Evaluating the ecological status of large rivers in the context of the WFD: the new phytoplankton index for French large rivers

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Evaluating the ecological status of large rivers in the context of the WFD: the new phytoplankton index for French large rivers

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Context – the WFD

Since 2000, the Water Framework Directive (WFD - *2000/60/EC*) :

► **Main objective:** all waterbodies in at least a **GOOD** ecological status

► The **WFD** quickened the development or revision of biological indices to assess the ecological status of European waterbodies *(Hering et al., 2006; Logez et al., 2019)*

eg. in France: IPLAC(Laplace-Treyture & Feret, 2016) , I_2M_2 (Mondy et al., 2012), IBMR (Haury et al., 2006)

► For **large rivers**, development of the « missing » indices is ongoing

ie. fish- and phytoplankton-based indices for large rivers

Objective

INRAE
UR/1454
ÉCOSYSTÈMES AQUATIQUES
& CHANGEMENTS GLOBAUX [EABX]

+ Cerema
CLIMAT & TERRITOIRES DE DEMAIN

+ OFB
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DIPCEAU Project

= partnership between INRAE, Cerema and the French Office for Biodiversity

Goal: To develop a WFD-compliant index based on phytoplankton

To be compliant, the index should

- include relevant parameters :
  taxonomic composition, abundance
  frequency and intensity of blooms

- exhibit a good relationship with gradient of anthropogenic pressures

Context – Phytoplankton

= microscopic algae suspended in the water column

► A diverse syntaxonomic group

► Primary producers = lowest level of trophic networks

► Short generation time

► May be the source of problems, such as high turbidity and blooms

Therefore, phytoplankton communities exhibit a **potential** to be a powerful tool for **bioindication** of **anthropogenic pressures**.

European methods – common metrics

The two most common metrics included in European methods (Mischke *et al.,* 2016):

(1) a **biomass metric**, based on concentrations of **chlorophyll-a**

$$MET_{chlo\text{-}a} = a \times \ln([chlo\text{-}a]) + b$$

ou

$$MET_{chlo\text{-}a} = a \times [chlo\text{-}a] + b$$

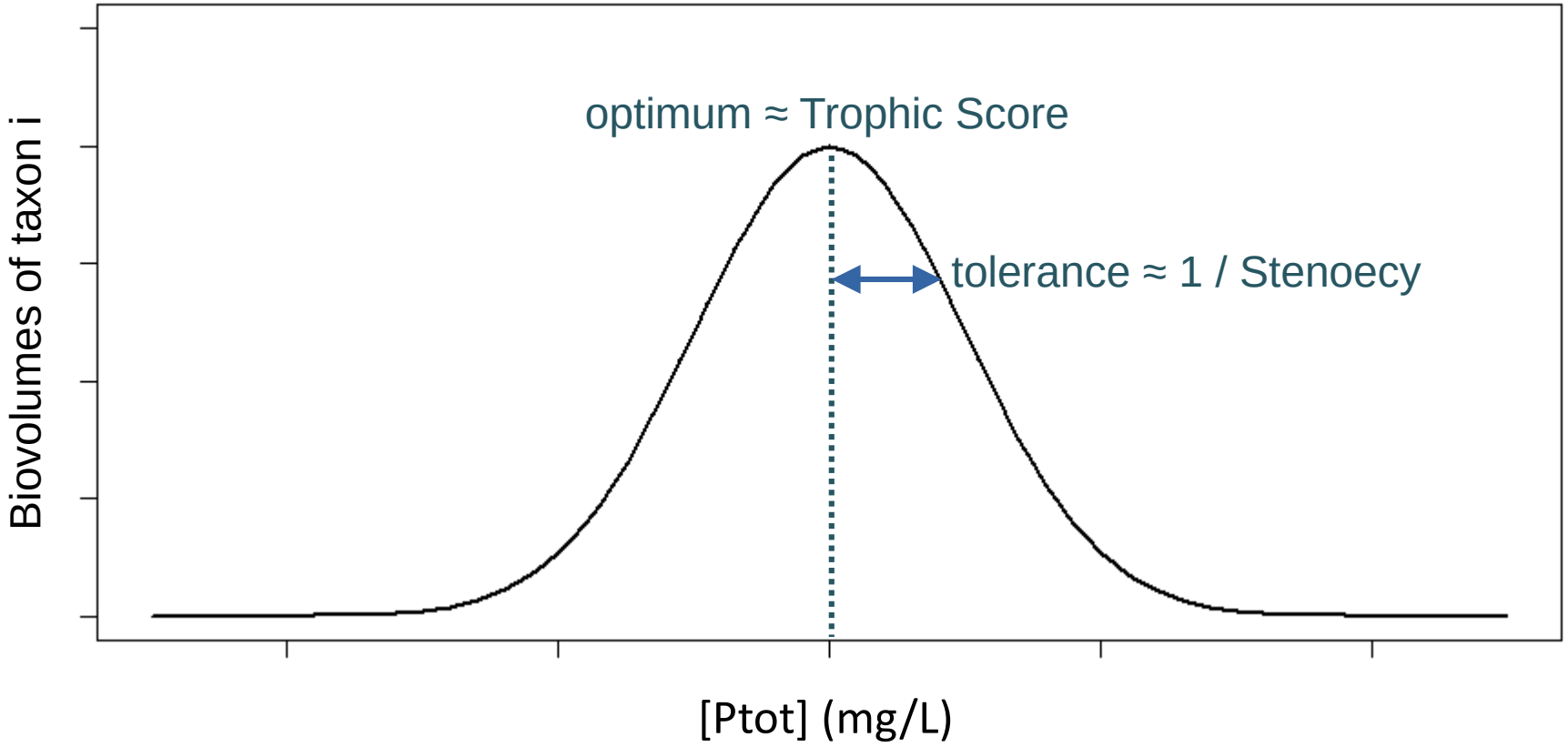
(2) a **trophic metric (TM)**, based on the formula from Zelinka & Marvan (1961)

