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Trends of Eutrophication in the Loire River (France)

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Minaudo C., Meybeck M., Moatar F., Gassama N., & Curie F. (2015). Eutrophication mitigation in rivers: 30 years of trends in spatial and seasonal patterns of biogeochemistry of the Loire River (1980–2012). Biogeosciences, 12(8), 2549–2563.

Context

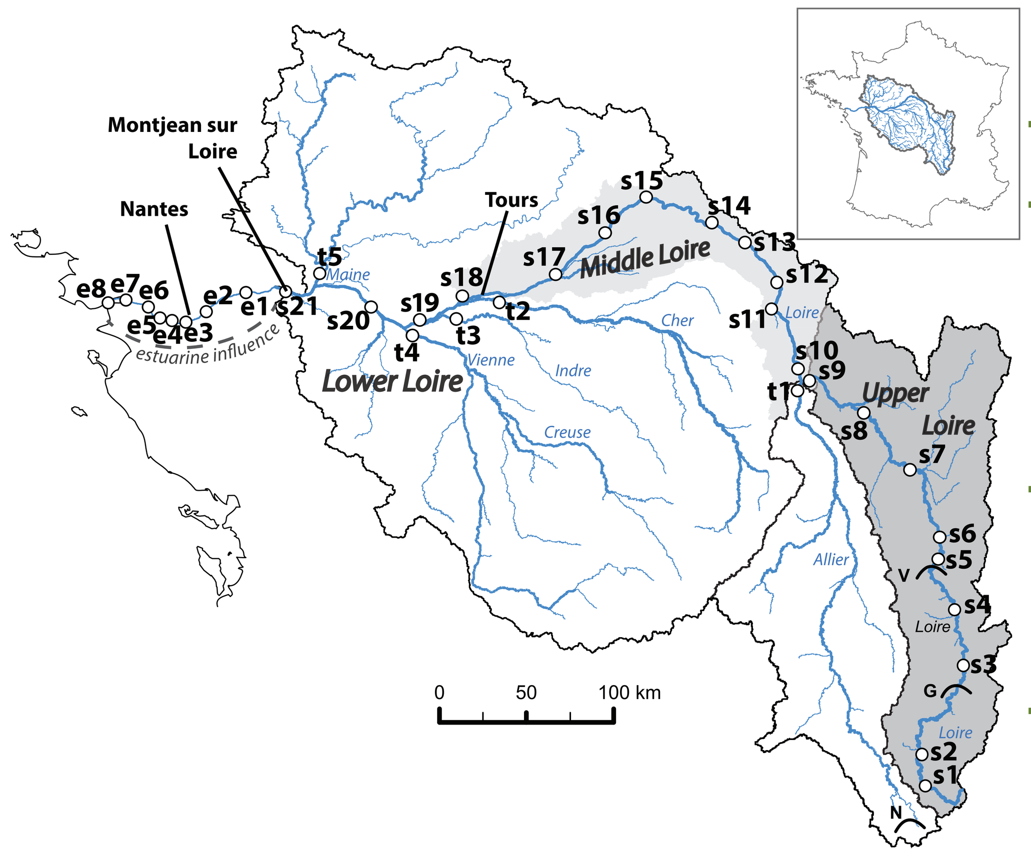

Figure 1. Loire Basin presentation and stations locations. Stations 1 to 21: freshwater, Loire River; stations t1 to t5: main tributaries outlets; stations e1 to e8: estuarine zone, Loire River. Reservoirs Villerest (V), Grangent (G) and Naussac (N)

Previous studies

- Hypoxia in the estuary [1, 2]
- Middle Loire = most eutrophic sector
  During the 1980s, Chl. a ≈ 250 µg L^{-1} in summer [3, 4, 5, 6]
- Hyper-eutrophication in Grangent (G) and Villerest (V) reservoirs (Fig. 1) [7, 8]
- Phytoplankton decrease since 1990 [9, 10]
- With climate change, lower low flows, increased water temperature [11]

Question

Eutrophication evolution in the Loire River and its tributaries since the extreme conditions (1980s) and the EU Directives enforcements (1990s)?

