Supporting Information

Assessing the importance of spatial variability versus model choices in life cycle impact assessment: the case of freshwater eutrophication in Europe

Authors: Ligia B. Azevedo[1], Andrew D. Henderson[2,3], Rosalie van Zelm[1], Olivier Jolliet[2], and Mark A. J. Huijbregts[1]*

*Corresponding author: Ligia B. Azevedo. Tel: + 31 (0)243653291; fax: + 31, (0)243553450; e-mail: l.azevedo@science.ru.nl

[1] Department of Environmental Science, Institute for Water and Wetland Research, Radboud University Nijmegen, P.O. Box 9010, 6500 GL, Nijmegen, the Netherlands

[2] Department of Environmental Health Sciences, School of Public Health, University of Michigan, 1415 Washington Heights, Ann Arbor, MI 48109, USA

[3] Division of Epidemiology, Human Genetics and Environmental Sciences, School of Public Health, The University of Texas Health Science Center at Houston, 1200 Herman Pressler, Houston, Texas 77030, USA

This Supporting Information has four appendices. The construction of the log-logistic function of the potentially not occurring fraction (PNOF) of species and TP is shown in appendix S1. The temperate zones of Europe and the calculation of total P concentration data in receiving grids are described in appendix S2. Grid and river-basin specific CFs and the results of the analysis of variance (ANOVA) and of the assumptions of the ANOVA are described in appendix S3. The calculation procedure to isolate the spatial variability in CFs due to the fate and effect factors is described in appendix S4. The references used in this Supporting Information are in the end of this document.

Appendix S1: Species sensitivity distributions

We employed the observational field data on TP concentration ranges where temperate heterotrophic species were observed in lakes and streams reported by Azevedo et al.[1]. We considered the maximum TP level of each species as the highest concentration at which the species was observed in the environment. Second, we constructed log-logistic regressions of with the maximum P levels for lake species (683 in total) and stream species (852 in total). The regressions were defined as

$$PNOF_w = \frac{1}{1+e^{-\left(\frac{\log_{10} C_w-\alpha_w}{\beta_w}\right)}} \qquad \text{(S1)}$$

where $PNOF_w$ is the potentially not occurring fraction (PNOF) of species in freshwater type *w* (i.e. lake or stream) at concentration C_w of TP. The regression coefficients α_w and β_w represent, respectively, the $\log_{10}$ TP concentration at which PNOF is 0.5 and the slope of the log-logistic function (Fig. 1, main text).

Appendix S2: Selection of grids and of concentration monitoring data

We selected European grids (resolution: 0.5° x 0.5°) that were located within one of the three European temperate zones (i.e. temperate coastal rivers, temperate flooplain rivers and wetlands, or temperate upland rivers), defined by Abell et al.[2], Fig. S1. These temperate regions comprise a large number of water bodies which are monitored for TP levels by the European Environment Agency, EEA[3]. On average, there was one lake and stream monitoring station per 25 and 5.9km^2 of land area, respectively.

For each selected grid, we included the latest mean annual TP record (up to 2011) at each monitored station reported by the EEA[3]. The locations of the monitoring stations reporting mean annual TP data are shown in Fig. S2. We determined the concentration of P in each grid as the average of the TP concentrations of the monitoring stations for lakes and streams separately. For grids where no monitoring station was present, we used the mean average of the TP concentrations in the monitoring stations within a 0.5° distance from the grid. For grids where no monitoring station was present within a 0.5° distance, we used the monitoring stations within a 1.0° distance, and so on, until all continental European grids were assigned a TP concentration estimate. Finally, we determined the concentration of TP in freshwater w in grid j ($C_{w,j}$) as the mean of the individual annual mean TP concentrations in monitored lake or stream stations within j. Grid-specific $C_{w,j}$ concentrations are shown in Fig. S3.

Figure S1. Temperate European zone (dark grey).

