Freshwater eutrophication

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2. Currently recommended method
3. Proposed method by LC-IMPACT
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1. Introduction to eutrophication

- Increase of nutrients leading to excessive primary productivity and biodiversity losses
- The two most common nutrients driving aquatic eutrophication are nitrogen (N) and phosphorus (P)
- In special cases, other nutrients may also trigger eutrophication, such as iron (especially in oceans) and silicon. Keep in mind that increases in atmospheric carbon levels triggers eutrophication in terrestrial systems!

1. Introduction to eutrophication

- **In LCIA, we assume that freshwater eutrophication is caused by P. However, keep in mind that this has been questioned recently**

Ecology Letters, (2007) **10**: 1135–1142 doi: 10.1111/j.1461-0248.2007.01113.x

LETTER

Global analysis of nitrogen and phosphorus limitation of primary producers in freshwater, marine and terrestrial ecosystems

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Abstract

The cycles of the key nutrient elements nitrogen (N) and phosphorus (P) have been massively altered by anthropogenic activities. Thus, it is essential to understand how photosynthetic production across diverse ecosystems is, or is not, limited by N and P. Via a large-scale meta-analysis of experimental enrichments, we show that P limitation is equally strong across these major habitats and that N and P limitation are equivalent within both terrestrial and freshwater systems. Furthermore, simultaneous N and P enrichment produces strongly positive synergistic responses in all three environments. Thus, contrary to some prevailing paradigms, freshwater, marine and terrestrial ecosystems are surprisingly similar in terms of N and P limitation.

1. Introduction to aquatic eutrophication

Recommended reading to understand the main drivers of freshwater eutrophication

Issues in Ecology

Technical Report

Ecological Applications, 8(3), 1998, pp. 559–568

NONPOINT POLLUTION OF SURFACE WATERS WITH PHOSPHORUS AND NITROGEN

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1. Freshwater eutrophication in the context of LCIA

- **Sources of P to freshwater systems: sewage and agricultural (manure or synthetic) fertilizers.**
- **Keep in mind that natural biogeochemical processes may also cause eutrophication if they are affected by human activities, e.g. atmospheric deposition (in the case of N) and erosion**

1. Fate model

Transport of P from soil to water

Transport of P directly to water

Transport of P in the freshwater compartment

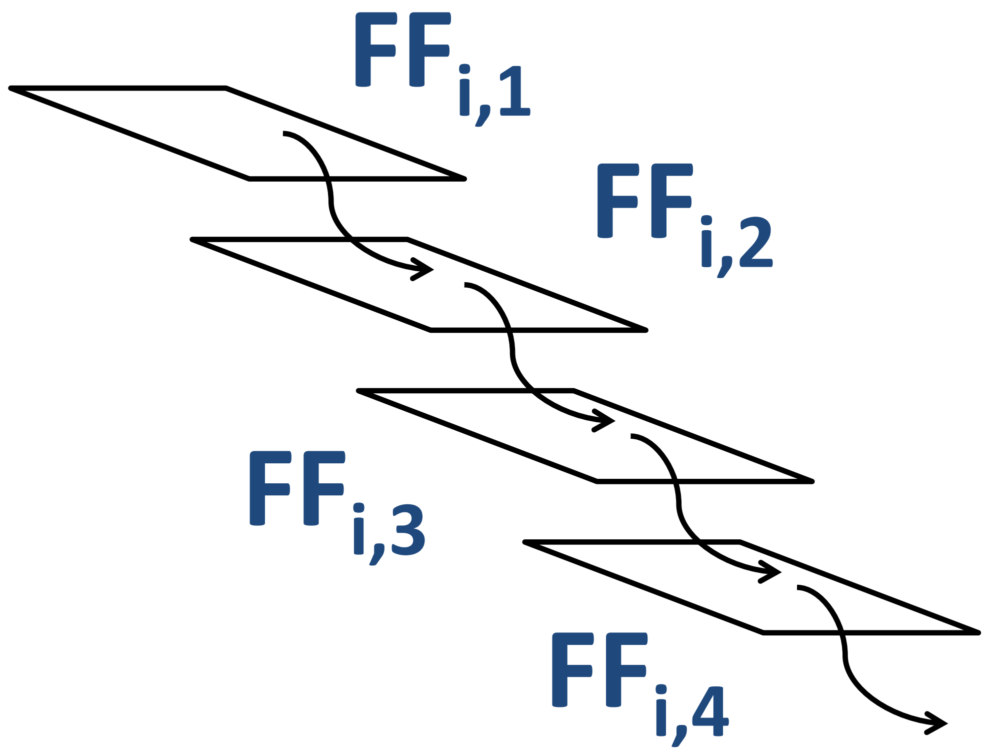
1. Fate (FF) of P from the grid where P was emitted to downstream grids

Driving mechanisms:

-Advection (k_{adv}) → determined by the rate of water flow

-Retention (k_{ret}) → determined by the rate of biological uptake and particle adsorption