$$TM = \Sigma i\ (TSi \times SCi \times Ai) / \Sigma\ (SCi \times Ai)$$

With TSi, the trophic score of taxon i
Si, the stenoecy coefficient of du taxon i
Ai, the abundance of taxon i

European methods – common metrics

The **trophic scores (TS)** and **stenoecy coefficients (SC)** are derived from the distribution of abundances (or biovolumes) against concentrations of **total phosphorus** [Ptot] (ter Braak & van Dam 1989):



Development dataset

Large rivers

= natural and heavily-modified large rivers with Strahler rank > 5

eg. the Loire river, the Saône river, the Dordogne river, the Seine river

Two datasets

- Floristic dataset (2010-2019)
  Phytoplankton samples (at least 4 per year; during the april-october period)
  N = 6055 Site Sampling Events
  N = 1017 « Site x Year »

- Pressure dataset
  - Physico-chemistry (nutrients and micropollutant concentrations)
  - Urbanization, anthropization, river straightening, dams, etc…

Development dataset

Metrics

- **Biomass** metrics
  based on seasonal mean and max. of [chlorophyll-a] and total biovolume

- **Trophic** metrics
  based on Zelinka & Marvan's formula
  varying methods used to define/calculate the trophic scores

- **Structural** metrics
  based on the structure of the phytoplankton communities = abundance & composition
  eg. Taxonomic richness (total or per taxonomic group of interest), diversity indices, ...

- **Functional** metrics
  based on the available and described bioecological traits (Laplace-Treyture et al. 2021)
  Community Weighted Means, niche overlap, specialization, diversity, ...

Development dataset

Metrics

- Metric values were expressed as Ecological Quality Ratio (EQR) :