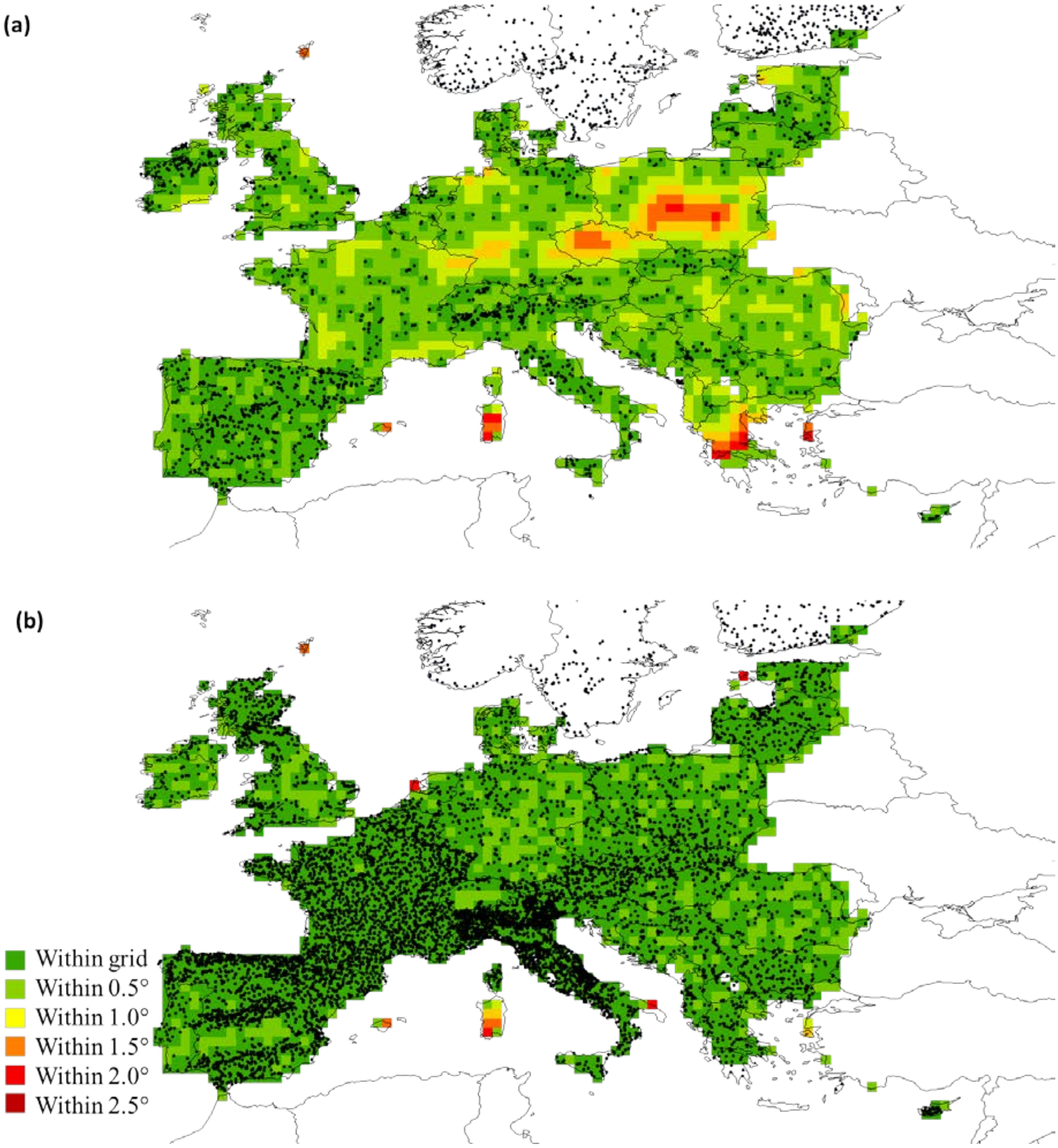

Figure S2. Distance from grids to their nearest **(a)** lake (n = 2451) and **(b)** stream (n = 9525) monitoring station (dots) in Europe. The percentage of grids with a lake monitoring station within the grid and within a distance of 0.5°, 1.0°, 1.5°, 2.0°, and 2.5°, respectively, is 34%, 46%, 13%, 4%, 2%, and 1%. The percentage of grids with a stream monitoring station within the grid and within a distance of 0.5°, 1.0°, 1.5°, 2.0°, and 2.5°, respectively are 83%, 16%, <1%, <1%, <1%, and < 1%.