-Water use (k_{use}) → determined by water withdrawn



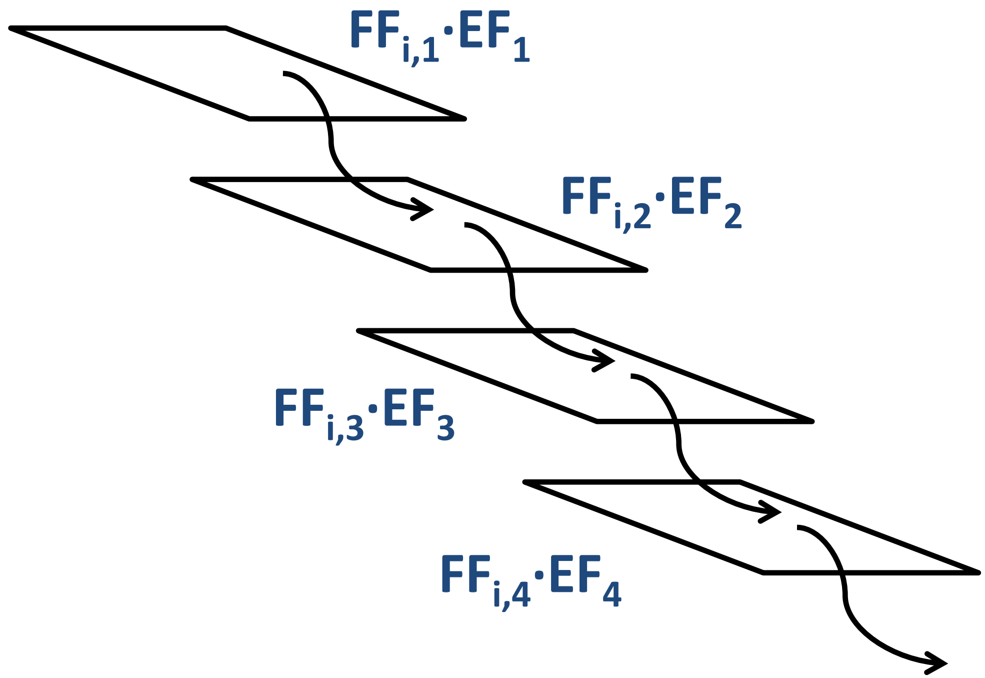
1. Effect (EF) occurs in every downstream grid from where the emission occurred

Driving mechanisms:

- Type of freshwater exposed to P increases: lakes or streams

- Type of species exposed to P increases: autotrophs or heterotrophs

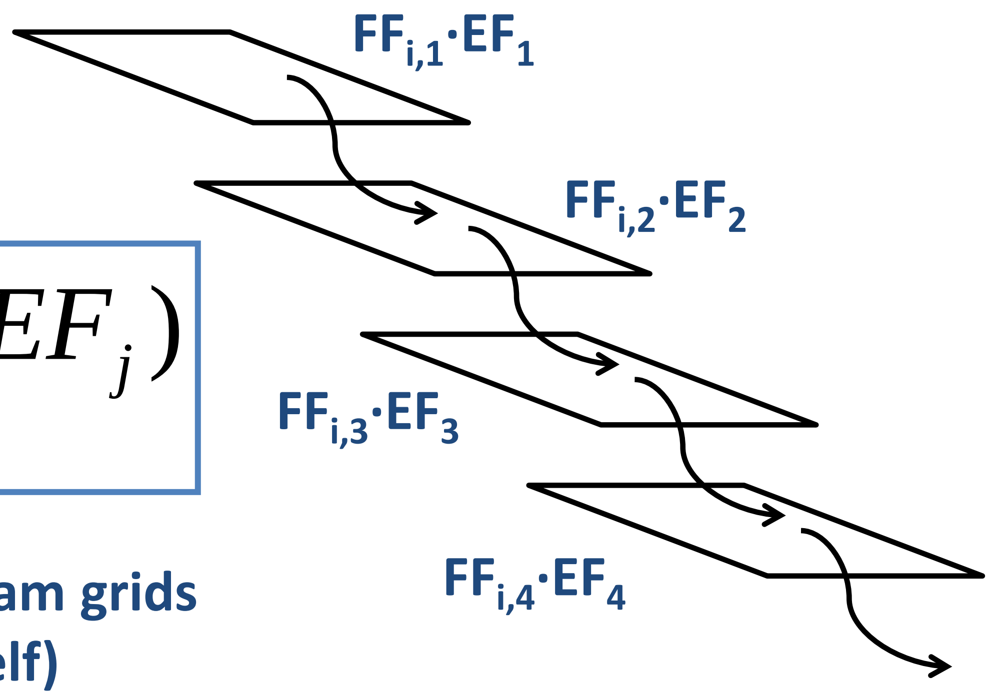
- Location of effect: temperate, cold, (sub)tropical, or xeric



In this example, j = 4 downstream grids (including the emitting grid itself)

1. Characterization model: is the summation of the impact across all downstream grids exposed to P increases caused by emitting grid upstream

$$CF_i = \sum_j \left(FF_{i \to j} \cdot EF_j \right)$$



In this example, j = 4 downstream grids (including the emitting grid itself)

2. Currently (interim): method OVERVIEW

- Coverage: Europe
- Resolution: 1/6°
- Fate model: based on CARMEN
- Effect model: based on stressor-response relationships

2. Currently recommended method

Recommended reading to understand the characterization model

Int J Life Cycle Assess (2011) 16:59–64
DOI 10.1007/s11367-010-0232-z

LCIA OF IMPACTS ON HUMAN HEALTH AND ECOSYSTEMS

Characterization factors for inland water eutrophication at the damage level in life cycle impact assessment

Jaap Struijs • Arthur Beusen • Dick de Zwart • Mark Huijbregts

2. Currently (interim) method

Recommended reading to understand the effect model

Integrated Environmental Assessment and Management — Volume 9999, Number 00—pp. 1–7

Field Sensitivity Distribution of Macroinvertebrates for Phosphorus in Inland Waters

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2. Currently (interim) method: FATE MODEL

$$FF_{k,i} = \frac{V_j \cdot \Delta C_j}{\Delta M_{k,i}}$$

$FF_{i,j}$: Fate factor of source k due to intervention k (unit: day)