$$MET_{EQR} = (MET_{OBS} - worst) / (best - worst)$$

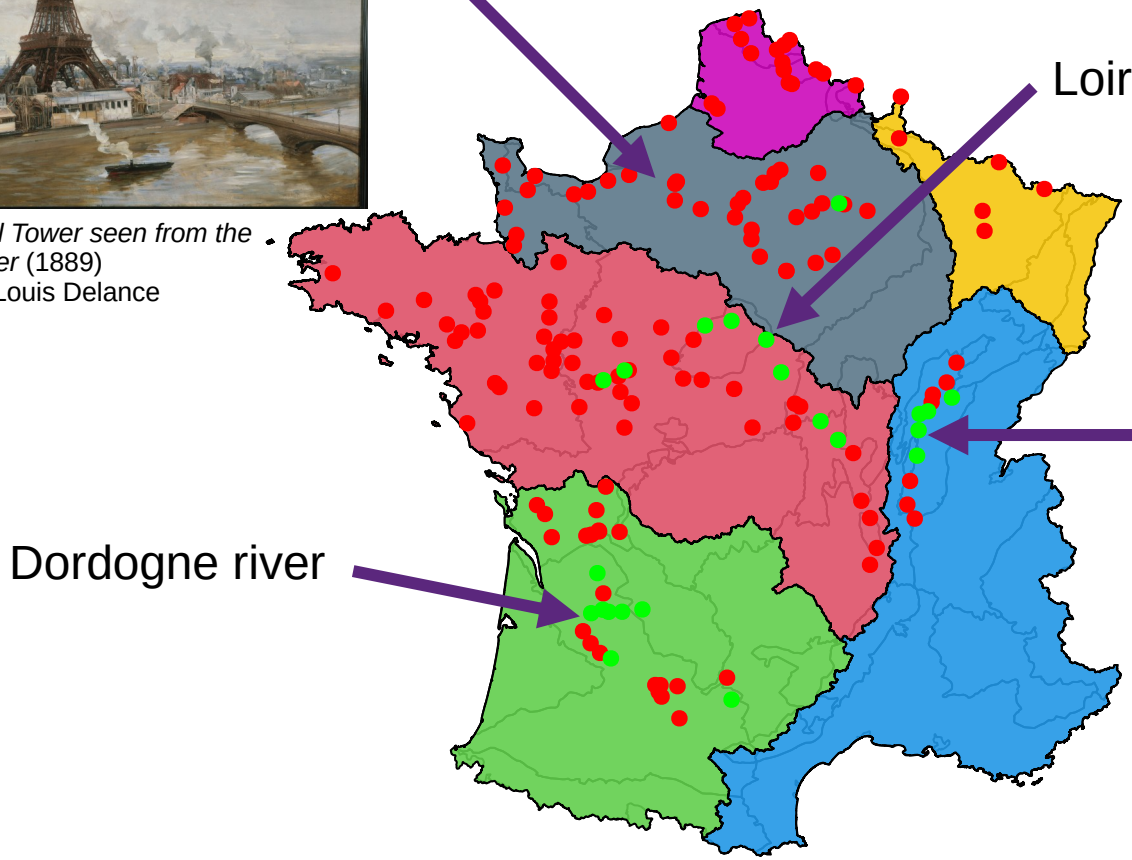
- **best** values were defined based on the « reference » values observed in **Least Impaired River Reaches** (**LIRR**)

- **LIRR** = « site x year » with *low level* of trophic anthropogenic pressures based on 4 pressure categories =
  Nitrates, Nitrogen compounds, Phosphorus compounds and Organic matter
  low level of pressure = 3 **High** and 1 **Good** chemical status among the 4 categories

Least Impaired River Reaches

158 sites, including **22** with at least one year as a **LIRR**.

The Eiffel Tower seen from the Seine river (1889)
By Paul-Louis Delance



- **Least Impaired River Reaches**
- **Impaired River Reaches**

Delinations indicate administrative watersheds

Metrics performances

► Linear regressions with the main parameters:

- total phosphorus **(TP)**, PO_4^{3-}, NKJ, NH_4^+, NO_3^-, NO_2^-, Cl^-

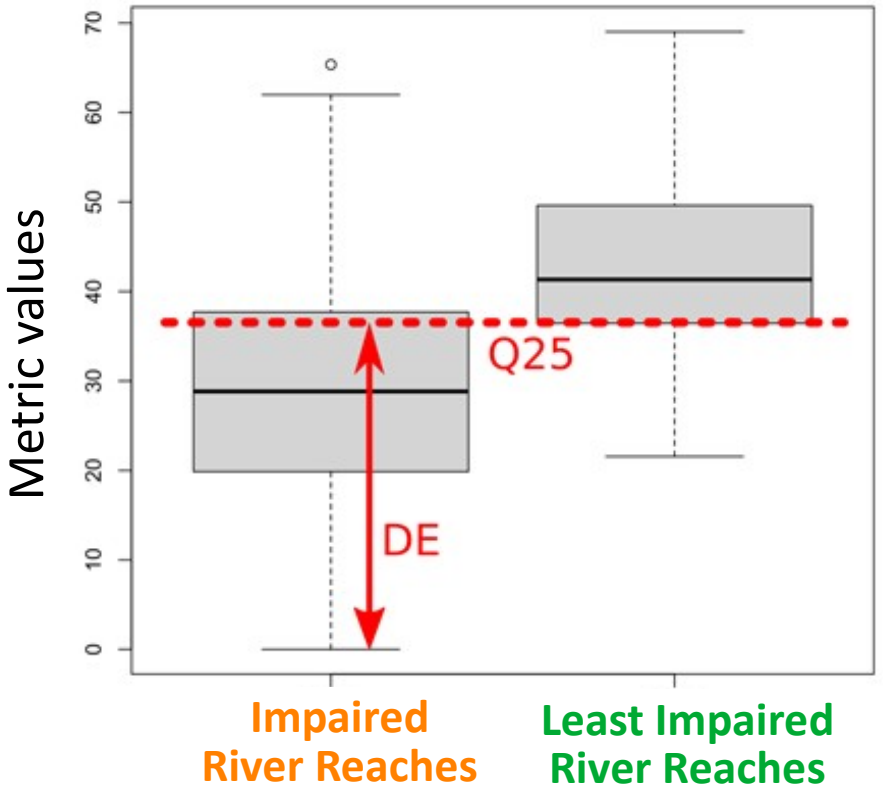
► Discrimination Efficiency (DE) [0;1]:

- higher is better

- between **LIRR** and **Impaired River Reaches**

- globally, or per pressure category
Nitrates, Nitrogen compounds,
Organic matter, Phosphorus Compounds

- for **blooms** (described in 422 « site x year »)
if at least one bloom/year = **IRR_{bloom}**
else, **$LIRR_{bloom}$**



Results – structural and functional metrics

Performance of **structural** metrics

Metrics	R^2 (TP)	DE.avg
Euglenophyceae.BVrel	0,1422	0,7323
Trebouxiophyceae.Stot	0,1132	0,6943

Performance of **functional** metrics

Metric	R^2 (TP)	DE.avg
CWM_protub.typ_Granule	0,1070	0,5837

Desmodesmus magnus (Chlorophyceae),
Ochromonas sp. (Chrysophyceae)

► **Structural** and **functional** metrics (linked to traits) exhibit **low performances** related to highlighting trophic pressures.

TP = total phosphorus
DE.avg = average of the DE values

Results – biomass metrics

Performance of **biomass** metrics

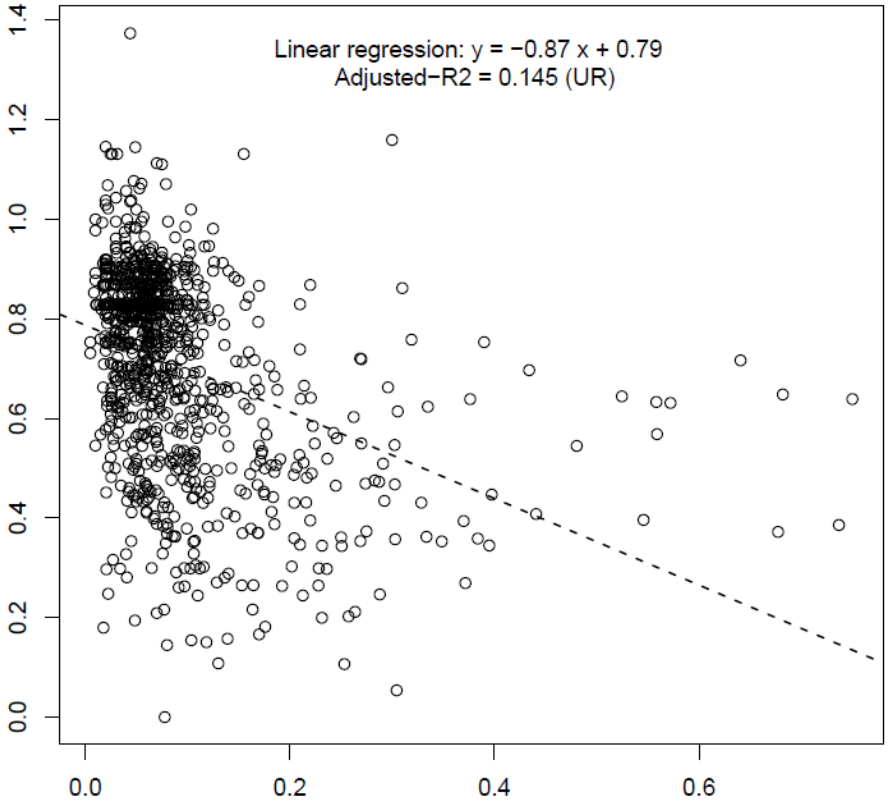
Metrics	R^2 (TP)	DE.avg
Chlo-a	0,0884	0,7250
Total biovolume (BVtot)	0,0026	0,6979
MBA.Chlo-a	0,1292	0,7250
MBA.Chlo-a.&.Chlo-a.max	0,1445	0,7985
MBA.BVtot	0,0861	0,6979
MBA.BVtot.&.BVtot.max	0,0963	0,7071