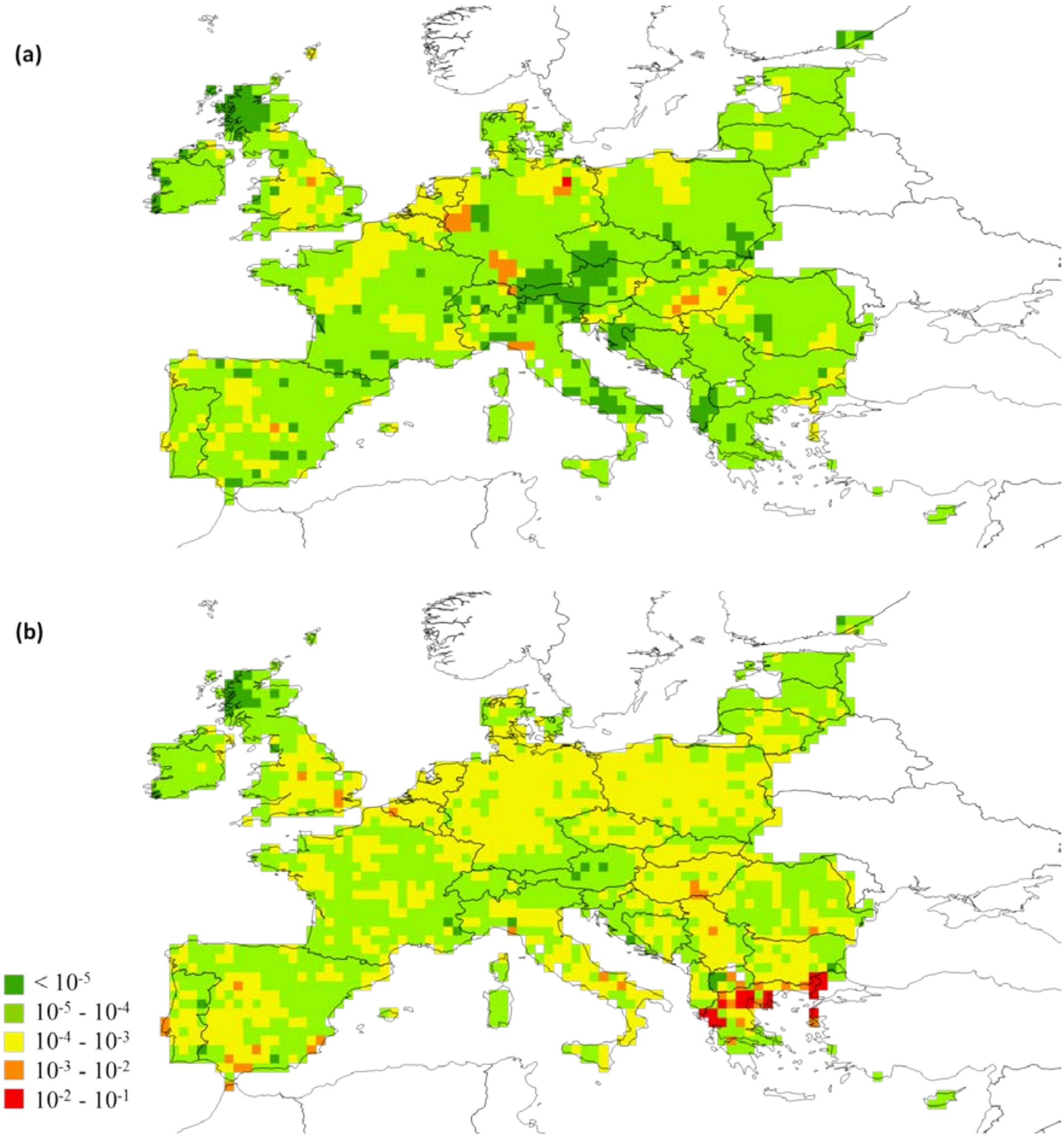

Figure S3. Concentrations of mean annual TP ($C_{w,j}$, unit: kg P·m^{-3}), for **(a)** lakes and **(b)** streams in Europe.

Appendix S3: Statistical analysis results

Grid-specific CFs based on the three effect models are shown in Fig. S4 (for lakes) and Fig. S5 (for streams). River-basin specific CFs based on the three effect models are shown in table S1 for lakes and in table S2 for streams. The results of the assumption tests of normality of residuals and of homogeneity of variances of the analysis of variance (ANOVA) are shown in Fig S6 and S7, respectively. The results of the ANOVA are shown in table S3.