V_j: Volume of river j (m^3)

ΔC_j: Change in concentration of P in river j ($kg \cdot m^{-3}$)

ΔM_i: Change in emission of P in source i ($kg \cdot day^{-1}$)

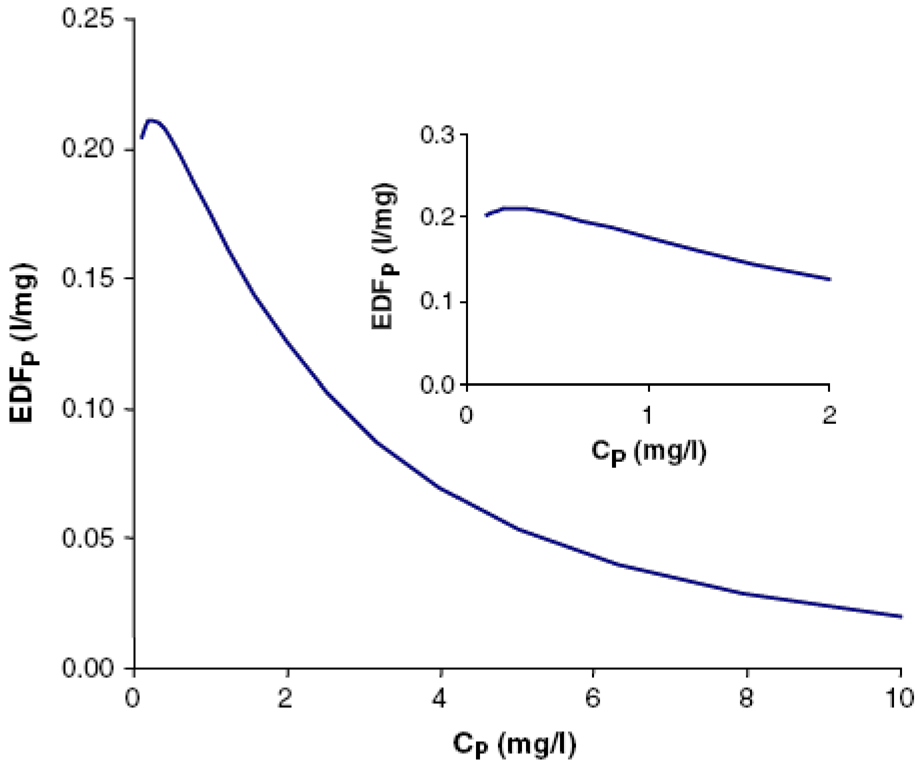
2. Currently (interim) method: EFFECT MODEL

$$EDF_j = \frac{\partial DF_j}{\partial C_j}$$

EDF_j: Effect factor in river j (unit: $m^3 \cdot kg^{-1}$)

DF_j: Damage factor in river j (no unit)

C_j: Concentration of P in river j ($kg \cdot m^{-3}$)



Source: Struijs et al., 2011 (Int. J. LCA)

3. Proposed method by LC-IMPACT

- Coverage: Global
- Resolution: 1/2°
- Fate model: based on Helmes et al., 2011 (Int. J. LCA)
- Effect model: based on stressor-response relationships

3. Proposed method by LC-IMPACT

Recommended reading to understand the fate model

Int J Life Cycle Assess
DOI 10.1007/s11367-012-0382-2

NON-TOXIC IMPACT CATEGORIES ASSOCIATED WITH EMISSIONS TO AIR, WATER, SOIL

Spatially explicit fate factors of phosphorous emissions to freshwater at the global scale

Roel J. K. Helmes · Mark A. J. Huijbregts ·
Andrew D. Henderson · Olivier Jolliet

3. Proposed method by LC-IMPACT

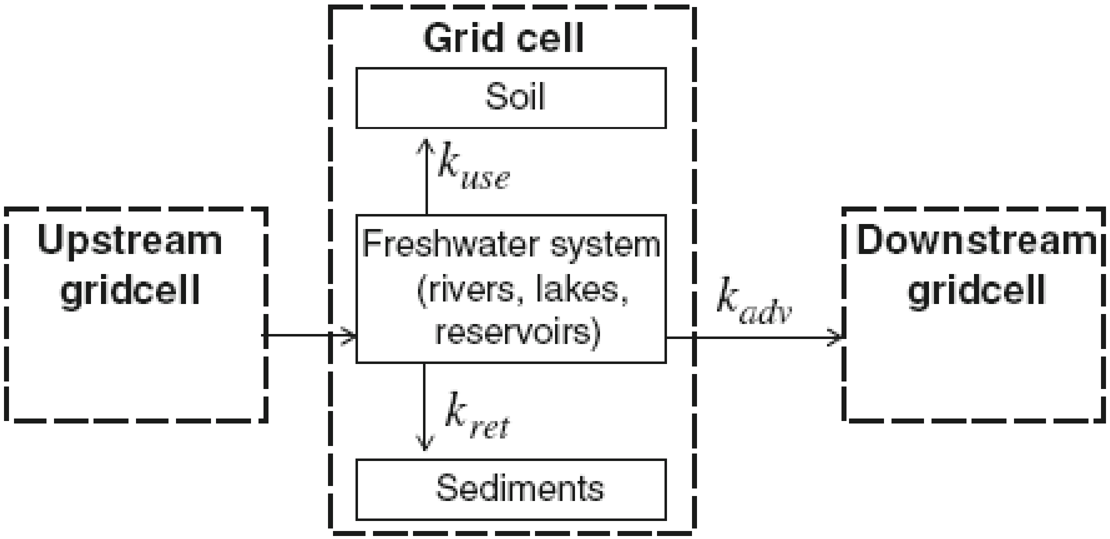
Recommended reading to understand the effect model