► Performances of **biomass-based** metrics are also **somewhat limited**

TP = total phosphorus
DEavg = average of the DE values

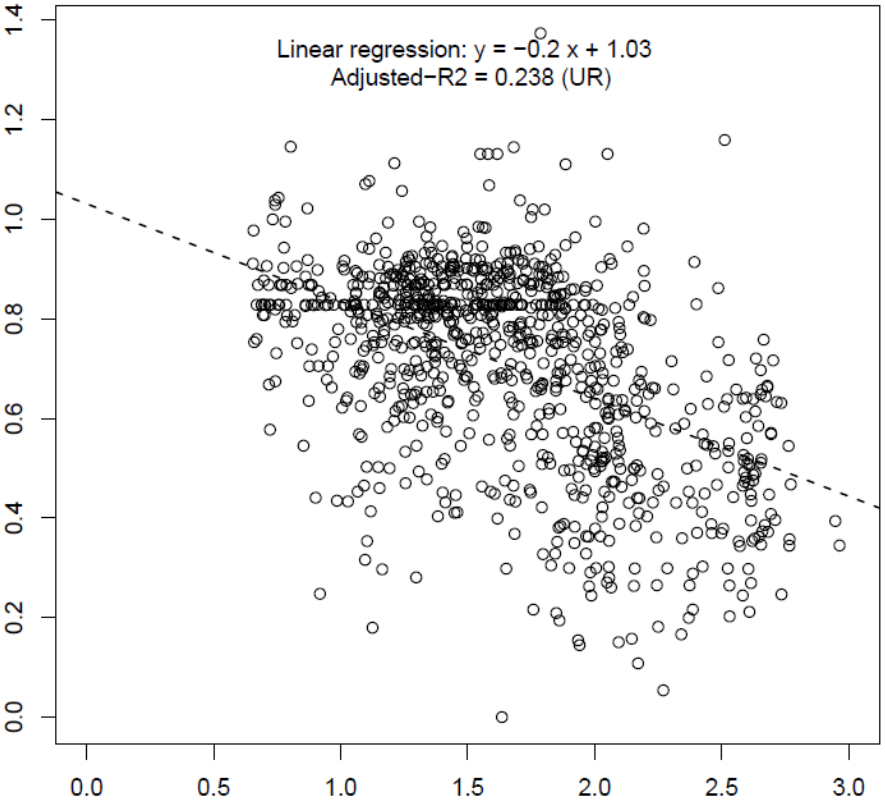
Results – biomass metrics

Distribution of the EQR values of the best biomass metric (MBA.Chlo-a.&.Chlo-a.max) against total phosphorus concentrations and against a combined stressor index.



Total Phosphorus (mg/L)

MBA.Chlo-a.&.Chlo-a.max (EQR)



Combined Stressor Index
(based on [TP], [TN] and [chlorides])

Higher values indicate higher stress

Results – trophic metrics

Performance of **trophic** metrics

Determination level	Method used for calculations of Trophic Scores		R^2 (TP)	DE.avg
Species	Weighted mean		0,3055	0,8815
Species	WA-PLS		0,4001	0,9009
Genera	Weighted mean		0,2960	0,8593
Genera	WA-PLS		0,4735	0,8974

TP = total phosphorus
DE.avg = average of the DE values

Results – trophic metrics

Performance of **trophic** metrics

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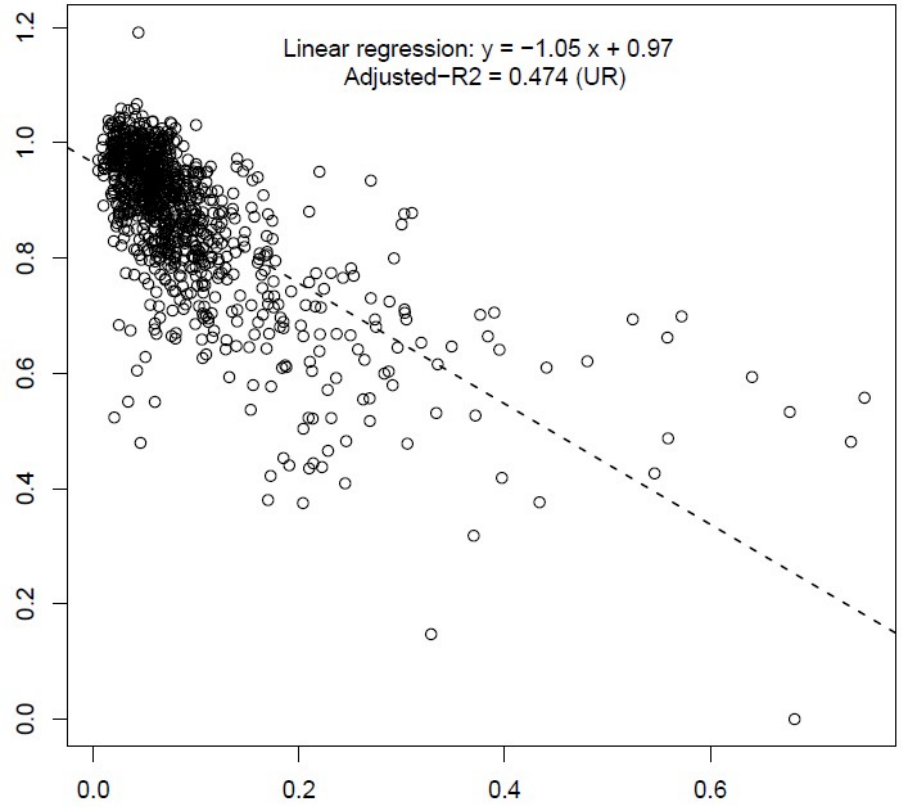
► The WA-PLS method (Weighted Average – Partial Least Square) is a very potent method to calculate trophic scores, whatever the determination level (species or genera) (ter Braak & Juggins 1993, Liu et al 2020)