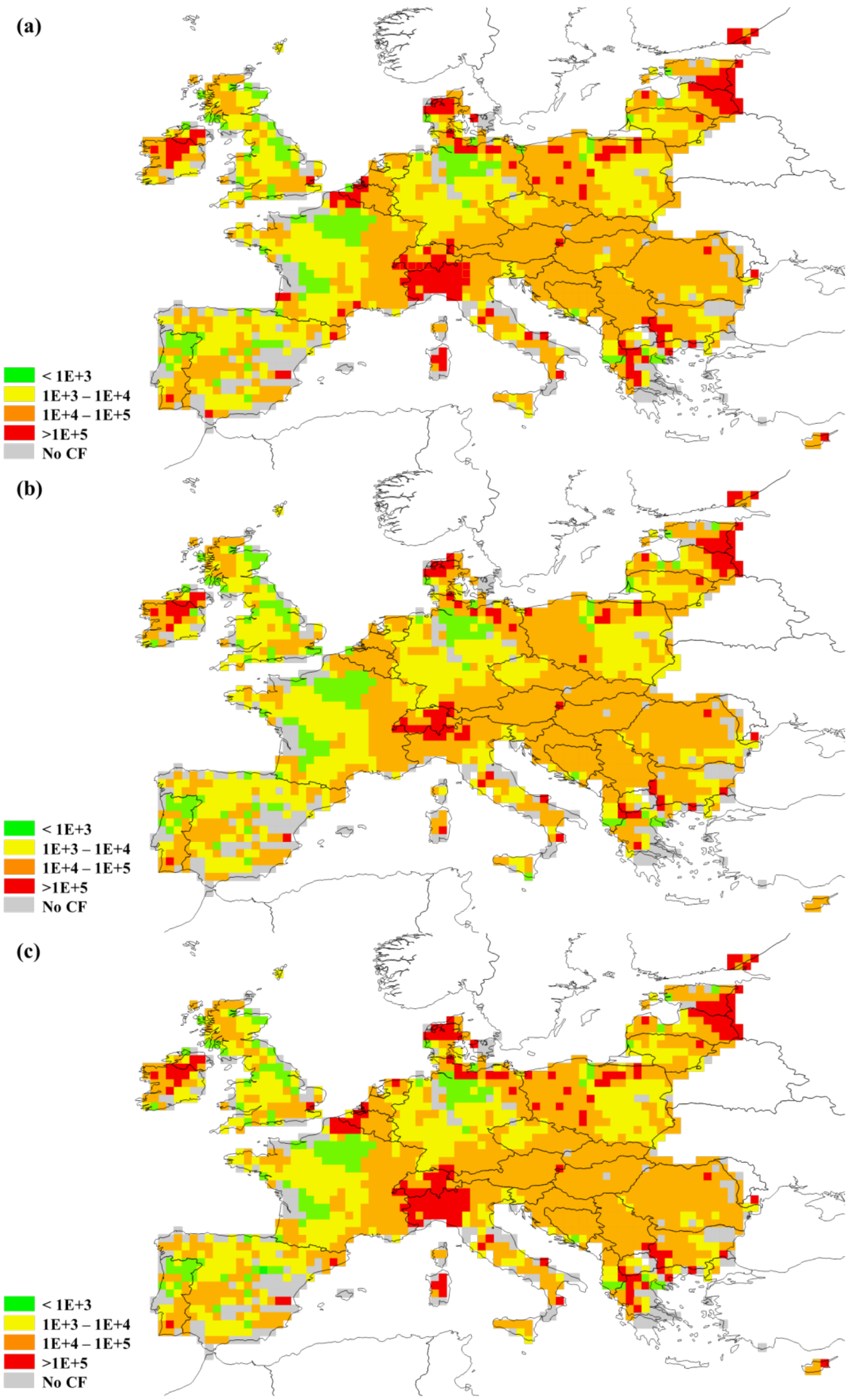

Figure S4. Grid CFs (unit: day·kg $P^{-1}\cdot m^3$) for lakes determined with **(a)** marginal effect factors, **(b)** linear effect factors, and **(c)** average effect factors.