Basin features

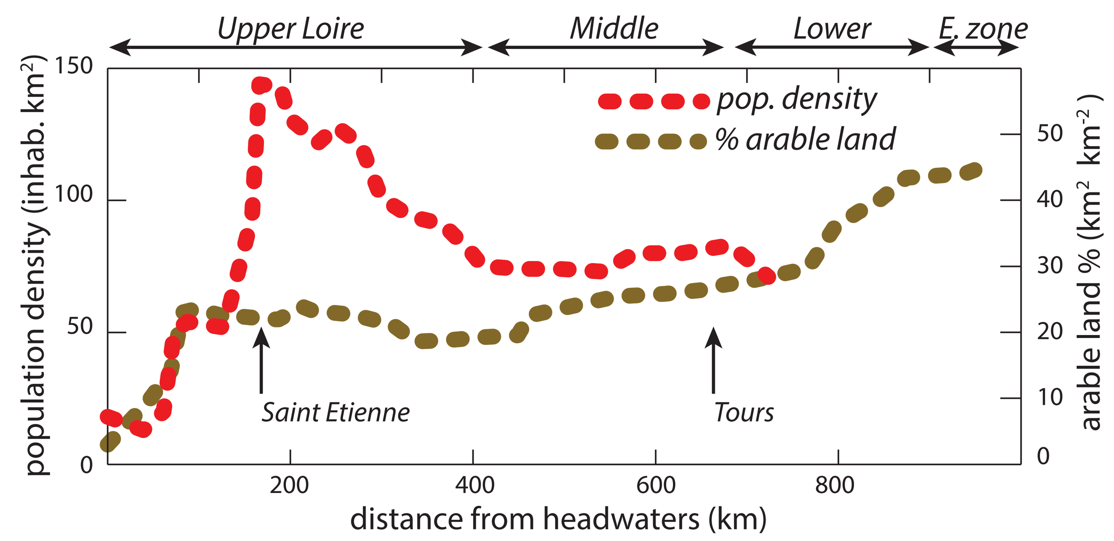

Figure 2. Population density and arable land percentage profiles along the Loire

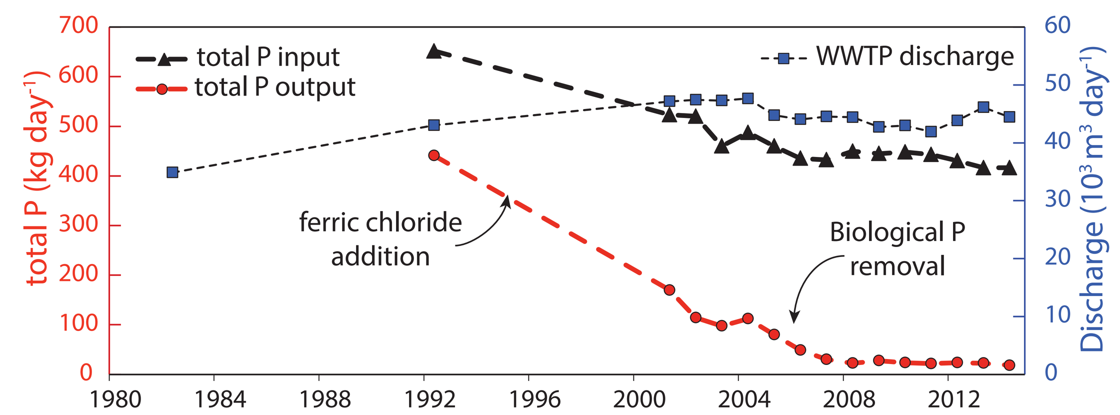

Figure 3. Input and output phosphorus load evolution at Tours city waste water treatmant plant (400 000 inhabitants equivalent)

At Basin outlet:

- 110 000 km^2
- 1000 km long (Fig. 1)
- 8 million inhab. concentrated along the Loire River 45% arable land (Fig. 2)

- Average annual discharge ≈ 860 $m^3\ s^{-1}$
- During low flows (≈ 100 $m^3\ s^{-1}$, water depth ≈ 1m) ≈ 10 days to travel Middle and Lower reaches

Anthopogenic N and P inputs evolutions:

- P point sources reduction since 1991 (Fig. 3)
- N surplus reduction since 1991 [1]

Datasets

Loire Basin reglementary surveys (Agence de l'Eau Loire-Bretagne)

	stations on Fig. 1	period	sampling frequency	parameters
Upper Loire	s1 to s9	1980-2012	monthly	total pigments (chl. a + pheopigments), NO_3^-, PO_4^{3-}
Middle Loire	s10 to s18			total pigments, NO_3^-, PO_4^{3-}, Ntot, Ptot
Lower Loire	s19 to s21			total pigments, NO_3^-, PO_4^{3-}
Main tributaries	t1 to t5	1980-2012	monthly	total pigments, NO_3^-, PO_4^{3-}
Estuary	e1 to e8	1990-2012	monthly	O_2

Phytoplankton and nutrients trends

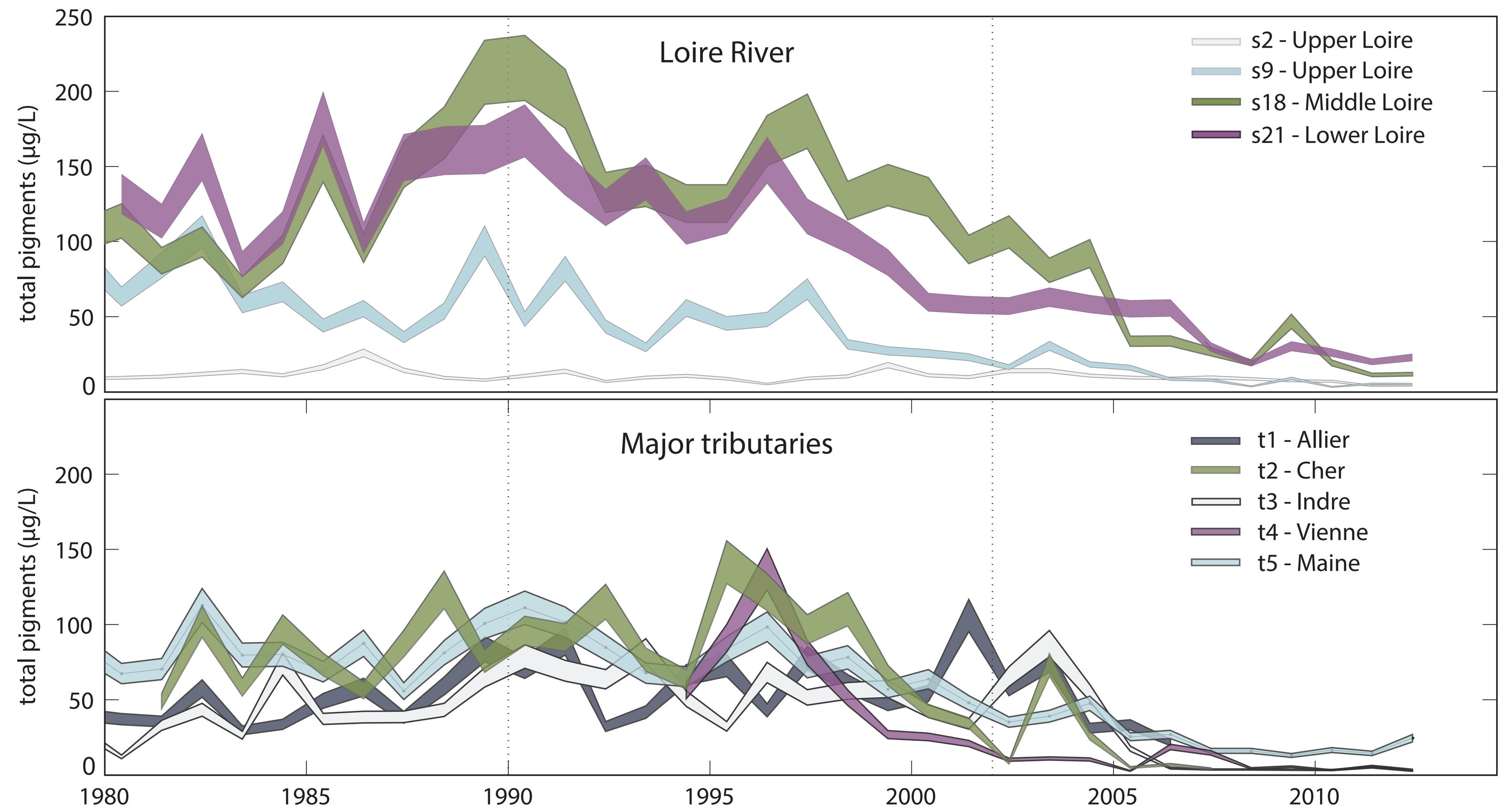

Figure 4. Evolultion of summer phytoplankton averages in the Loire and the major tributaries outlets since 1980

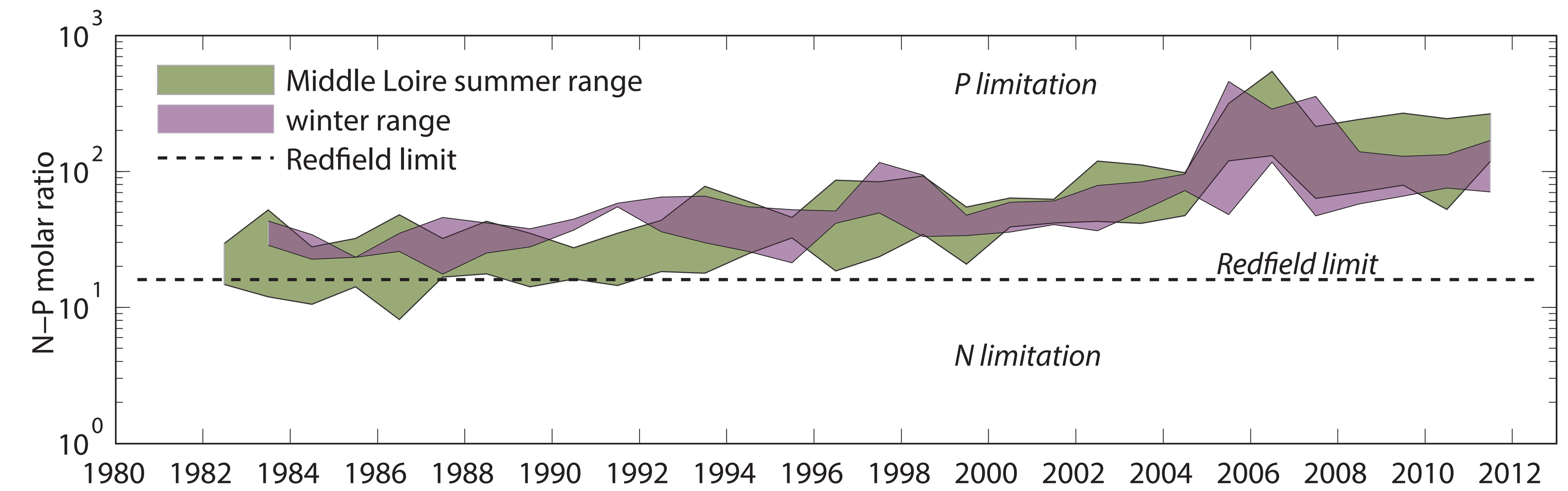

Figure 5. Evolution of Ntot:Ptot molar ratios ranges during summer and winter in the Middle Loire compared to the Redfield limit (dotted line). The y-axis is logarithmic