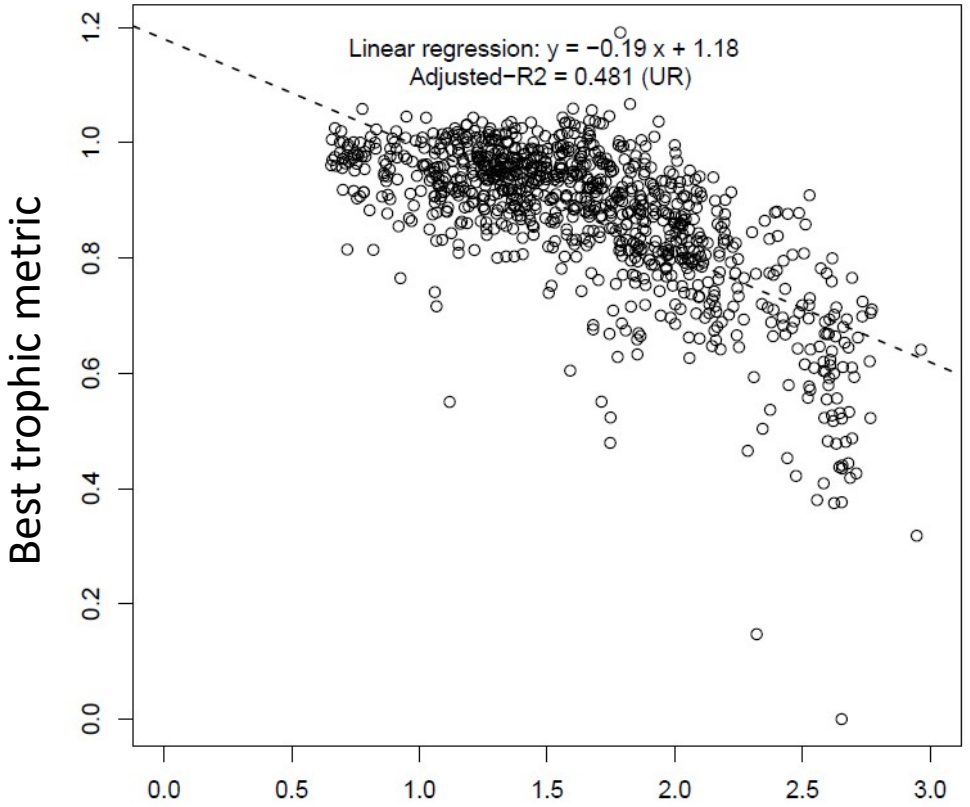
TP = total phosphorus
DE.avg = average of the DE values

Results – trophic metrics

Distribution of the EQR values of the best trophic metric (using the WA-PLS method, at the genus level) against total phosphorus concentrations and against a combined stressor index



Total Phosphorus (mg/L)



Combined Stressor Index
(based on [TP], [TN] and [chlorides])

Higher values indicate higher stress

Results – candidate indices (CI)

Multi-metric index = weighted mean of EQR values of the selected metrics

→ Selected metrics = 1 biomass metric + 2 trophic metrics
→ Maximization of R^2 (total phosphorus)
→ Pairs of metrics (ie. three pairs)
→ All three metrics

Weights (%) of the metrics found in each candidate index (CI)