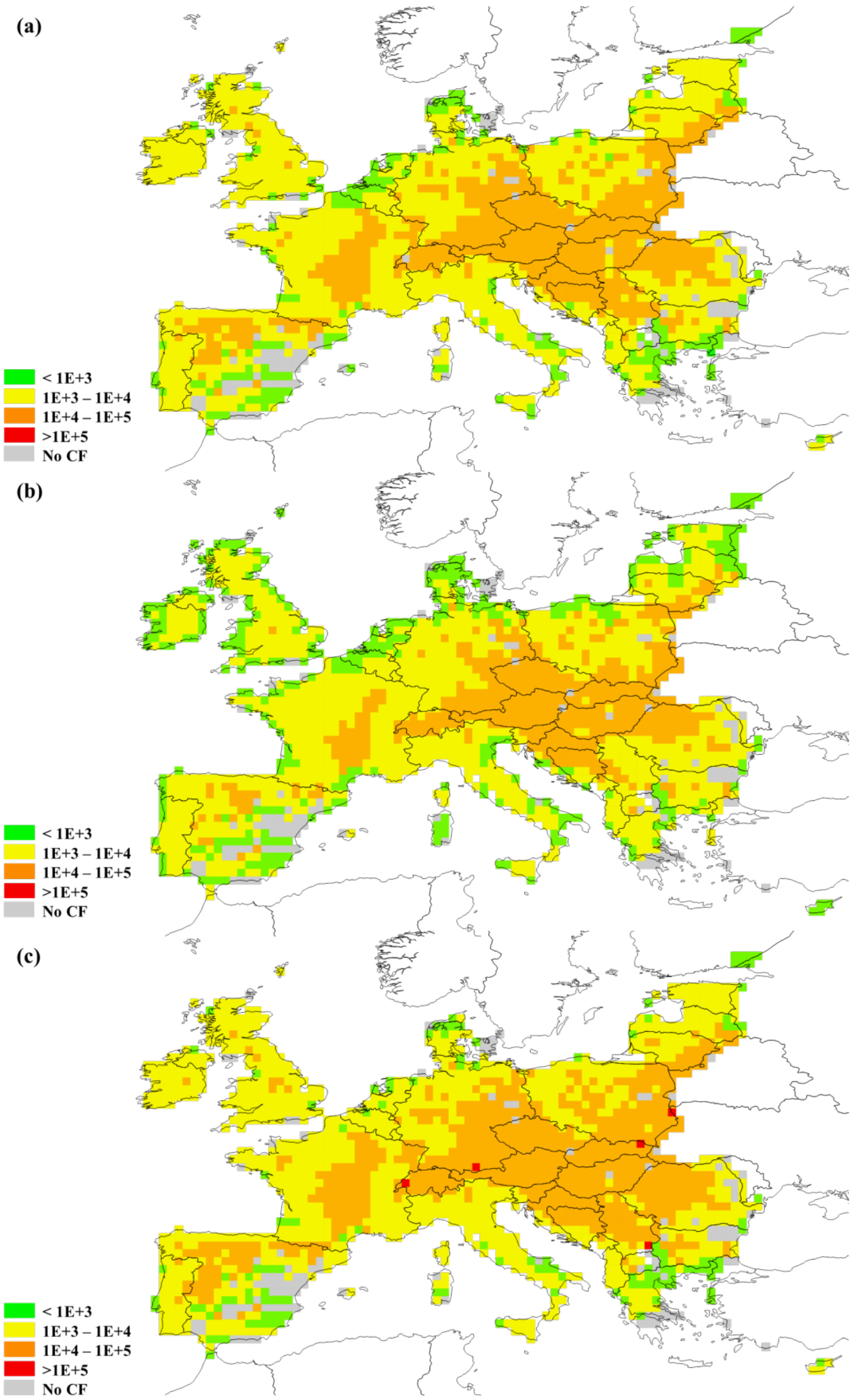

Figure S5. Grid CFs (unit: day·kg $P^{-1}\cdot m^{3}$) for streams determined with **(a)** marginal effect factors, **(b)** linear effect factors, and **(c)** average effect factors.

Table S1 River-basin specific CF based on the three effect models (marginal – MEF, linear – LEF, and average – AEF) for lakes. All units are reported as day·kg $P^{-1}·m^3$.

River Basin	CF_{MEF}	CF_{LEF}	CF_{AEF}
Adour	12084.37	8818.56	10910.6
Algarve	29926.6	21415.93	27142.06
Andalusia	34230.14	26948.19	30123.35
Anglian	23724.54	17571.44	23032.07
Black Sea	46081.95	55696.21	63273.45
Cantabrian	6181.93	4861.13	5977.29
Catalan	35923.2	27135.41	34501.39
Cavado	2565.54	1950.44	2278.46
Central Macedonia	2921.9	2166.69	2927.66
Corsica	14364.4	10387.74	14038.38
Cyprus	72105.15	52727.79	64602.98
Danube	26293.48	21445.01	26769.19
Daugava	90016.35	65243.84	84673.75
Douro	5976.2	4927.85	6246.38
East	27492.49	20113.16	24596.89
East Aegean Isl.	34610.83	26535.35	35300.65
East Alps	19458.29	14804.26	17533.57
East Estonia	209884.3	149242.7	194755.4
Ebro	10389.35	7651.07	9488.49
Eider	16927.19	14441	18998.02
NorthWest (IRL)	29635.62	21111.87	28040.66
SouthEast (IRL)	17801.32	13044.88	15918.78
SouthWest (IRL)	25560.07	19687.9	22561.76
Elbe	14798.8	14634.21	14864.56
Ems	11503.52	9077.94	12087.41
Epirus	62972.73	44565.24	57802.38
Galician	7577.12	10076.31	11015.51
Gauja	85097.2	62241.85	81829.82
Guadalete	108552.6	86845.82	95319.81
Guadalquivir	10354.97	8171.41	10310.79
Guadiana	30343.24	24200.97	29947.16
Humber	4200.71	4288.23	4791.47
Jucar	62369.7	45018.51	59598.72
Jutland	97951.88	76286.99	99090.98
Koiva	174683.6	126308.2	167831
Lielupe	27931.63	20437.86	27057.53
Loire	8534.87	6739.51	8731.61
Meuse	29748.49	27182.81	34098.45
Middle Appenines	99271.99	70749.01	92255.13
Minho	19146.42	16069.94	18335.91
Mosel	7286.35	7438.16	8156.63
Neagh Bann	205231.3	172815.7	224487.9