Spatiotemporal evolutions

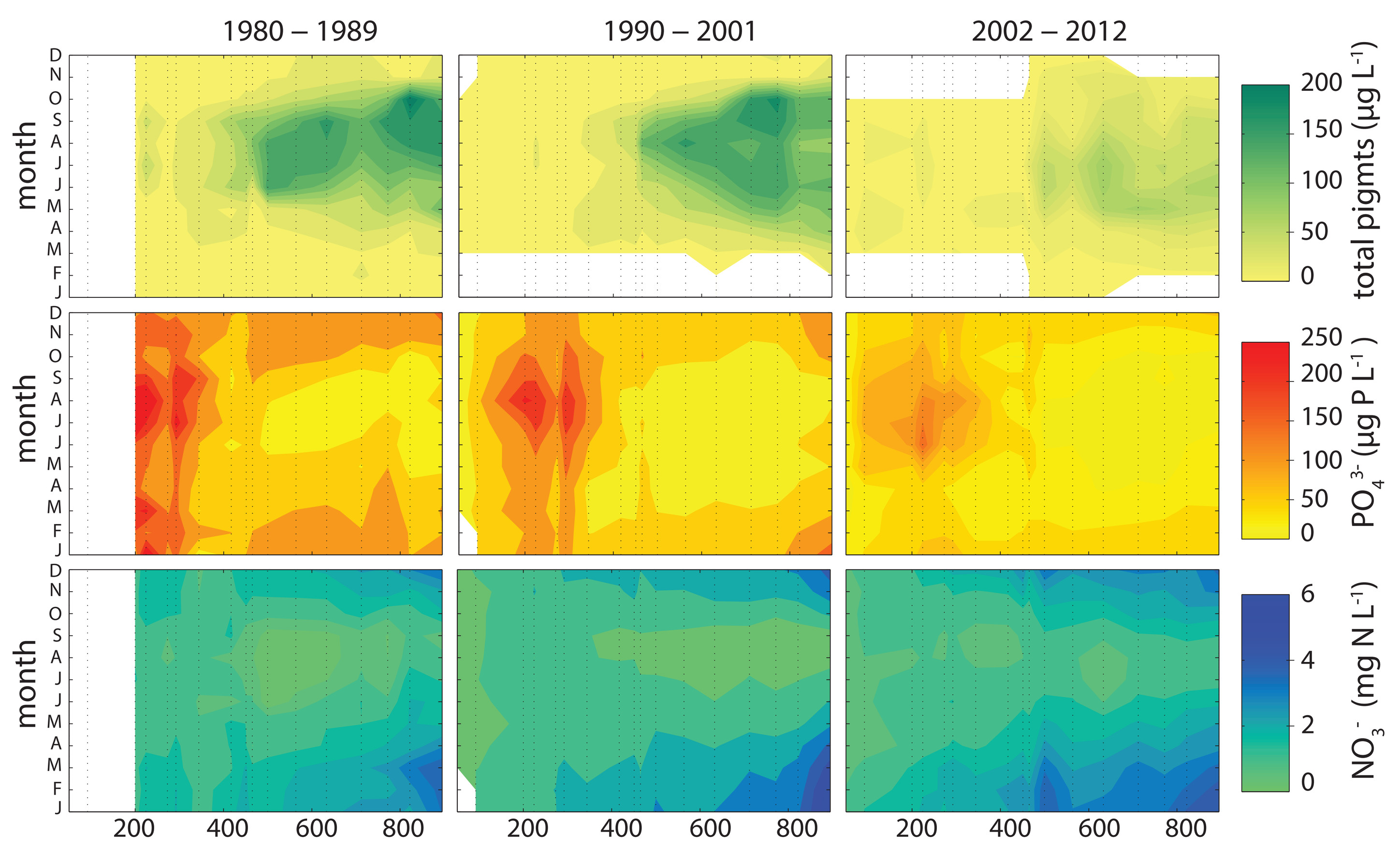

Figure 6. Spatiotemporal diagrams of monthly median levels of total pigments, PO_4^{3-} and NO_3^- during three periods along a longitudinal profile