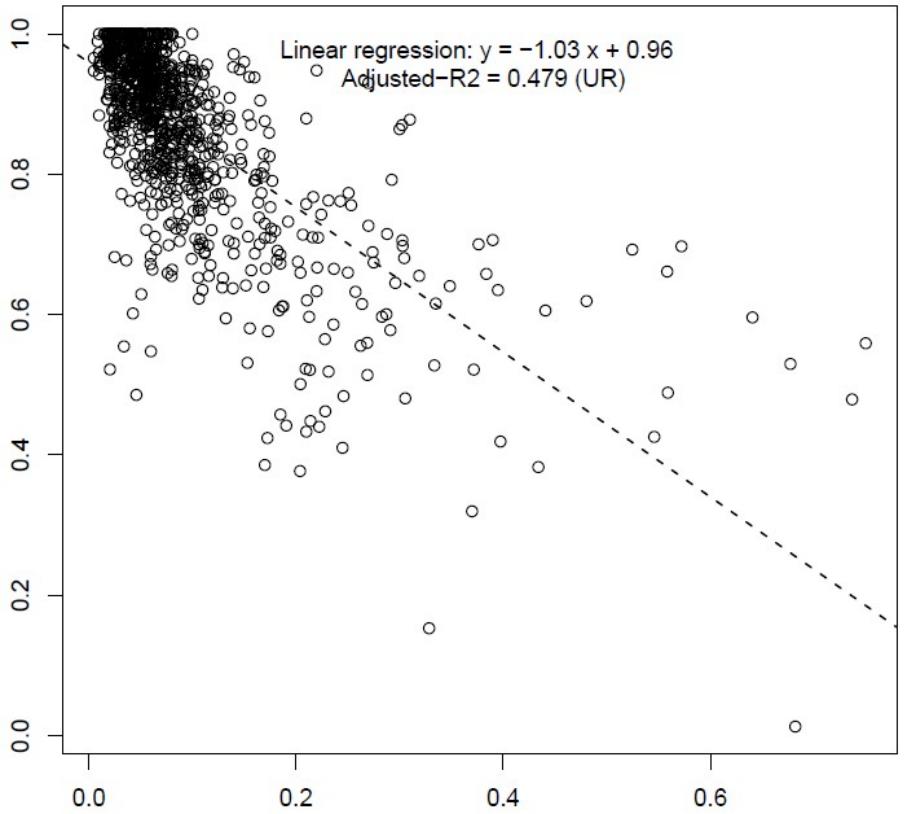
Biomass metric

Trophic metric

	Metrics		
	BM	**TM1-sp**	**TM2-gn**
CI1	2,0	-	98,0
CI2	12,0	88,0	-
CI3	-	16,0	84,0
CI4	1,7	15,5	82,8

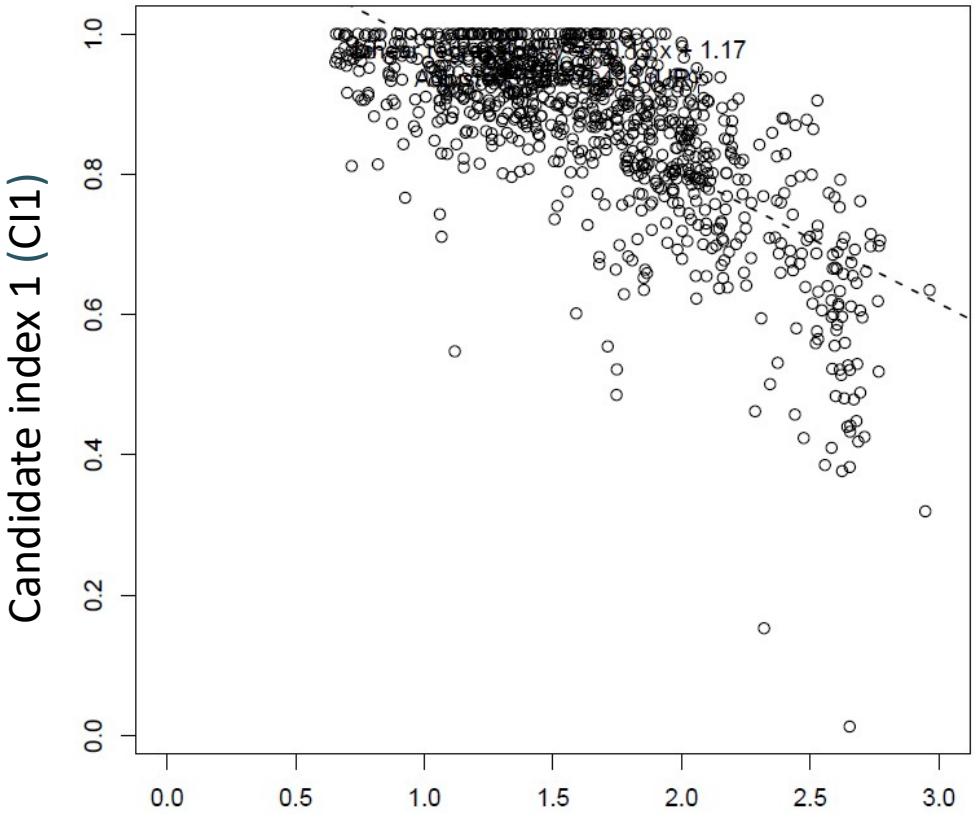
Results – candidate index

Distribution of the EQR values of the **candidate index 1 (CI1)** against total phosphorus concentrations and against a combined stressor index.