River Basin	CF_{MEF}	CF_{LEF}	CF_{AEF}
Nemunas	25879.64	19022.83	24239.1
North Adriatic	4137.53	3478.07	3618.52
North Appenines	25072.62	18347.88	23849.15
Northumbria	5691.5	4086.45	5322.07
Oder	48647.18	41942.85	50848.9
Po	341890.5	249785.8	312877.8
Pregolya	55881.34	39944.84	50925.88
Rhine	50332.93	81619.22	56727.85
Rhone	227821.4	167250.4	207916.1
Sado	69124.67	49207.61	65474.47
Sardinia	136509.2	98717.84	133410.9
Scheldt	57182.19	52025.47	66752.12
Schlei	99574.47	85891.29	110036.7
Scotland	16234.26	13092.9	14483.33
Segura	53072.39	40389.02	49078.75
Seine	7304.05	5471.55	6808.58
Serchio	112073.4	89041.22	109417.7
Severn	7395.3	6507.67	7843.29
Shannon	145082.6	108867.8	131141.1
Sicily	30300.4	22493.97	29761.1
Solway	10647.91	7960.84	9868.28
South Appenines	51116.74	40234.28	48094.26
Tagus	21327.75	17297.27	22329.12
Tagus West	14239.61	11768.61	15429.66
Thames	17163.26	13900.53	18400.34
Thessalia	61256.88	43359.92	56236.75
Thrace	6428.48	4893.35	6591.86
North West (UK)	37995.76	27511.53	35689.24
South East (UK)	8248.33	6560.34	8724.28
South West (UK)	6209.73	4819.06	6340.26
Venta	41660.18	29773.95	38963.36
Vistula	25094.47	18848.07	23941.3
Vouga	17714.87	12745.69	17183.27
Warnow	77766.29	60782.73	80799.21
Weser	9343.23	6970.55	9290.44
West Aegean Isl.	132319.1	95604.97	128383.8
Western	83681.68	63710.64	74354.74
Western Wales	8655.44	6378.17	8099.35
West Estonian	29431.2	23465.05	29570.41
West Macedonia	201875.2	149631.6	198417.3
West Sterea	137996.8	101321.2	127378.3
Zealand	23005.2	17595.17	23755.04

Table S2 River-basin specific CF based on the three effect models (marginal – MEF, linear – LEF, and average – AEF) for streams. All units are reported as day·kg $P^{-1}\cdot m^3$.

River Basin	**CF_{MEF}**	**CF_{LEF}**	**CF_{AEF}**
Adour	8440.98	5315.4	9149.19
Aegean Isl.	389.99	1071.59	908.21
Algarve	1788.33	1018.12	1835.26
Andalusia	653.09	839.98	847.07
Anglian	1550.61	1124.92	1804.22
Balearic Isl.	646.83	1058.24	1156.66
Basque County	1520.32	1052.99	1742.27
Black Sea	10548.58	6292.03	10744.91
Cantabrian	1865.64	1166.37	2019.37
Catalan	1088.5	1094.27	1494.27
Cavado	7217.81	4487.43	7748.62
Central Macedonia	29.04	1692.31	280.37
Corsica	1929.99	1176.61	2054.77
Cyprus	1155.47	659.97	1185.37
Danube	19385.12	14798.3	22693.85
Daugava	9239.01	5603.69	9834.79
Douro	11935.65	8637.77	13762.93
East	2934.67	1742.05	3079.58
East Aegean Isl.	5154.11	5480.35	6281.03
East Alps	4666.51	2920.46	5026.5
East Estonia	2440.27	1405.71	2522.08
East Sterea	1743.92	1241.77	2028.29
Ebro	9401.49	5747.17	10033.18
Eider	1751.22	1240.83	2030.46
NorthWest (IRL)	3641.08	2102.42	3768.98
SouthEast (IRL)	2874.8	1760.73	3072.93
SouthWest (IRL)	2318.94	1327.98	2385.32
Elbe	20997.42	14411.01	23894.87
Ems	3857.94	3560.75	5087.23
Epirus	2526.84	3058.55	2668.34
Galician	1487.95	977.05	1651.41
Gauja	3010.72	1822.47	3204.34
Guadalete	1390.68	883.24	1517.65
Guadalquivir	2748.31	2897.46	3775.33
Guadiana	3082.47	2418.58	3727.02
Humber	5007.17	4391.99	6235.13
Jucar	173.34	135.98	203.01
Jutland	1590.64	1038.52	1765.05
Koiva	2464.45	1464.31	2594.9
Lielupe	3184.86	2229.31	3647.98
Loire	8652.48	6053.77	9918.74

