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Changing nutrients, changing rivers

Phosphorus removal from freshwaters has wide-ranging ecological consequences

By Carles Ibáñez[1] and Josep Peñuelas[2,3]

Eutrophication—the excessive enrichment of a body of water with nutrients such as nitrogen (N) and phosphorous (P)—is Earth's most widespread problem for water quality (*1, 2*). Growing evidence suggests that there is a global trend toward reversing eutrophication. However, in rivers and estuaries of developed countries and in lakes of emerging economies, the ongoing reduction in nutrient inputs—termed reoligotrophication—is much larger for P than for N (*3, 4*). Although the rapid emergence of this phenomenon has hindered detailed monitoring of the ecological effects, a few studies have documented an abrupt shift from green to clear waters and consequently from phytoplankton to macrophytes as dominant primary producers in response to reoligotrophication in rivers and estuaries (*6-8*). However, the improvement in water quality due to P decline does not mean returning to pristine ecological conditions, because high N:P ratios trigger undesirable changes in the ecosystem (9).

Understanding of the effects of eutrophication and reoligotrophicatrion mainly comes from studies of shallow lakes, which can be in two alternative states: turbid, dominated by phytoplankton, and characterized by low diversity and poor water quality; or clear, dominated by macrophytes, and characterized by higher diversity. Anthropogenic eutrophication or reoligotrophication causes abrupt shifts between these states (10). Many American and European lakes have recovered from eutrophication following the control of phosphorous inputs, providing a paradigm of successful environmental management (*1, 5*). This trend is also beginning to emerge in lakes throughout the world, for example in urban regions in China, linked mostly to rapid advances in the treatment of municipal wastewater (*11*).

Eutrophication changes in rivers and estuaries around the world are less well understood than those in lakes, but research is beginning to address this (*12*). During the second half of the 20th century, nutrient loads in rivers and estuaries rose in Europe and the USA, mostly due to fertilizers, manure, industrial pollution, and release of urban wastewater. In the past 20 to 30 years, P (and in some cases N) inputs have decreased in some eutrophicated rivers due to improved water treatment and crop management (*3, 4*).

The effects of eutrophication and reoligotrophication in rivers are not fully understood, partly because most studies have focused on streams, where phytoplankton cannot be a relevant component due to a shallow water column and high water turnover. Several studies have, nevertheless, shed light on the impacts of reoligotrophication in rivers. These studies have reported declines in chlorophyll concentrations or phytoplankton populations in rivers caused by P removal following the introduction of wastewater-treatment plants and P-free detergents (Table S1). The larger the river, the closer the relationship between P and phytoplankton becomes to that of lakes. Less data are available for reoligotrophication of coastal areas, but data are available for Danish estuaries (*6*) and a few other locations (Table S2). Two river studies have shown that the decrease in fluvial P concentrations triggered an abrupt ecosystem shift, with the collapse of phytoplankton populations and the subsequent increase in water transparency allowing the spread of macrophytes (see the figure) (*7,8*). These results suggest that the shallow-lake model of alternative equilibria can be adapted to lowland and dammed rivers, where the model predicts that reoligotrophication should lead to abrupt changes between states of turbid and clear water (*7*). The results in (7, 8) thus support the view that lake and river ecosystems respond similarly to P enrichment. However, the abundance of phytoplankton per unit of total P is lower in rivers than in lakes due to the higher water turnover rates in rivers. Besides phytoplankton decline, factors such as river depth, pulsing flow, load of suspended sediments, and substrate type may determine the spread of submerged macrophytes in rivers. It is possible that macrophytes are spreading in many rivers without being monitored, so long-term monitoring of phytoplankton and macrophytes in rivers is thus strongly warranted.

Long-term river data series often include dissolved nutrients, less frequently particulate nutrients, and rarely chlorophyll, phytoplankton, or macrophytes, making it difficult to assess the extent of ongoing reoligotrophication. This problem could be addressed with remote sensing data from satellites. Moreover, not only the effects of P decline but also of the changes in stoichiometric imbalances between N and P must be considered to better understand the ecological effects. In this respect, past research on lakes can be valuable, but research on cascading effects on rivers and estuaries is also warranted. This is now underway in a few rivers, such as the lower Ebre River (see the figure) (*7,8*). For instance, the decline in phytoplankton and the spread of macrophytes have triggered massive black fly blooms, the decline of massive may fly blooms in the river, and the recovery of biological communities in the estuary (13).

The responses of small, medium and large rivers to reoligotrophication are likely to differ, as will the responses of rivers with distinct river basin substrates, such as limestone or granite. The applicability of possible measures for managing river restoration, land use, and water flow to avoid negative impacts of stoichiometric imbalances between N and P must be assessed through monitoring, controlled experiments, and models. For example, improved monitoring and modeling of reservoirs can help to better understand their role in N and P retention and release (14).

The ecological effects of P decline and N/P imbalances on the structure and function of natural and managed ecosystem are pervasive around the globe (*9*), but the consequences for aquatic systems are not well understood (*15*). Moreover, the interactions with other global changes such as global warming, hydrological alteration, and invasive species are complex. The recent results on reoligotrophication of rivers and estuaries in developed countries and the resulting cascading effects on the physicochemistry of water and the trophic web show, however, that the implications of reoligotrication and increasing N:P ratios for ecosystem structure and function, and therefore for environmental management are profound. Reoligotrophication is good news in terms of water quality, but the effects on structure and composition of biological communities are complex and present a fundamental environmental management challenge.

REFERENCES

1. D. W. Schindler, *Proc. R. Soc. B* **279**, 4322 (2012).
2. C. J. Stevens, *Science* **363**, 578 (2019).
3. S. Cozzi, C. Ibáñez, L. Lazar, P. Raimbault, M. Giani, *Water* **11**, doi:10.3390/w11010001 (2019).
4. R. M. Kreiling, J. N. Houser, *Environ. Monit. Assessment* **188**, 454 (2016).
5. K. Sand-Jensen, H. H. Bruun, L. Baastrup-Spohr, *J. Ecol.* **105**, 690 (2017).
6. B. Riemann *et al.*, *Estuaries and Coasts* **39**, 82 (2016).
7. S. Hilt, J. Köhler, H. P. Kozerski, E. H. van Nes, M. Scheffer, *Oikos* **120**, 766 (2011).
8. C. Ibáñez *et al.*, *Sci. Total Environ.* **416**, 314 (2012).
9. J. Peñuelas *et al.*, *Nat. Commun.* **4**, 2934 (2013).
10. M. Scheffer, E. Jeppesen, Regime shifts in shallow lakes. *Ecosystems* **10**, 1 (2007).
11. Y. Tong *et al.*, *Nat. Geosci.* **10**, 507 (2017).
12. M. T. O'Hare*et al.*, *Front. Plant Sci.* **9**, 451 (2018).
13. A. Nebra *et al.*, *Scientia Marina* **75**, 577 (2011).
14. T. Maavara*et al.*, *Proc. Natl. Acad. Sci.* **112**, 15603 (2015).
15. Z. Yan *et al.*, *Ecol. Lett.* **19**, 1237 (2016).

Figure 1. **Reoligotrophication and abrupt shifts in physicochemical and biological traits of rivers and estuaries.** Conceptual model of the ecosystem changes occurred in the lower Ebre River during the last decades due to reoligotrophication and other factors of global change.

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