Azevedo et al., 2013 (Global Ecol. & Biogeogr., In press)

Azevedo et al. (unpublished)

3. Description of FATE MODEL

Transport of P through freshwaters can occur via retention **(k_{ret})**, advection **(k_{adv})**, or water use **(k_{use})**



Source: Helmes et al., 2011 (Int. J. LCA)

3. Description of FATE MODEL

$$FF_i = \sum_j FF_{i \to j} = \sum_j f_{i,j} \cdot \tau_j$$

CF_i: Characterization factor in emitting grid i (day)

$FF_{i \to j}$: Partial fate factor of emitting grid i in grid j (day)

τ_j: Persistence of P in grid j (no unit(

$F_{i,j}$: Fraction of P from i that reaches j

3. Description of EFFECT MODEL

$$LEF_j = \frac{\Delta PNOF_{j,s,w}}{\Delta C_{j,w}}$$

EF_j: Linear effect factor (kg·m^{-3})

$\Delta PNOF_{j,s,w}$: Change in PNOF* of species group s in freshwater w in receiving grid j

$\Delta C_{j,w}$: Change in P concentration in freshwater w in grid j

*** PNOF: Potentially not occurring fraction**

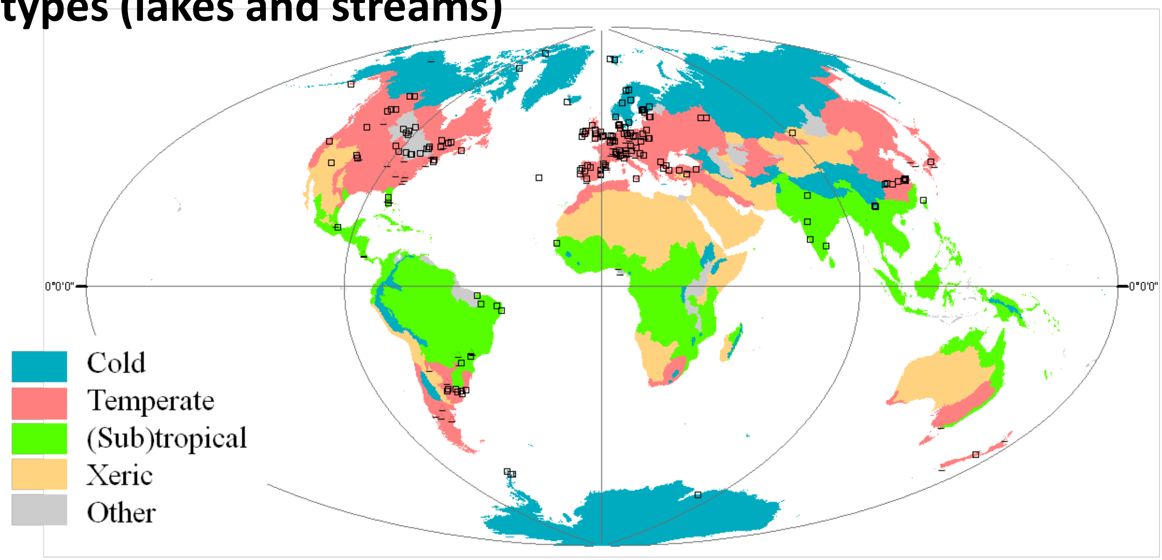
3. Description of EFFECT MODEL

The stressor-response relationship representing the influence on total P on PNOF is described by Azevedo et al. (Global Ecology & Biogeography, In press) for:

- 4 world's regions

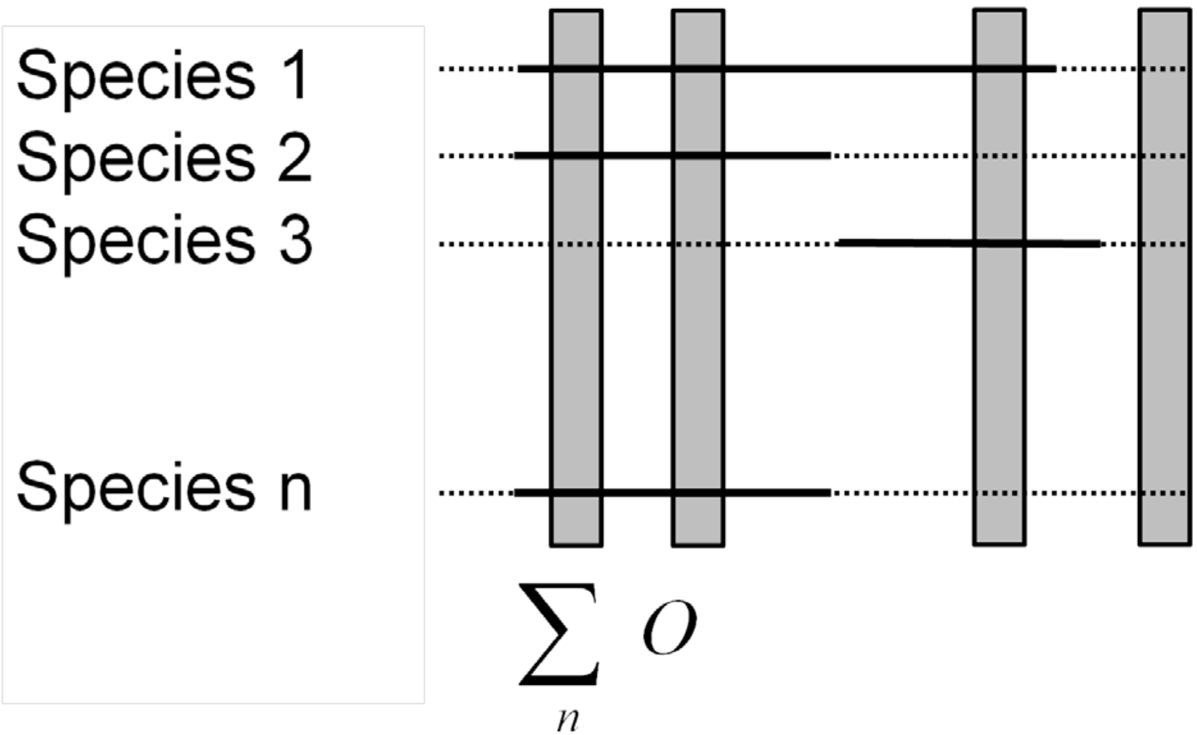
- 2 species groups (autotrophs and heterotrophs)