Meuse	3210.06	2336.09	3738.08
Middle App	2148.72	1627.46	2560.86
Minho	8233	4908.95	8645.18
Minho Lima	1699.76	950.77	1723.99
Mosel	6639.63	4748.83	7731.17
Neagh Bann	2334.46	1550.8	2606.88
Nemunas	13919.56	9441.05	15578.94
North Adriatic	3509.38	1921.29	3494
North Appenines	2590.4	1847.89	2984.27
North East	663.32	787.33	1006.38
North Peloponese	175.36	1208.66	651.17
Northumbria	3288.18	2076.89	3571.6
Oder	8247.77	6463.69	10044.14
Po	7073.66	5190.26	8263.8
Pregolya	12244.87	8665.33	14069.28
Rhine	13361.98	9005.97	15043.3
Rhone	7703.75	4656.97	8161.5
Sado	2049.63	1608.73	2479.68
Sardinia	892.79	497.85	902.93
Scheldt	1668.95	1269.78	1989.36
Schlei	1378.44	944.86	1570.72
Scotland	3379.1	1915	3440.89
Segura	300.77	186.04	314.86
Seine	9391.68	6192.45	10446.71
Serchio	4620.84	4001.96	5907.75
Severn	3688.9	3231.78	4600.99
Shannon	3236.43	1912.63	3393.88
Sicily	1921.08	1255.2	2108.01
Solway	6698.67	4170.18	7199.76
South Appenines	1458.83	1145.62	1745
Tagus	8931.89	7031.33	10724.37
TagusWest	4187.73	3830.49	5352.46
Thames	2535.37	3381.47	3814.84
Thessalia	1142.69	1665.7	1840.77
Thrace	463.18	1676.63	965.83
North West (UK)	2410.45	2008.74	2936.98
South East (UK)	1623.67	1584.11	2141.91
South West (UK)	1588.87	1076.62	1790.6
Venta	5740.41	3510.9	6144.19
Vistula	14294.19	10302.78	16672.79
Vouga	3223.73	2294.83	3687.59
Warnow	1508.21	1050.32	1732.64
Weser	7548.92	5525.03	8891.64
West Aegean Isl.	541.46	1095.47	900.57
Western	1836.47	1045.82	1883.44
Western Wales	1426.63	850.4	1497.55
West Estonian	2508.69	1455.23	2602.8

West Macedonia	353.65	2752.17	861.59
West Sterea	4821.28	2920.21	5038.43
Zealand	993.29	688.5	1138.78

