports P to many countries, including China, as fertilizers as well as 'embedded' in crops[7].

The r/c ratio by itself is not a reliable predictor of resource scarcity, but does offer an indication of the challenges ahead. The analysis of P cycling network resilience adds to r/c and other efficiency measures to provide a much more complete and nuanced picture of P resources. The identification of the most critical network nodes allows for better targeted sustainability policies. With better tools to evaluate measures, increasing the resilience of P cycling is a matter of will. ❐

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Competing interests

The author declares no competing interests.