- 2 freshwater types (lakes and streams)



2. TP – PNOF relationships worldwide

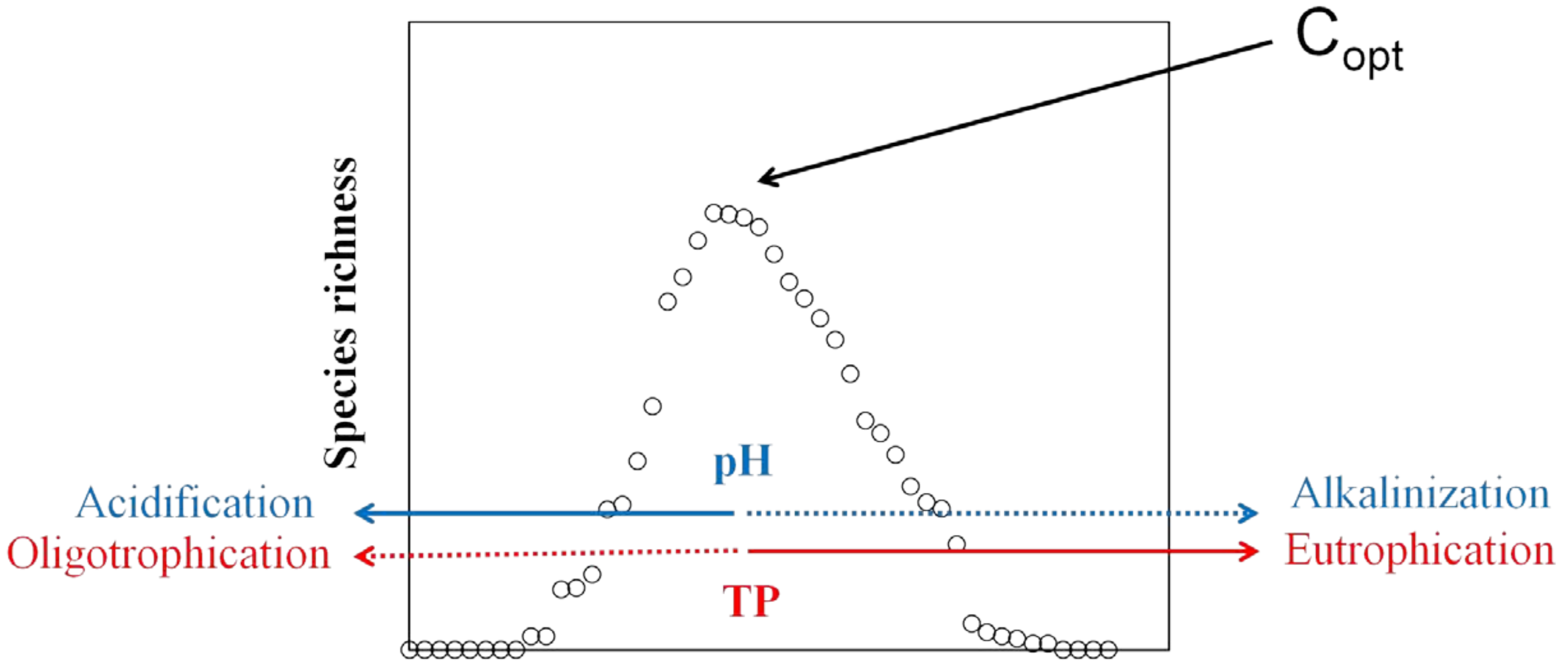
Step 1: Species occurrence ranges



Based on Azevedo et al., 2013 (Environmental Pollution)