Total Phosphorus (mg/L)

$R^2 = 0{,}493$



Combined Stressor Index
(based on [TP], [TN] and [chlorides])

Higher values indicate higher stress

Conclusion

Metrics

> Structural and functional metrics did not exhibit good performances
> Same for biomass metric, but « has to » be included (WFD)
> Trophic metrics did exhibit good correlations with [total phosphorus]

Candidate indices are skewed with high weights for trophic metrics, due to the low performances of the biomass metric

To be tested:

- other trophic metrics based on nitrogen compounds and/or nitrates
- performances of (future) candidate indices on an independant dataset

Development is still ongoing

References

¤ **Haury**, J., Peltre, M.-C., Trémolières, M., Barbe, J., Thiébaut, G., Bernez, I., Daniel, H., Chatenet, P., Haan-Archipof, G., Muller, S., Dutartre, A., Laplace-Treyture, C., Cazaubon, A., & Lambert-Servien, E. (2006). A new method to assess water trophy and organic pollution — the Macrophyte Biological Index for Rivers (IBMR) : Its application to different types of river and pollution. In J. M. Caffrey, A. Dutartre, J. Haury, K. J. Murphy, & P. M. Wade (Éds.), Macrophytes in Aquatic Ecosystems : From Biology to Management (Vol. 190, p. 153-158). Springer Netherlands. https://doi.org/10.1007/978-1-4020-5390-0_22

¤ **Hering**, D., Feld, C. K., Moog, O., & Ofenböck, T. (2006). Cook book for the development of a Multimetric Index for biological condition of aquatic ecosystems : Experiences from the European AQEM and STAR projects and related initiatives. In M. T. Furse, D. Hering, K. Brabec, A. Buffagni, L. Sandin, & P. F. M. Verdonschot (Éds.), The Ecological Status of European Rivers : Evaluation and Intercalibration of Assessment Methods (p. 311-324). Springer Netherlands. https://doi.org/10.1007/978-1-4020-5493-8_22

¤ **Laplace-Treyture**, C., & Feret, T. (2016). Performance of the Phytoplankton Index for Lakes (IPLAC) : A multimetric phytoplankton index to assess the ecological status of water bodies in France. Ecological Indicators, 69, 686-698. https://doi.org/10.1016/j.ecolind.2016.05.025

¤ **Liu**, M., Prentice, I. C., ter Braak, C. J. F., & Harrison, S. P. (2020). An improved statistical approach for reconstructing past climates from biotic assemblages. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 476(2243), 20200346. https://doi.org/10.1098/rspa.2020.0346

¤ **Logez**, M., Maire, A., & Argillier, C. (2019). Monte-Carlo methods to assess the uncertainty related to the use of predictive multimetric indices. Ecological Indicators, 96, 52-58. https://doi.org/10.1016/j.ecolind.2018.08.051

¤ **Mischke**, U., Wolfram, G., VanWichelen, J., Hlúbiková, D., Belkinova, D., Opatrilova, L., Birk, S., Piirsoo, K., Stanković, I., Varbiro, G., Borics, G., Jekabsone, J., Stankeviciene, J., Virbickas, T., Picińska-Fałtynowicz, J., Panek, P., Rotaru, N., Garbea, R., & Placha, M. (2016). XGIG Large River Intercalibration Exercise – Milestone 6 Report Intercalibrating the national classifications of ecological status for very large rivers in Europe Biological Quality Element : Phytoplankton 2. Version – November 2016 (p. 157).

¤ **Mondy**, C. P., Villeneuve, B., Archaimbault, V., & Usseglio-Polatera, P. (2012). A new macroinvertebrate-based multimetric index (I2M2) to evaluate ecological quality of French wadeable streams fulfilling the WFD demands : A taxonomical and trait approach. Ecological Indicators, 18, 452-467. https://doi.org/10.1016/j.ecolind.2011.12.013

¤ **ter Braak**, C. J. F., & Juggins, S. (1993). Weighted averaging partial least squares regression (WA-PLS) : An improved method for reconstructing environmental variables from species assemblages. In H. van Dam (Éd.), Twelfth International Diatom Symposium (p. 485-502). Springer Netherlands. https://doi.org/10.1007/978-94-017-3622-0_49

¤ **ter Braak**, C. J. F., & van Dame, H. (1989). Inferring pH from diatoms : A comparison of old and new calibration methods. Hydrobiologia, 178(3), 209-223. https://doi.org/10.1007/BF00006028

¤ **Zelinka**, M., & Marvan, P. (1961). Zur Präzisierung der biologischen Klassifikation der Reinheit fliessender Gewässer. Arch. Hydrobiol., 57, 389-407.