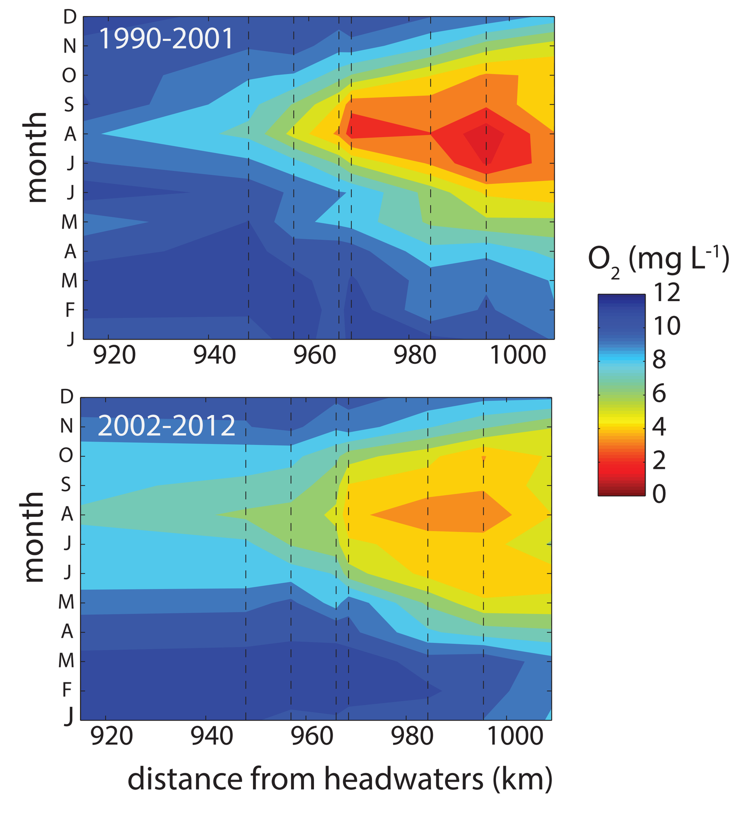

Figure 7. Spatiotemporal diagrams of monthly median levels of dissolved oxigen in the estuarine zone of the Loire River

Results and Discussion

- Summer phytoplankton biomass was divided 4-fold in Middle and Lower Loire and in major tributaries since 1990 (Fig. 4)
- PO_4^{3-} decreased 3-fold since 1990 (Fig. 5 & 6)
- Late summer blooms no longer occur

→ Phosphorus point sources reduction (WWTP improvements, P use regulations) decreased phytoplankton development and signs of eutrophication
The system is largely P-limited

- Inverted PO_4^{3-} seasonality between Upper and lower Loire reaches

→ Urban impact upstream
Phytoplankton P-uptake downstream

- 10% increase of NO_3^- since 1980
- Clear NO_3^- seasonality unchanged over time

→ No effect yet of the Nitrate Directive (1991) on the Loire River nitrate concentration
Minor influence of phytoplankton on N seasonal variations

- Higher O_2 concentration in summer within the estuarine zone (Fig. 7)

→ Less organic matter degradation within the estuarine zone => water quality improvement

Conclusions and perspectives

- Eutrophication mitigation started in the early 1990s as a response to the reduction of phosphorus inputs => when hydrologic conditions remain favorable for phytoplankton growth , P is the limiting factor
- Eutrophication trajectories in the main tributaries were similar to the evolution observed in the Middle and Lower Loire.
- Other recent changes should be considered: e.g. what is the impact of *Corbicula* clams spp. invasion which started during the 1990s [13] on the observed phytoplankton decrease (Fig. 8)?

Figure 8. *Corbicula* clams. www.fisheriesireland.ie Caffrey J., Millane M.

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