3. TP – PNOF relationships worldwide

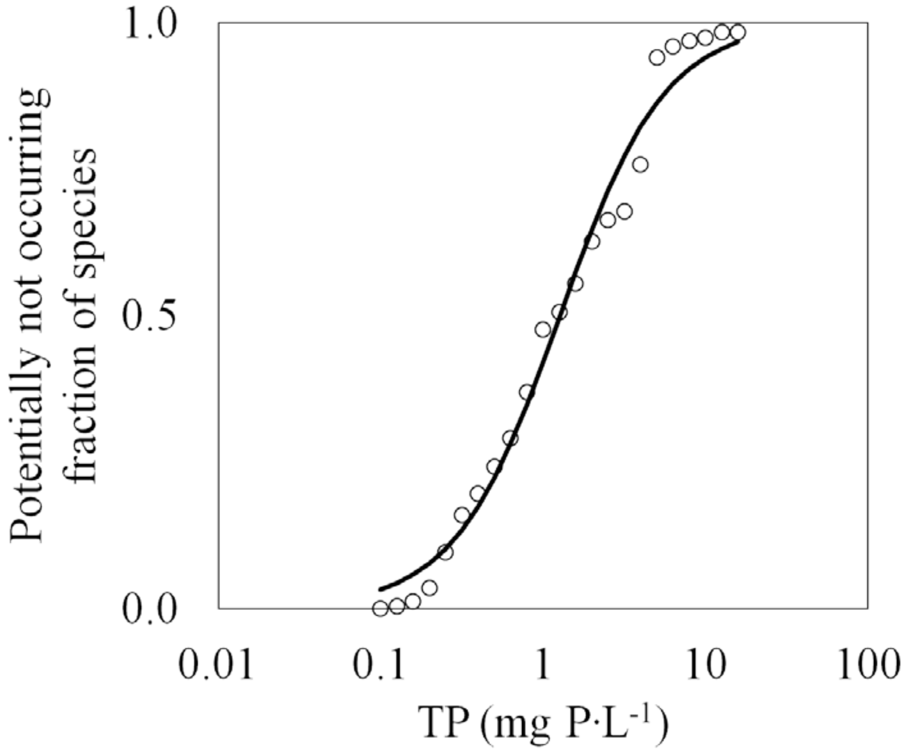
Step 2: Defining the optimum



Based on Azevedo et al., 2013 (Environmental Pollution)

3. TP – PNOF relationships worldwide

Step 3: Log-logistic regression



○ $ePNOF = 1 - \frac{SR}{SR_{max}}$

— $cPNOF = \frac{1}{1 + \exp\left[\frac{\log_{10}(TP) - \alpha}{\beta}\right]}$

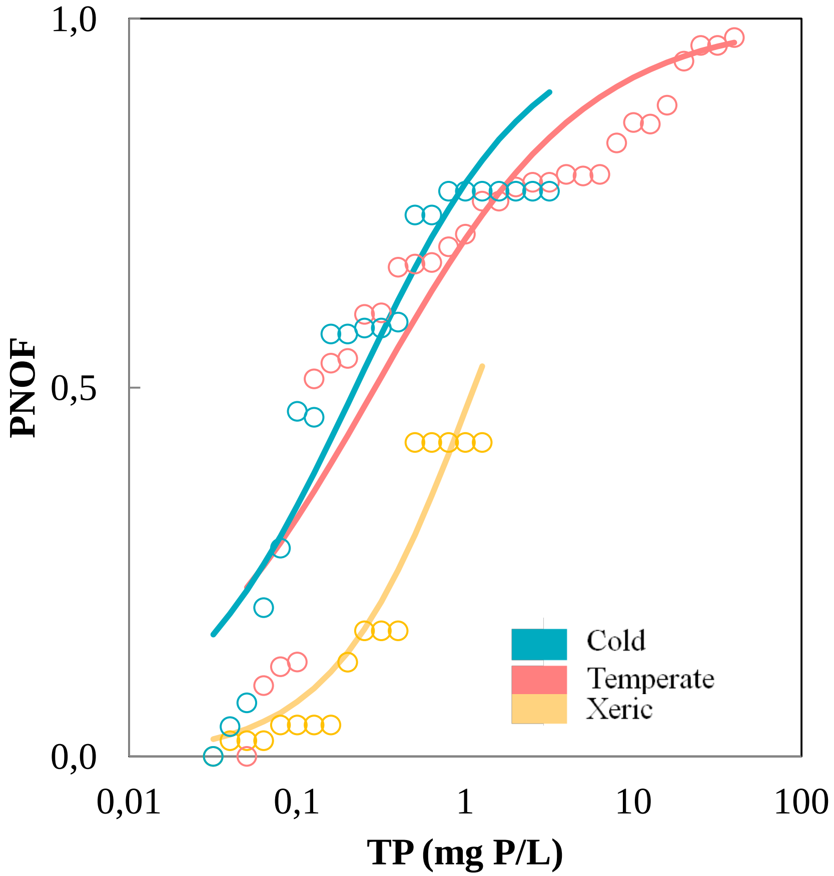
Azevedo et al. (Global Ecol. & Biogeogr.In press)