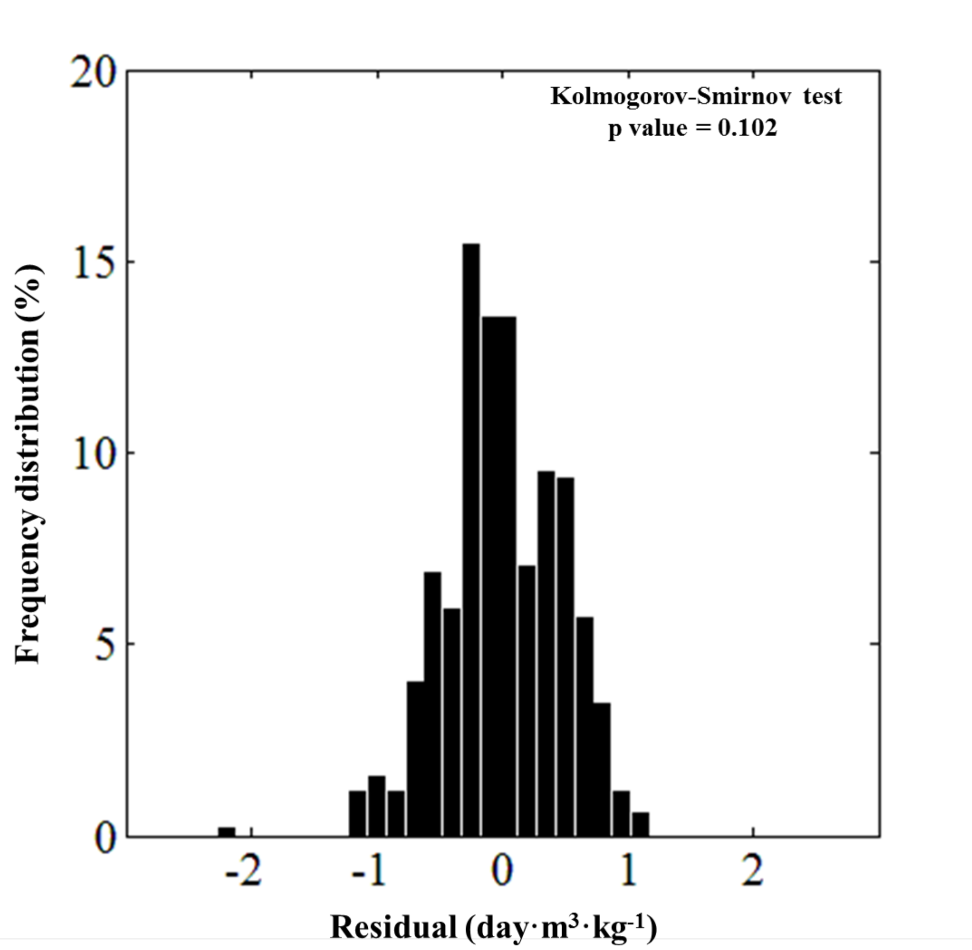

Fig. S6 Normality plot of residuals of the analysis of variance (ANOVA) test.

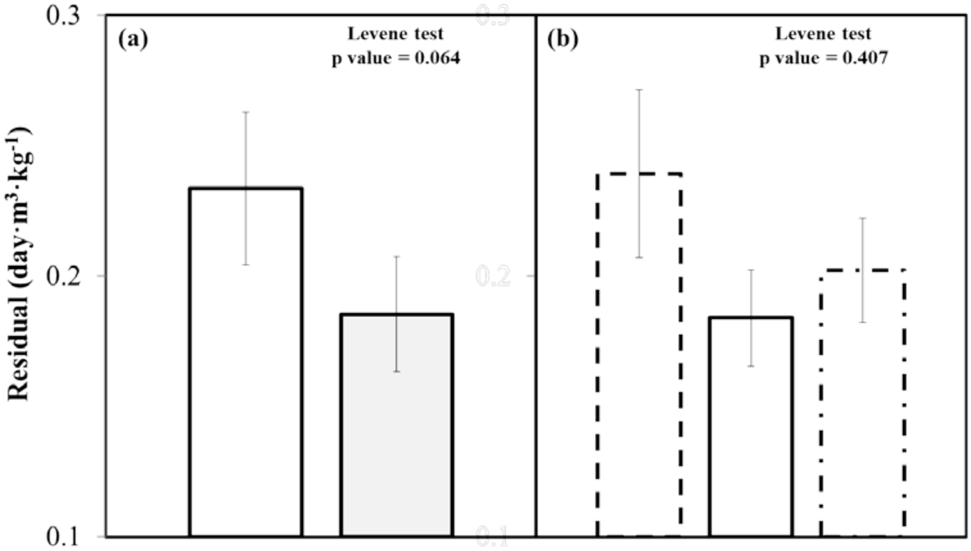

Fig. S7 Results of tests for homogeneity of variance performed in $log_{10}CF_{w,r}$ transformed results.

Table S3 Results of ANOVA performed in $log_{10}CF_{w,r}$ transformed results. R^2 of the model is equal to 0.56. The relative contribution of freshwater and model type to the total variance is shown as $\frac{SS_{effect}}{SS_{total}}$.

	Degrees of freedom	**Type III Sum of squares (SS)**	**Mean sum of squares**	**F value**	**P value**	$\boldsymbol{\frac{SS_{effect}}{SS_{total}}}$
Model	5	136.55	27.31	130.71	<0.001	
Error	519	108.44	0.21			
Total	524	244.98				
Explained variable						
Freshwater	1	134.71	134.71	644.77	<0.001	0.55
Method	2	1.62	0.81	3.88	0.021	0.01
Method*Freshwater	2	0.21	0.11	0.50	0.605	<0.001

Appendix S4: Isolation of fate and effect factor variability

In order to isolate the variability of CFs across river basins due to the fate factors, we calculated CFs To attain that, we calculated grid-specific CFs ($CF_{w,i}$) in each basin without variability in effect factors as

$$CF_{w,i} = \sum_j FF_{i \to w,j} \quad \text{(S2)}$$

where $FF_{i \to w,j}$ is the partial fate factor of emitting grid *i* to freshwater type *w* receiving grid *j*, namely the residence time of P in freshwater w emitting to grid *i*. Likewise, we calculated grid-specific CFs in each basin without variabily in fate factors as

$$CF_{w,i} = \overline{EF_{w,\mathrm{j}}} \quad \text{(S3)}$$

where $\overline{EF_{w,\mathrm{j}}}$ is the mean effect of grid *i* on species in freshwater *w* in receiving grids *j*. River basin CFs ($CF_{w,r}$) were calculated as the mean of grid CFs within basin similarly to that described in the main text for the analysis of variance (ANOVA).

REFERENCES OF THIS SUPPORTING INFORMATION

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