3. TP – PNOF relationships worldwide

Example of PNOF – total P relationship

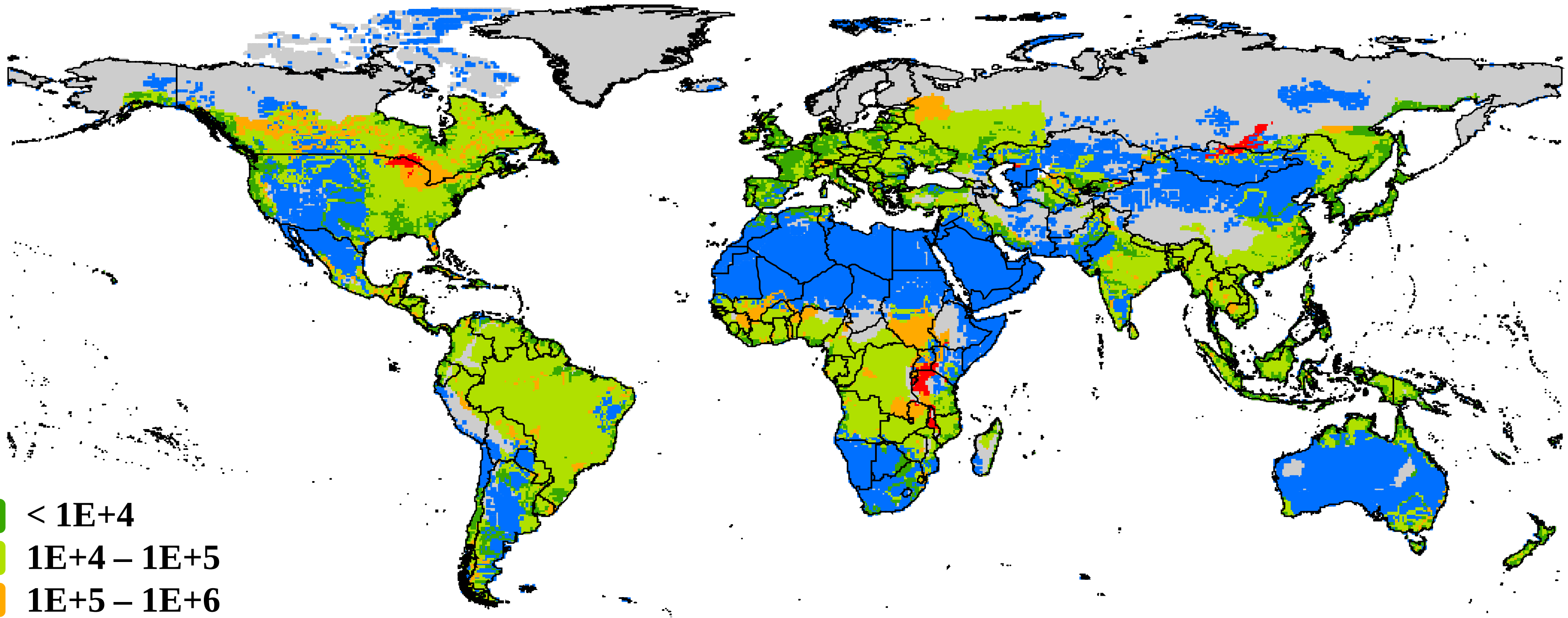
$$PNOF_{j,s,w} = \frac{1}{1+\exp^{-\left(\frac{\log_{10} C_{j,w}+0.54}{0.63}\right)}}$$

Grid j: in temperate region
Species group s: autotrophs
Freshwater type w: lake



Azevedo et al. (Global Ecol. & Biogeogr.In press)

2. Worldwide characterization factors (day·kg P^{-1}·m^3)

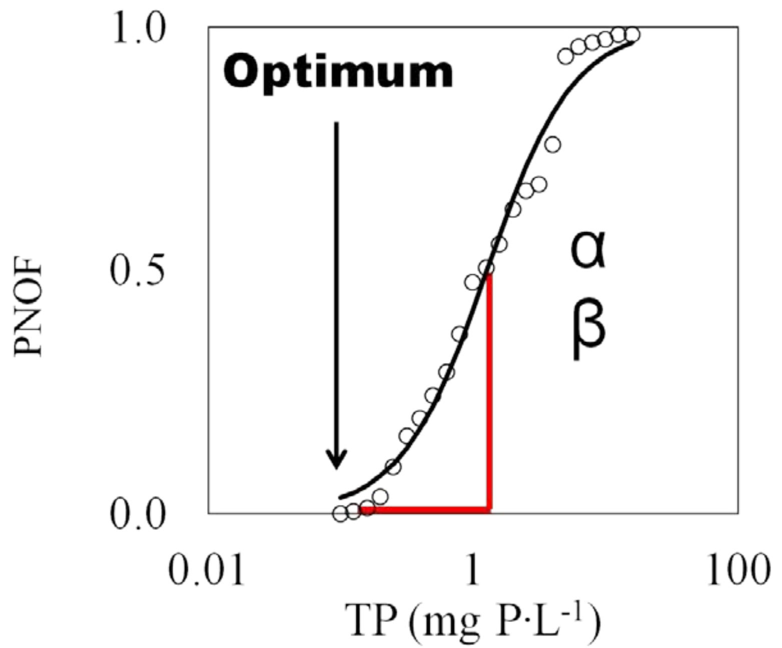


- < 1E+4
- 1E+4 – 1E+5
- 1E+5 – 1E+6
- > 1E+7
- Arid
- No CF

Azevedo et al. (unpublished)

3. Linear effect factor type

$$cPNOF = \frac{1}{1+\exp\left[\frac{\log_{10}(TP)-\alpha}{\beta}\right]}$$

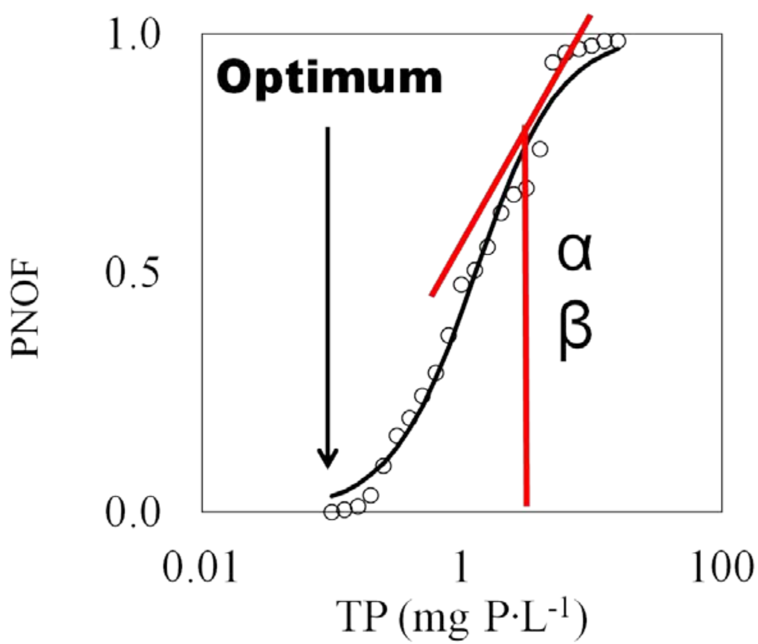


LEF (LINEAR):

$$LEF = \frac{0.5}{10^{\alpha} - Opt}$$

3. Marginal effect factor type

$$cPNOF = \frac{1}{1+\exp\left[\frac{\log_{10}(TP)-\alpha}{\beta}\right]}$$

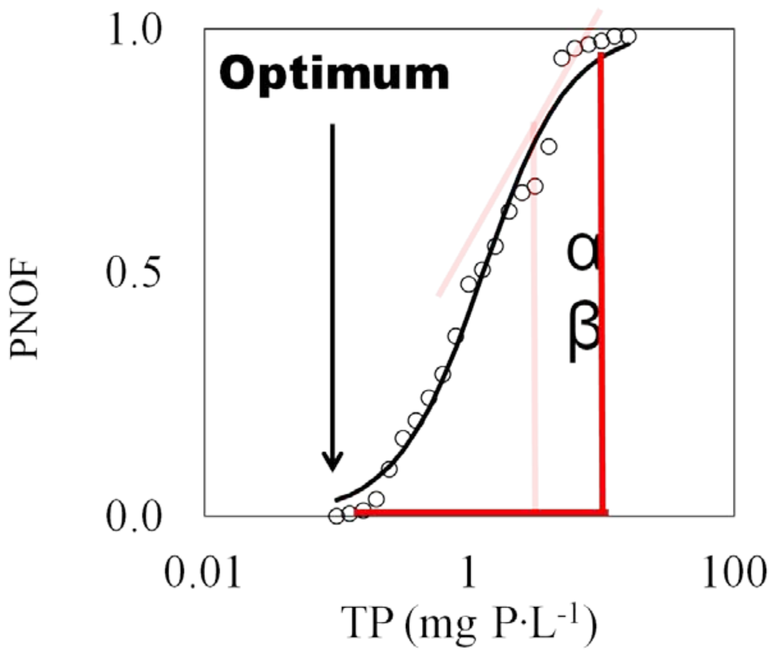


MEF (MARGINAL):

$$MEF = \frac{\partial PNOF}{\partial TP}, TP > Opt$$

3. Average effect factor type

$$cPNOF = \frac{1}{1+\exp^{\left[\frac{\log_{10}(TP)-\alpha}{\beta}\right]}}$$

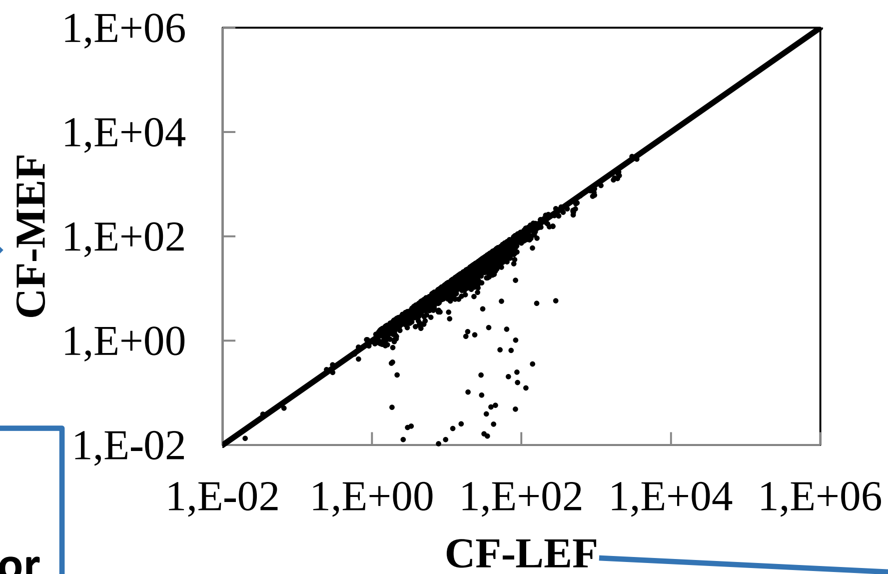


AEF (AVERAGE):

$$AEF = \frac{\Delta PNOF}{TP - Opt}, TP > Opt$$

3. Endpoint characterization factors

ATTENTION: Different effect models currently in use in LCIA may change the results for characterization factors



Characterization factor using a marginal effect factor

Characterization factor using a linear effect factor

Azevedo et al. (unpublished)

4. Main differences between current interim and proposed methods: MIDPOINT

Feature	Struijs et. al., 2011 (Int J LCA)	Helmes et. al., 2011 (Int J LCA)
Coverage	Europe	Global
Resolution	1/6°	1/2°
Fate transport from soil to water	Included	Not included
Fate transport via P retention	Not included	Included
Fate transport via water use	Not included	Included
Fate transport via lakes	Not included	Included

Improvement

4. Main differences between current interim and proposed methods: ENDPOINT

Feature	Struijs et. al., 2011 (Int J LCA)	Azevedo et. al. (unpublished)
Same differences reported for the MIDPOINT plus….		
Species group	Macroinvertebrates	Autotrophs and heterotrophs
Freshwater group	Streams	Streams and lakes

5. Conclusions of lecture

- Freshwater eutrophication is generally considered to be caused by P
- The sources of P are: sewage and agricultural fertilizers
- The effect of eutrophication is the decrease in species richness (or increase in the potentially not occurring fraction – PNOF – of species)
- The characterization factor is determined by a fate and an effect factor, both spatially-explicit